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CONTENTS

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THE TECHNOGRAPH.

No. 9. UNIVERSITY OF ILLINOIS. 1894-95.

EFFICIENCY TESTS

Of the Urbana and Champaign Electric Street Railway.

BY C. H. TREGO, '94, AND O. E. GOLDSCHMIDT, '94.

DESCRIPTION OF THE RAILWAY SYSTEM.

The present electric street railway is the outgrowth of a horse railway built in 1860. The change to the electric system was made in 1890. In making the change, nearly all of the old road was abandoned and the line was greatly extended.

The road now consists of a main line connecting the cities of Champaign and Urbana, in the state of Illinois, and of several branches extending into different parts of Champaign.

Beginning near the west boundary of Champaign, the main line runs in an easterly direction by the West End Park, through the best residential and business quarters of the city and past the University Athletic Park, and, entering Urbana, passes the buildings of the University of Illinois, runs through the residential and business portions, and terminates in the east part of the town.

One branch extends south on New street, through a good residential quarter. Another branch runs north on Neil street to the car barn, passing the stations of the Wabash and Big Four railroads. A loop leaving the main line at Third street runs to the Champaign county fair ground and thence to the main line at the corner of Wright and Green streets. A short loop of old track in Urbana connects a point of the main line on Wright street and another point on Goodwin avenue. This loop is only used in case of emergency.

The length of the main line is about $4\frac{1}{4}$ miles, the length of the branches about $2\frac{1}{4}$ miles. This gives a total length of track of $6\frac{1}{2}$ miles.

All the churches, hotels, places of amusement, railroad stations, factories and public buildings are on, or near, the main line or its branches. Plate I. shows the location of the road. The track extends about two-thirds of a mile west of the limits shown in Plate I. A curve connecting tracks on Neil and Church streets was put in just before the general test was made.

The whole length of road is single track. Turnouts are placed at convenient distances apart. A T-rail weighing 48 pounds to the yard is used. The rails are laid on 6 inch x 8 inch oak ties, 8 feet long, and placed so that their centers are 2 feet apart. The streets are paved with brick along most of the line in Champaign, and along part of the line in Urbana. Some of the remaining portions of the track are ballasted with cinders; others are yet without ballast.

The rails are bonded with $\frac{5}{16}$ inch tinned copper wire. Most of the track has alternate pairs of rails cross-bonded. Two grounds are provided at the power house. One consists of a number of car wheels at the bottom of a well with connections of copper and iron wire; the other of a large coil of iron wire in a bed of charcoal. Grounds are made along the line by burying rails in permanently wet places, and using copper and iron wire for connections. The water pipes are also made use of.

The overhead construction is mostly of the ordinary side-pole, span-wire type. A few short pieces are of the side-bracket type. In the residential part of Champaign octagonal posts are used. The poles are placed 125 feet apart along the line. The trolley wire is No. 0 in Champaign and mostly No. 1 in Urbana. A main No. 00 feeder connects with the trolley in Champaign at corner of Main and Neil streets, at corner of Third street and University avenue, and at corner of Wright street and Springfield avenue. A No. 0 sub-feeder runs from the latter point to North street in Urbana. A No. 1 subfeeder runs in Champaign from corner of Main and Neil streets to New street. All feeders are "Shield Brand" wire.

Three "Keystone," six "Wirt," and six "swinging ball" lightning arresters are distributed along the line.

The road has no heavy grades as may be seen from the profile shown in Plate II.

The maximum grade is 4.1 %, but is for a distance of 200 feet only. The longest incline is 2 200 feet; the grade, however, is only about 1%.

The power station, comprising a power house and boiler house, and the car barn are located together in the northern part of Champaign. These buildings are all one story structures with brick walls and slate roofs.

The length of the line from the station to the extreme west end is 1.97 miles, to the extreme east end 3.33 miles, to the extreme south end (on New street) 1.50 miles.

The power house contains not only the engines and generators for the railway, but also engines and generators for the arc and incandescent lighting circuits for both Champaign and Urbana.

The railway generators*, Nos. 1 and 2 on Plate III., are Westinghouse compound wound machines run at 525 revolutions with a normal output of 90 amperes at 520 volts or capacity of 46.8 K. W. each. The two machines are run in parallel with an equalizing wire connecting them at points between armature and series coils. On the switch-board, between each machine and the bus bars, is an automatic circuit breaker set to operate at 125 amperes. A number of lightning arresters of different types protect the machines.

The engine used to drive the railway generators is a Porter-Allen 16x16 high-speed automatic engine, run at 285 revolutions. It has a 6-foot driving pulley of 20-inch face. This engine is No. 1 on the station plan (see Plate III.) It is belted to a section of the line shaft which serves the entire lighting and power station.

The boiler house contains three Babcock & Wilcox water tube boilers, rated at 250 H. P. each, carrying steam at from 90 to 125 pounds pressure. The feed water is obtained from the Champaign city water works, and is heated by an exhaust steam feed water heater. A duplex pump is used to feed the boilers.

The steam is carried into the engine room by a 10 inch main 50 feet long. From this main, branches lead to the several engines. The branch supplying the railway engine is 8 inches in diameter and 40 feet long.

The car barn has a capacity of 20 cars. There are 5 tracks connected by a transfer table. Two of the tracks have a pit under them.

*These generators are now used for the stationary motor circuit. A large multi-polar Westinghouse machine supplies the railway.

The car outfit consists of 7 single motor cars and several trailers. The electrical equipment was made by the Westinghouse Co. Brill trucks are used on all cars except one (No. 16) which has a McGuire truck. The wheels of car No. 12 are 36 inches, all others are 33 inches. Some of the car bodies are from the Brownell & Wight Co., others from the Laclede Car Co. At time of making the general test the arrangement of motor cars was as follows:

Car No. 10, 16 foot, closed body. 25 H. P. single reduction motor.

Car No. 11, 16 foot, closed body. 16 H. P. double reduction motor.

Car No. 12, 20 foot, open body. 25 H. P. single reduction motor.

Car No. 13, 16 foot, closed body. 16 H. P. double reduction motor.

Car No. 14, 16 foot, closed body. 25 H. P. single reduction motor.

Car No. 15, 22 foot, open body. 25 H. P. single reduction motor.

Car No. 16, 20 foot, closed body. 30 H. P. single reduction motor.

Car No. 17, 20 foot, closed body. 25 H. P. single reduction motor.

Several stationary motors and a few lamp circuits are operated by current from the trolley wire.

The scheme for operating the road is as follows:

Four motor cars are in regular service. One of these cars plies back and forth on New street. The other three make round trips from the west end of line in Champaign to the east end in Urbana and back. One hour is required for the round trip. At the even hour and at twenty minutes after and twenty minutes before the hour two cars leave Neil street, one for the west end, the other for Urbana, and one car leaves Urbana for Champaign. The car which leaves Champaign at twenty minutes before the hour makes its trip via the fair ground loop, the other two cars go by the way of Wright street. The first car leaves Champaign at 6:20 A. M. The last car leaves Urbana at 10:20 P. M. Trailers are used whenever occasion requires.

Preliminary Tests.

These tests were made in order to obtain information as to the best method of taking the observations which it would be necessary to make during the general test.

Special Car Test No. 1, January 12, 1894.

This test was made at a time when the ground was covered to a depth of 3 inches with fresh dry snow, the day being selected as one on which more than the ordinary difficulties of operating would be encountered.

The car used was No. 16 above described. Readings were taken every 10 seconds of the total electromotive force, current, speed, and location. Weston electrical instruments and a Schaeffer and Budenburg tachometer were used.

The voltmeter was connected between trolley and ground, and the ammeter between motor and ground. The tachometer was belted to the free axle. This test may be divided into two parts, A and B, as shown in Plates IV. and V. Part A was made at the west end of the line where the snow had not been disturbed. Part B consisted of a run over into Urbana and back to the power house.

In the plates the time is plotted as abscissæ and the E. M. F., current and speed as ordinates. In attempting to run through the dry snow, it was found that the car would only run a short distance before the wheels would begin to slip. The snow between the wheels and rails to which the slipping was due caused a marked drop in voltage. The wheels, continuing to revolve, would wear through the snow in a few moments; the voltage would immediately rise and the car move ahead, only to stop again a few moments later through the same cause.

In this connection it might be observed that the motor is in danger of a burnout if the controller is turned on full, and the wheels, revolving slowly, suddenly make good contact with the rails.

The second part of the test was made in order to obtain values at various parts of the line, of the quantities mentioned above. The results plotted in Plate V. show an average current of 25 amperes, corresponding to about 17 H. P. The current taken by the car attained a maximum of 70 amperes. This occurred in going around the Wright and Green street curve. The maximum E. M. F. was 520 volts, the minimum 430. The latter was at the extreme end of the line, and was at the moment when two cars, near that end, started simultaneously. The speed attained a maximum of 23 miles per hour. The average was 13 miles per hour.

Special Car Test No. 2, April 15, 1894.

This test was made on a clear dry day when the conditions of operating were better than the average. The object was to get fuller and more accurate information concerning the performance of a car than was obtained in the first test.

The observations were made on car No. 16, the car used in test No. 1. Measurements of total electromotive force, current, speed and location were made every 10 seconds as in the previous test, and, in addition, measurements of volts lost in the controller. Weston electrical instruments were used. The tachometer was belted to a pulley on the free axle, of such diameter that measurements of speed down to 1½ miles per hour could be made with accuracy.

As in the preceding case this test may be divided into two parts. The first part consisted of a run over the whole line; the second part, made on John street, consisted of several runs back and forth in order to get measurements with the controller at different notches.

The results of the first part of this test, consisting of direct observations of current, electromotive force, speed and location, and of computations of total applied E. H. P., lift and propelling H. P., are shown by the curves of Plate VI.* The first part of the run, *i. e.* that from Neil street to the west end, is shown as the last part in order to represent a round trip from the west end. The part of the curves for the run going east show a break for the time the car was on John street. It is to be noted in plotting the curves in this test that distance (instead of time, as in test No. 1) has been taken as abscissæ. The profile is drawn under the curves in order to show at a glance the relation of the above mentioned results to the grades.

By the applied E. H. P. is meant the total power taken from the line. The lift H. P. is that power which will be required to overcome the grade at any time. It is obtained from the formula:

$$\text{Lift H. P.} = \frac{\text{Wt. of car (in pounds)} \times \text{lift (feet per minute)}}{33\,000}$$

The lift H. P. is positive on an up grade and negative on a down grade, and will obviously depend upon the weight and speed of the car and also upon the grade. By the propelling H. P. is meant that power which at any time is actually causing the car to move; it is the summation of the lift H. P. and the applied E. H. P. after deducting from the latter the losses in the motor. It may be expressed by the following formula:

Propelling H. P. = applied E. H. P. × efficiency + the lift H. P.

* A few parts of the curve for lift H. P. have been plotted, by mistake, positive instead of negative, and vice versa.

This does not take into consideration the power required to accelerate the car, or that given out in stopping.

It would be natural to suppose, on account of the low efficiency of street railway motors in general, that the propelling H. P. should be considerably lower than the applied E. H. P., even on an ordinary decline, and this, it appears from the curves, is the case.

The current ran up to more than 60 amperes several times at starting and in going around curves. The average was 17.5 amperes. The average electromotive force was 500 volts; the highest value was 560. The maximum speed attained was 22 miles per hour; the average was 17. The maximum applied E. H. P. was 43; the average was 11.7. This maximum applied E. H. P. was at starting on a curve. The maximum lift H. P. was 9. This was required in running up a grade at high speed. The propelling H. P. is largest at starting; it may be large also in going down hill at a high rate of speed. It should be remarked, however, that in the latter case the applied E. H. P. is comparatively small, the lift H. P. being negative and therefore increasing the propelling H. P.

In the second part of the test, besides readings as taken in the preceding part, the fall of potential through the controller resistance was observed. The piece of track on John street was selected on account of being very level. The car was run the entire stretch on one notch, back on the next, and so on, the controller being placed on the notch desired after the car had been brought up to speed.

The observations and some of the computations are graphically represented by the sets of curves in Plate VII., with the profile shown under each set. On account of the shortness of the run and the variation of the speed, this part of the test is rather unsatisfactory. By reference to the plate it will be observed that the vertical dotted lines enclose in each case the parts of the curves to be compared. The fifth notch readings were not plotted because of the great variation in speed. Through an oversight the values of the H. P. lost in the resistance were not plotted. They have been computed, however, and are shown in the following table:

TABLE I.

Notch	1	2	3	4	5
Amperes	16.0	19.3	20.3	22.0	16.0
Fall of Potential through resistance, in volts	70.0	40.0	20.0	10.0	0.0
Speed, in miles per hour	15.5	13.8	15.5	14.0	18.5
Total applied E. H. P.	9.2	13.0	13.5	15.0	10.0
E. H. P. lost in resistance	1.50	1.03	0.54	0.29	0.00

It will be observed that the power lost in the resistance is not large at any time. However, the per cent. loss of the total applied E. H. P. is large on the lower notches, being 17% for the first notch. It is only 2% for the fourth notch. The apparent anomalous increase in current with decreased resistance is due to the fact that the speed of the car was being accelerated. This would also affect in the same manner the total E. H. P. The small H. P. for the first and fifth notches is due to the fact that the speed was decreasing.

Special Station Output Test, April 28, 1894.

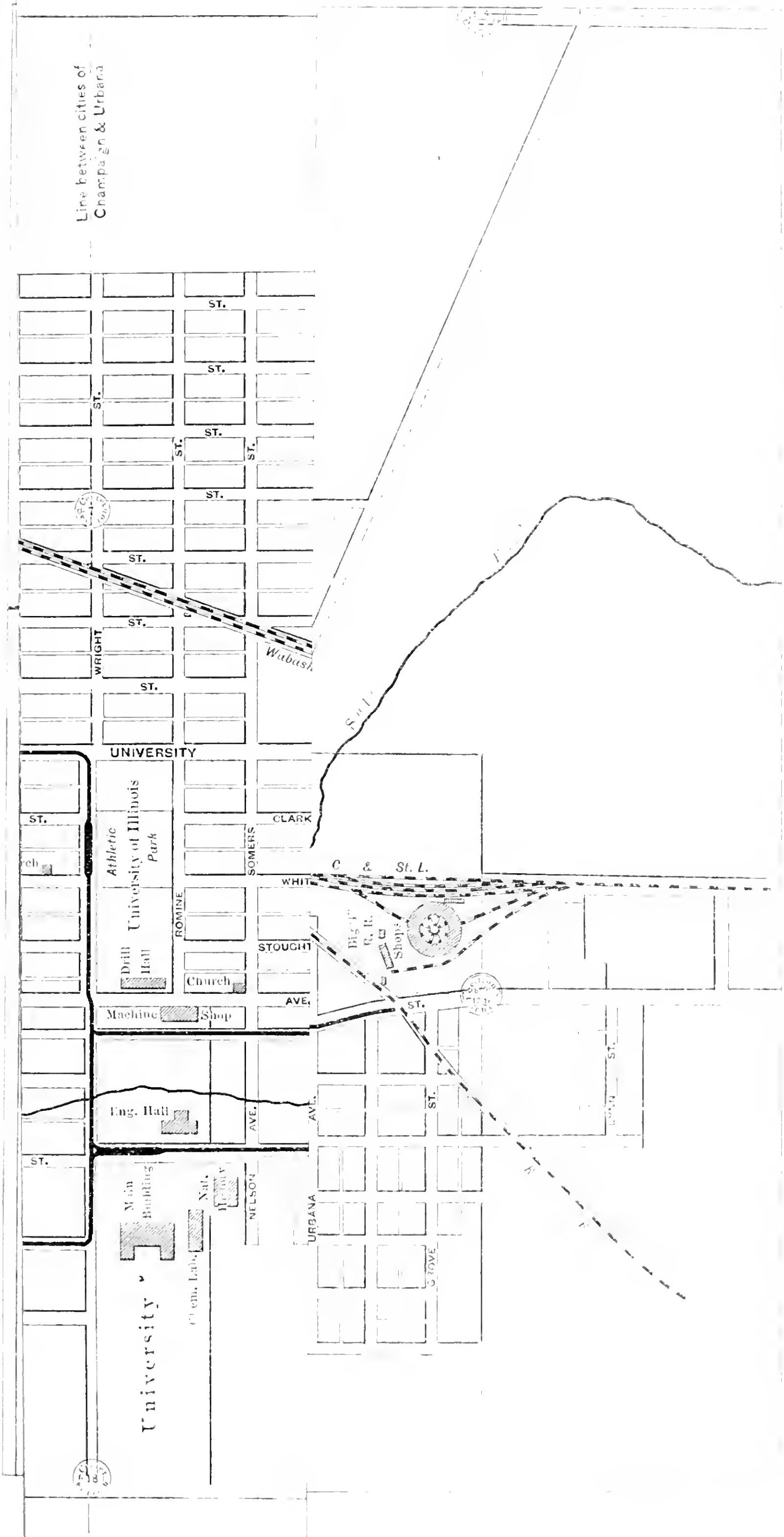
This test was made in order to obtain such information as would enable entire preparation for taking observations of the station output during the general test. On account of special attractions offered at the West End Park during the evening, this day was decided upon as one which would show the plant running at more than its ordinary load. Readings of electromotive force and current were taken with Weston instruments every minute for the entire time of the run, from 6 A. M. to 11:30 P. M.

In general the electromotive force did not differ much from 500 volts. Occasionally it rose as high as 600 volts. These high values were caused either by the speed running up when the load was suddenly diminished by a considerable amount or by the over-compounding of the generators when a heavy load was retained for a sufficient time for the engine to regain its normal speed under that load. The latter occasions were rare as the load was generally reduced before the engine regained its normal speed. The electromotive force fell but once below 500 volts and then only for a short time.

The current was very irregular, often instantly changing 150 amperes. This excessive change was due to several cars starting at the same time, and was noticed particularly at intervals of 20 minutes, corresponding to the schedule for departure of cars from certain points of the line. The current varied from 0 to 250 amperes, being largest in the evening when all the cars, including trailers, were pressed into service.

The General Test, May 17, 1894.

This was a complete test of all parts of the system. Numerous tests, in addition to those which have been briefly discussed, and extensive preparations had been going on during the winter and spring. The two or three days immediately preceding that on which the test was made were spent in putting into position the devices and instru-



Line between cities of
Champaign & Urbana
ST.
WRIGHT
Wabash
UNIVERSITY
CLARK
SOMERS
ROMINE
WHIT
STOUGHT
AVE.
C & St. L.
Athletic
University of Illinois
Park
Drill Hall
Church
Machine Shop
Eng. Hall
AVE.
Main Building
Chem. Lab.
Nat.
NELSON
URBANA
GROVE
Shops
University

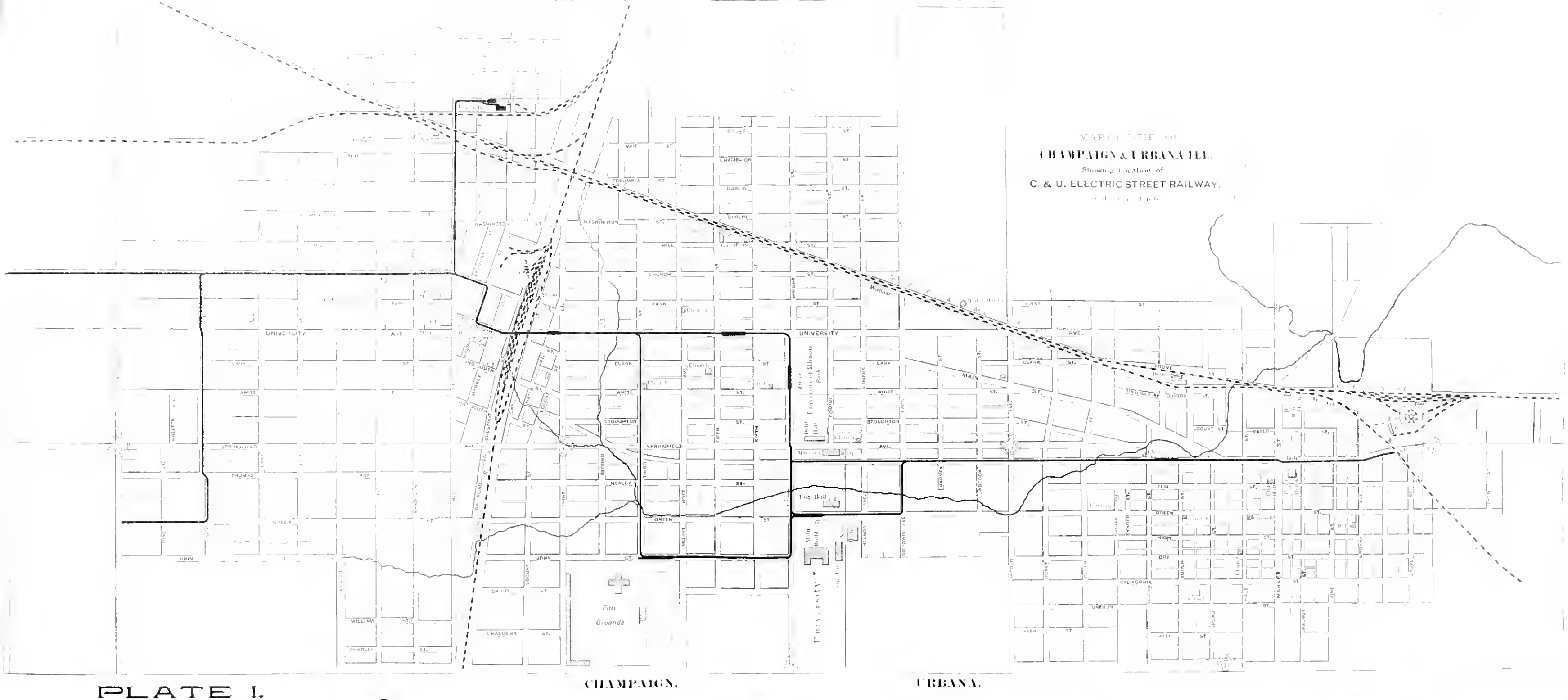
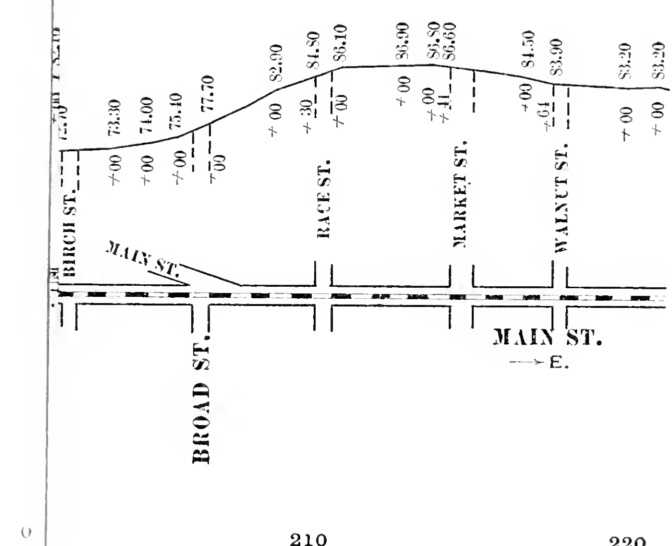
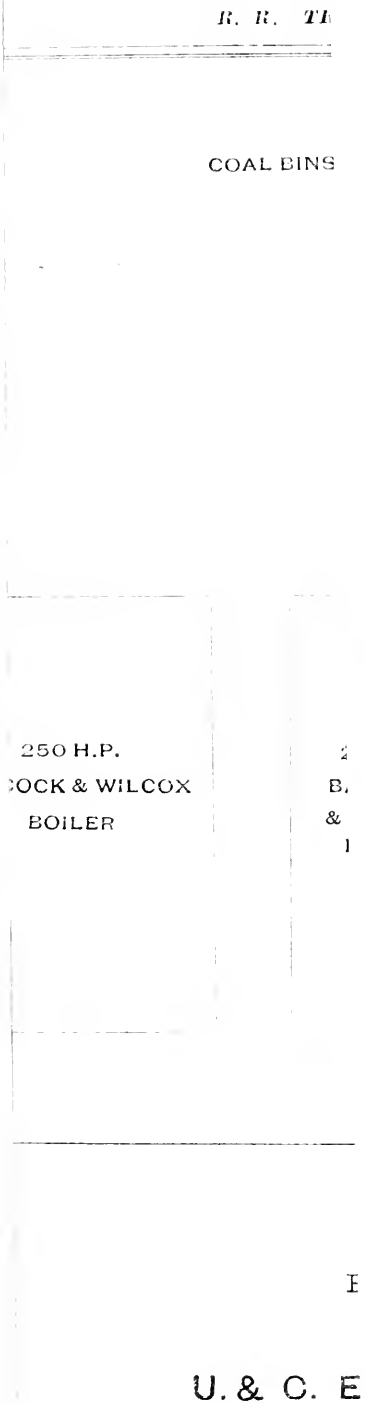

CHAMPAIGN & URBANA ILL.
C. & U. ELECTRIC STREET RAILWAY.
UNIVERSITY AVE.
WASHINGTON ST.
CHAMPAIGN
DUBLIN
BERLIN
CHURCH
PARK
CLARK
WHITE
STOUGHTON
SPRINGFIELD AVE.
HEALEY
GREEN
JOHN ST.
DANIEL
CHALMERS ST.
WILLIAM
CHARLES
THOMAS
MAIN ST.
LOCUST ST.
WATER
ELM
HIGH
CALIFORNIA
OREGON
Fair Grounds
University of Illinois Park
Main Building
University
Drill Hall
CHAMPAIGN.
URBANA.

PLATE I.

RAILWAY

MIDT




R. R. Th
COAL BINS
250 H.P.
COCK & WILCOX
BOILER
U. & C. E

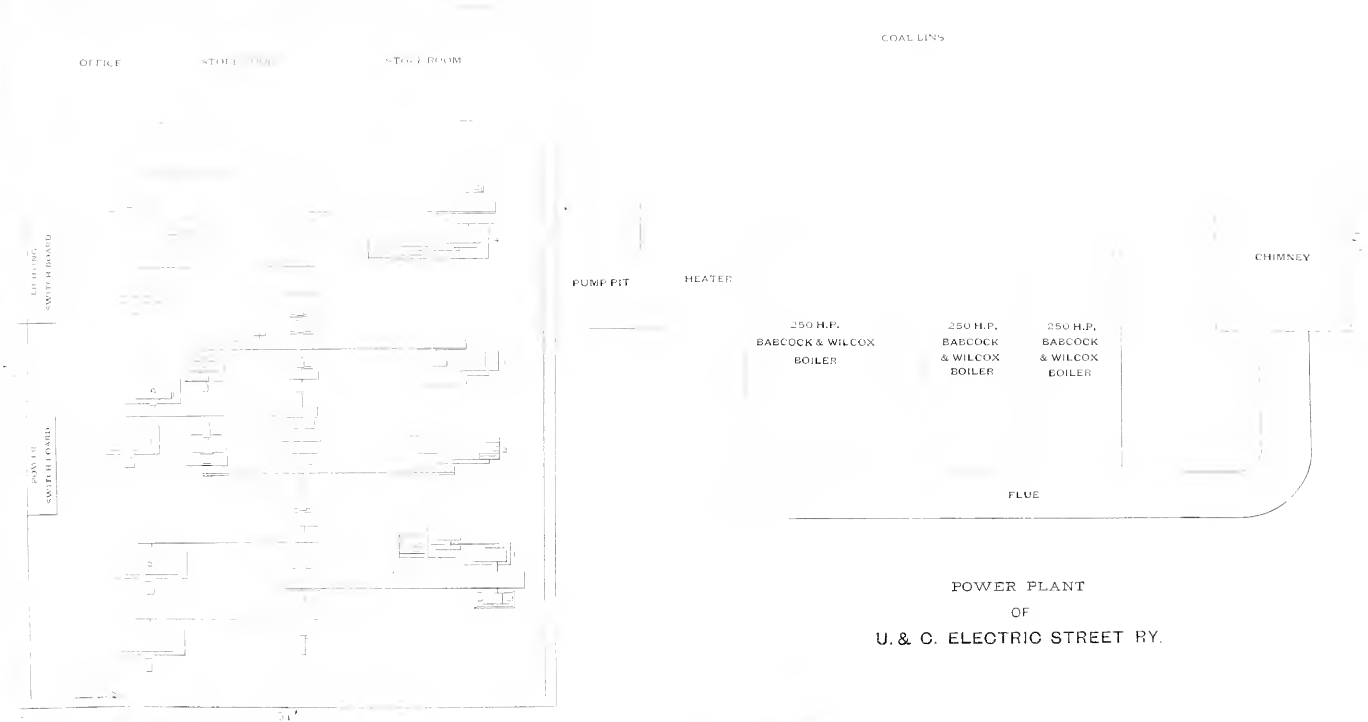

OFFICE
LIGHTING SWITCH BOARD
POWER SWITCH BOARD
51'
COAL BINS
PUMP PIT
HEATER
250 H.P. BABCOCK & WILCOX BOILER
250 H.P. BABCOCK & WILCOX BOILER
250 H.P. BABCOCK & WILCOX BOILER
CHIMNEY
FLUE
POWER PLANT
OF
U. & C. ELECTRIC STREET RY.

PLATE III.

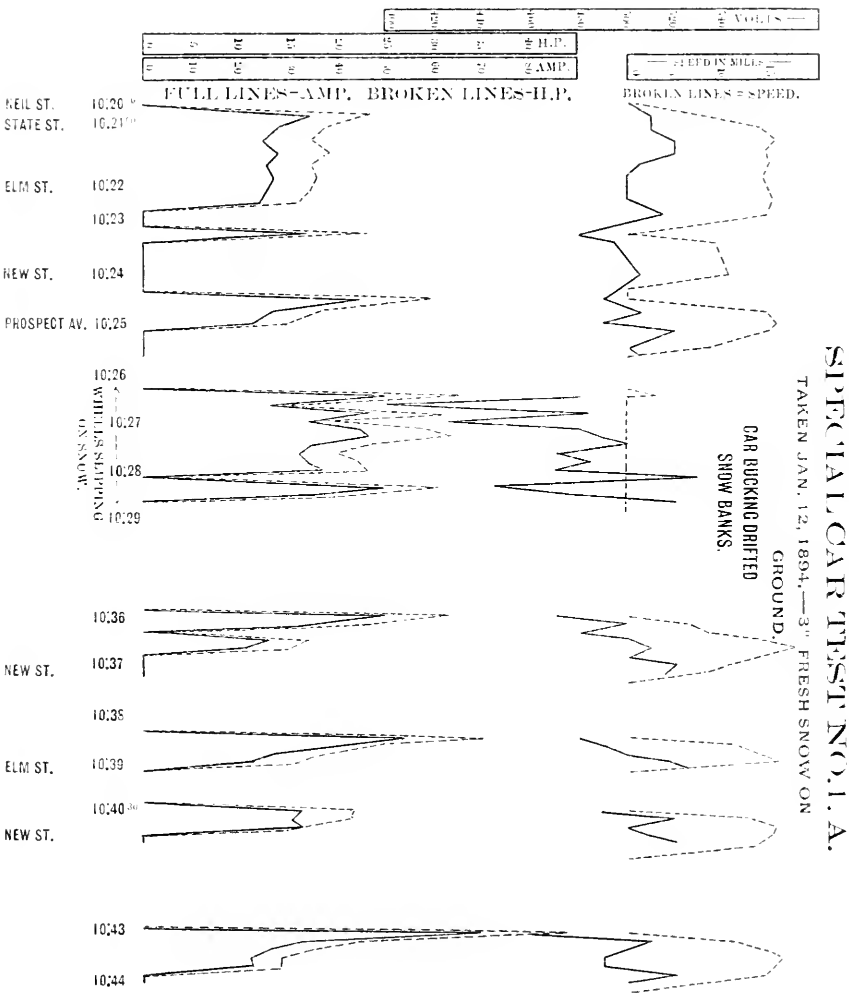
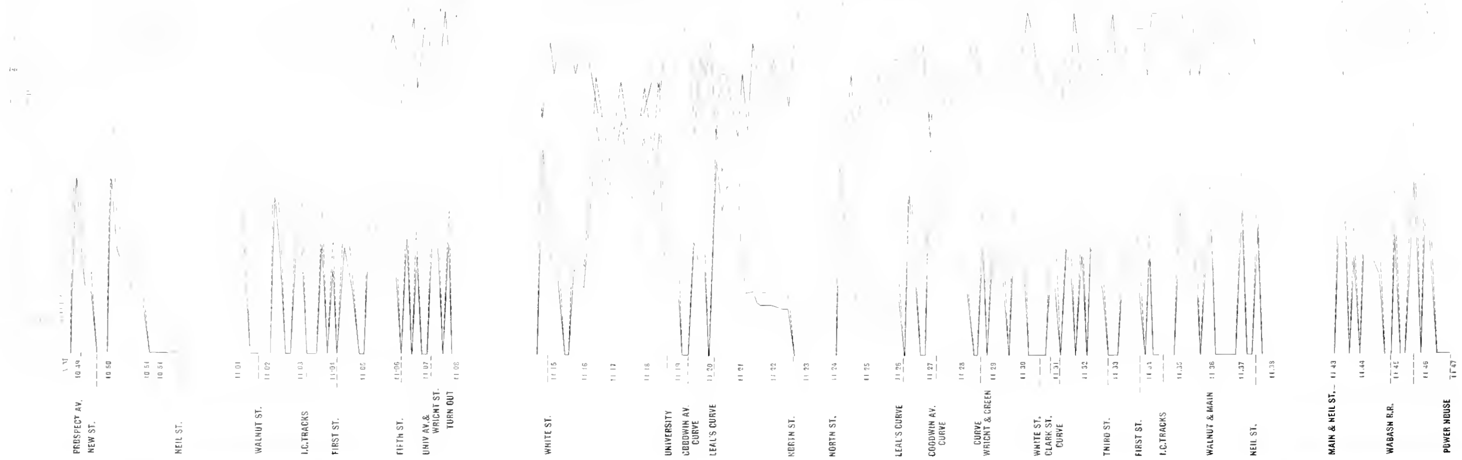

FULL LINES-AMP. BROKEN LINES-H.P.
BROKEN LINES = SPEED.
NEIL ST.
STATE ST.
ELM ST.
NEW ST.
PROSPECT AV.
NEW ST.
ELM ST.
NEW ST.
WHEELS SLIPPING ON SNOW.
SPECIAL CAR TEST NO. 1. A.
TAKEN JAN. 12, 1894,—3" FRESH SNOW ON GROUND.
CAR BUCKING DRIFTED SNOW BANKS.

PLATE IV.

CAR-TEST NO.1.B.
AR NO.16.

894. TEMP.15°BELOW ZERO.
D WITH 3 IN. OF FRESH SNOW.
TTED HORIZONTALLY.

D & GOLDSCHMIDT '94.

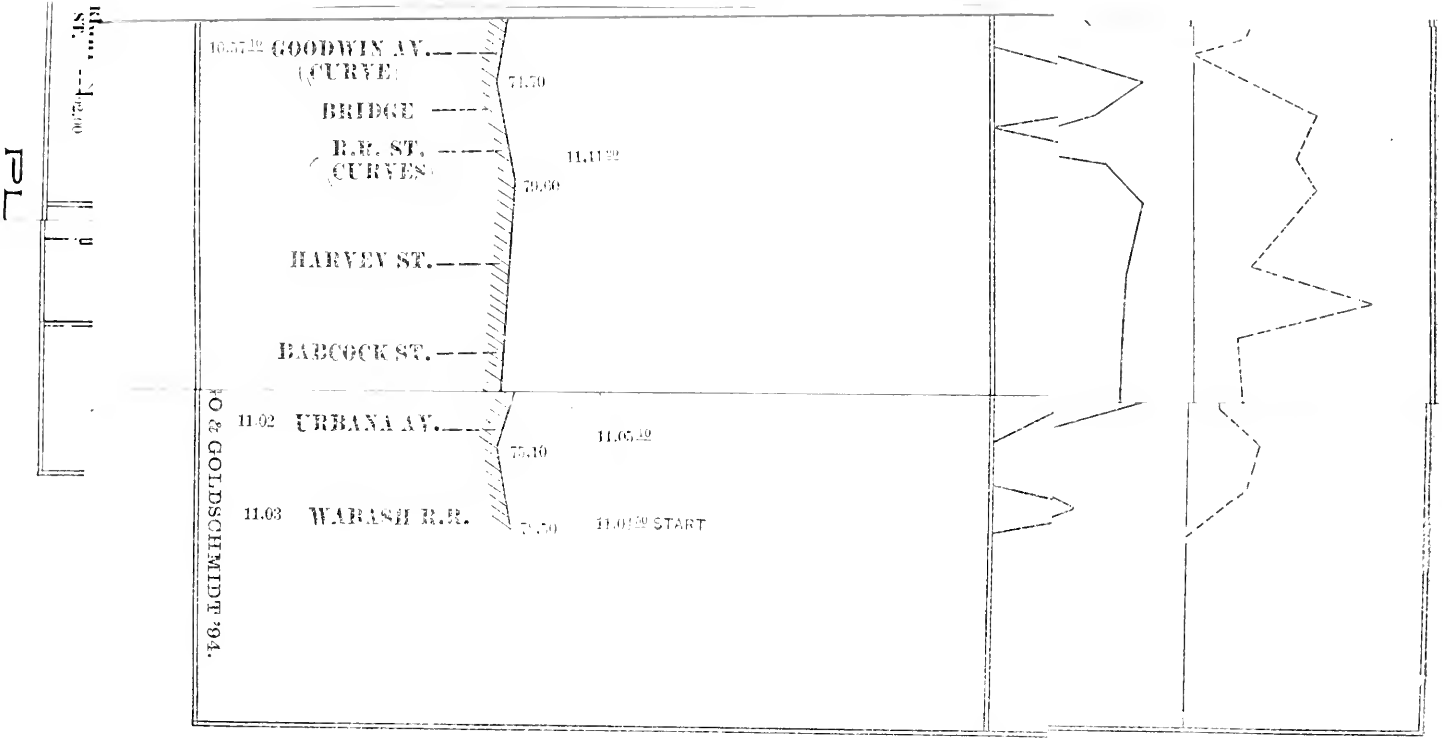


SPECIAL CAR TEST NO.
CAR NO. 16.

TAKEN JAN. 12. 1894 TEMP. 15 BELOW ZERO
GROUND COVERED WITH 3 IN. OF FRESH SNOW
TIME PLOTTED HORIZONTALLY

TREGO & GOLDSCHMIDT '04

PLATE V.


GOODWIN AV.
(CURVE)
BRIDGE
R.R. ST.
(CURVES)
11.11
79.60
HARVEY ST.
BABCOCK ST.
11.02 URBANA AV.
75.10
11.05
11.03 WABASH R.R.
START
O & GOLDSCHMIDT '94.
ST.
PL

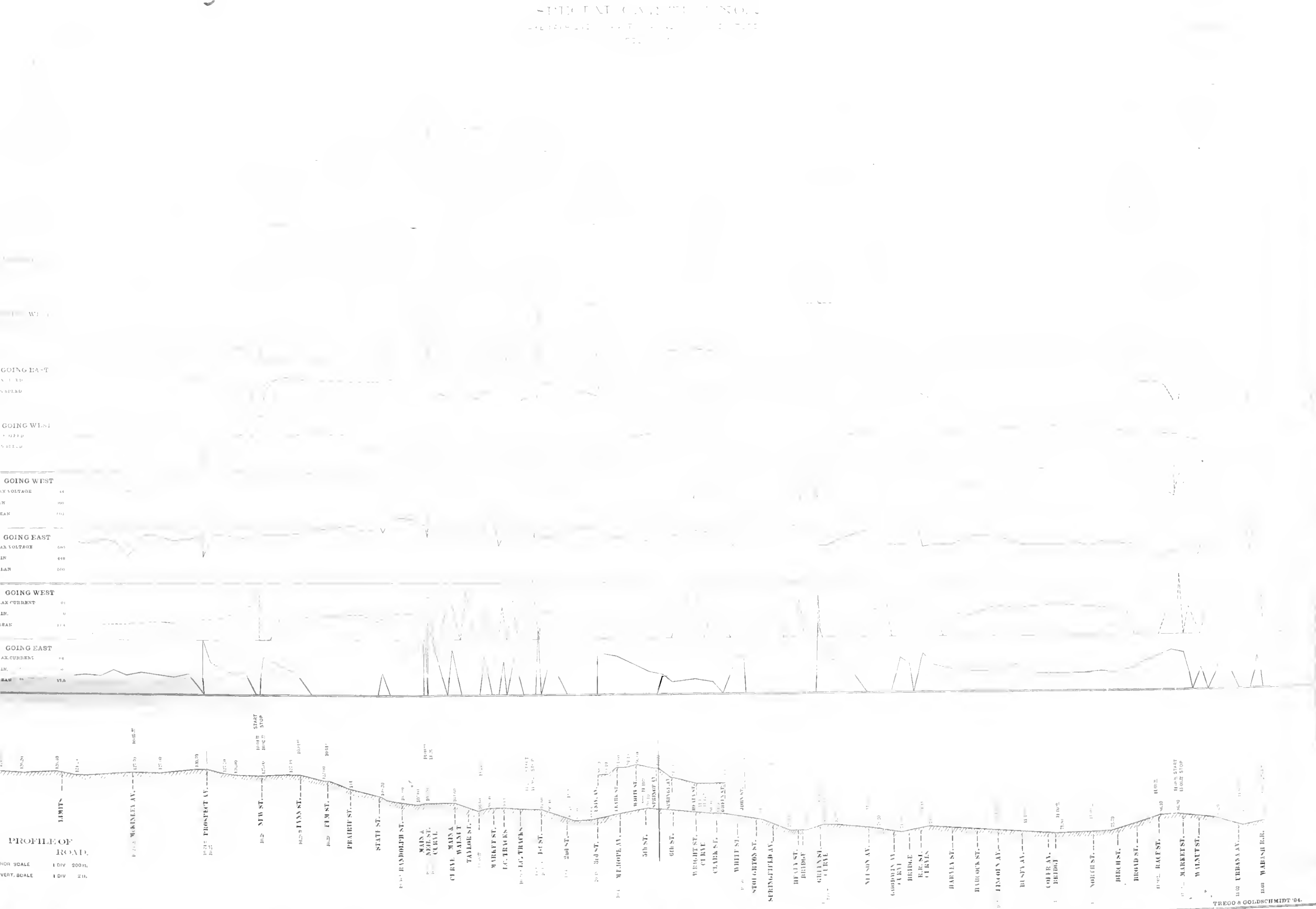
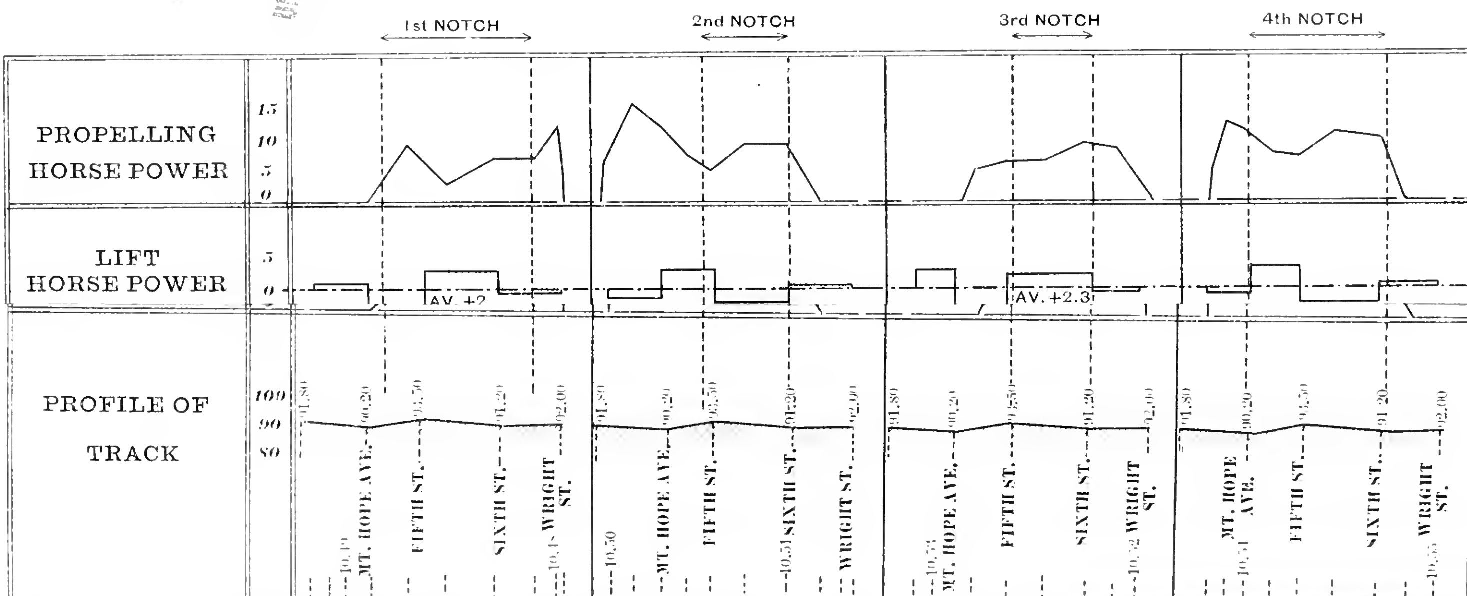

GOING EAST
GOING WEST
GOING WEST
MAX VOLTAGE
MIN.
MEAN
GOING EAST
MAX VOLTAGE
MIN.
MEAN
GOING WEST
MAX CURRENT
MIN.
MEAN
GOING EAST
MAX CURRENT
MIN.
MEAN
PROFILE OF ROAD.
HOR. SCALE 1 DIV. 200 ft.
VERT. SCALE 1 DIV. 2 ft.
LIMITS
McKINLEY AV.
PROSPECT AV.
NEW ST.
LYNN ST.
ELM ST.
PRAIRIE ST.
STATE ST.
RANDOLPH ST.
TAYLOR ST.
MARKET ST.
I.C. TRACKS
1st ST.
2nd ST.
3rd ST.
5th ST.
6th ST.
WRIGHT ST.
CLARK ST.
WHITE ST.
STOUGHTON ST.
SPRINGFIELD AV.
NELSON AV.
HARVEY ST.
BABCOCK ST.
LINCOLN AV.
BUSEY AV.
BIRCH ST.
BROAD ST.
RACE ST.
MARKET ST.
WALNUT ST.
URBANA AV.
WABASH R.R.
TREGO & GOLDSCHMIDT '04.

PLATE VI.

SPECIAL CAR TEST

CONTROLLER AT DIFFERENT NOTCHES.



PL

SPECIAL CAR TEST

CONTROLLER AT DIFFERENT NOTCHES.

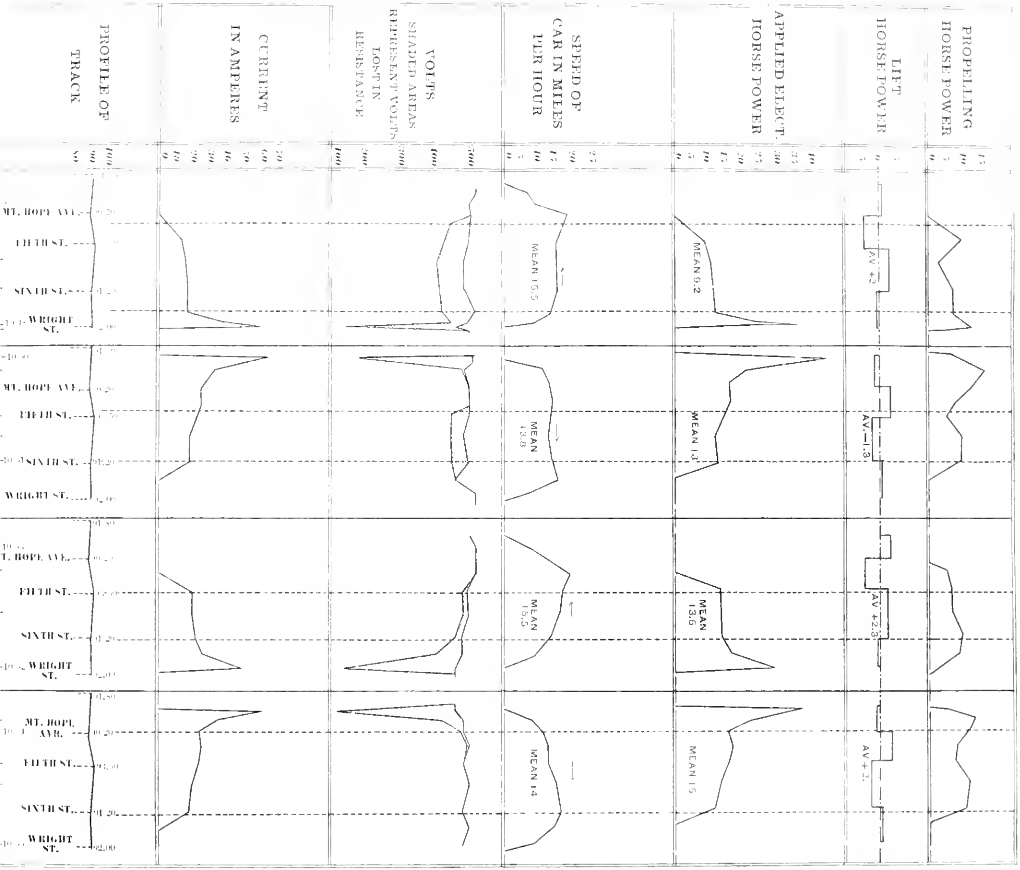
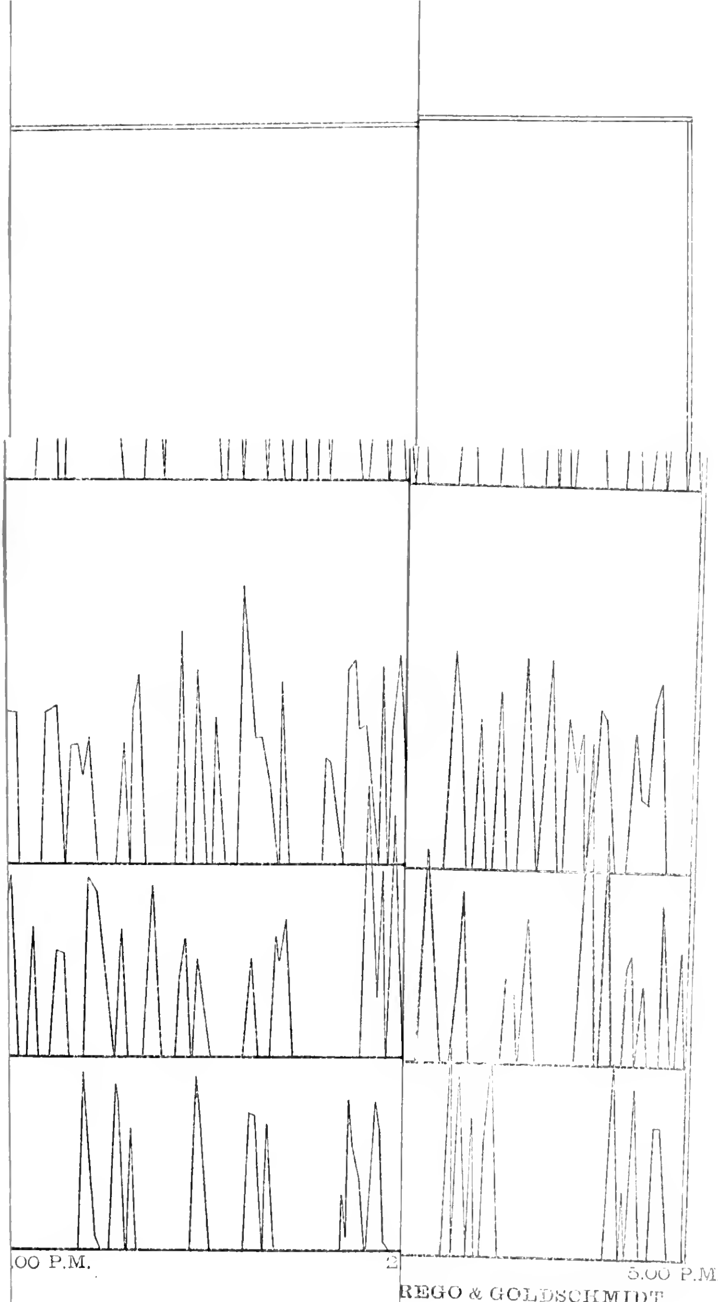
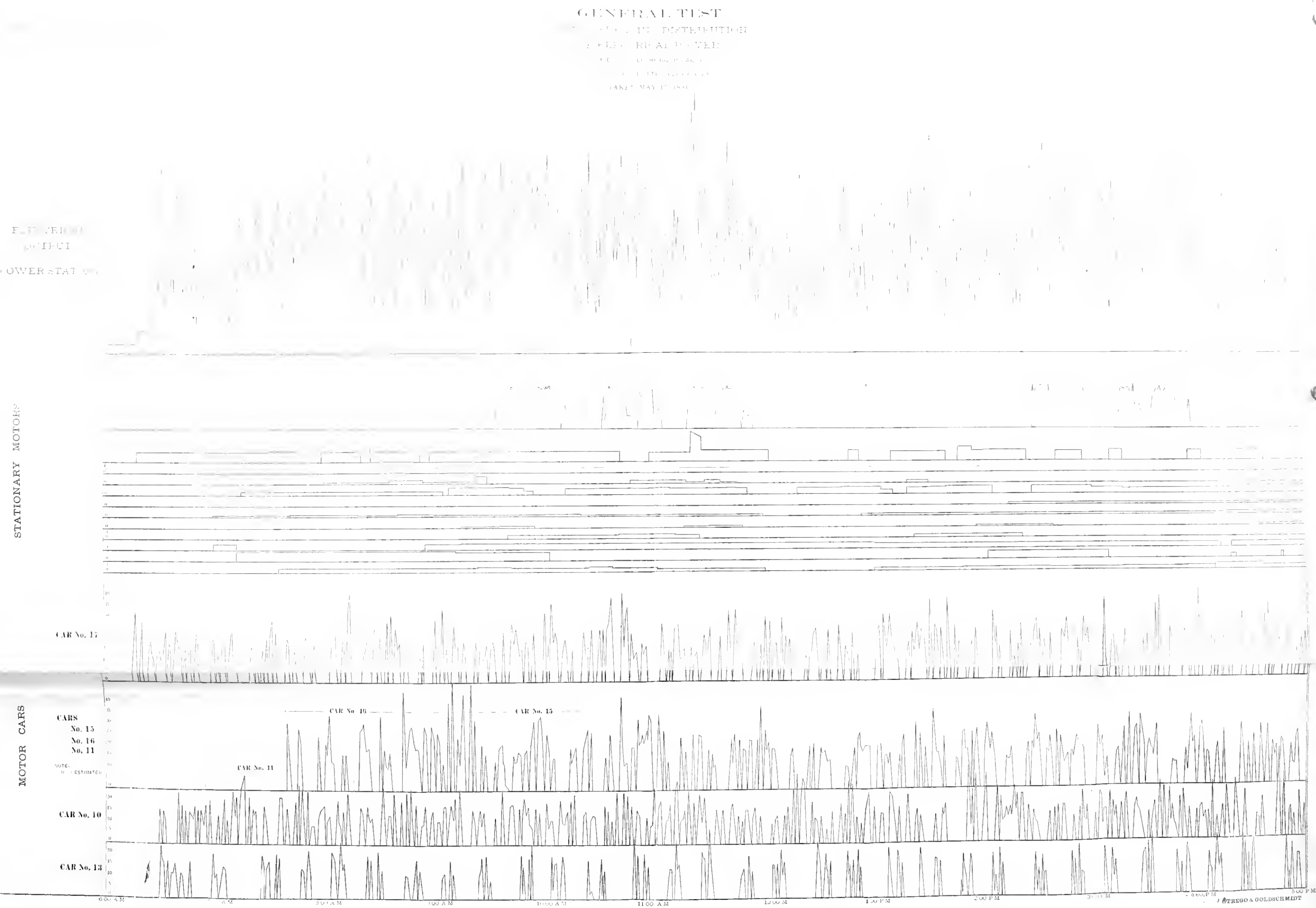


PLATE VII.


.00 P.M.
2
5.00 P.M.
REGO & GOLDSCHMIDT



GENERAL TEST
STATIONARY MOTORS
CAR No. 17
MOTOR CARS
CARS
No. 15
No. 16
No. 11
CAR No. 16
CAR No. 15
CAR No. 11
CAR No. 10
CAR No. 13
11.00 A.M.
5.00 P.M.

PLATE VIII.

ments which experience had shown to be best suited for the purpose. Observations began at 6:00 A. M. and were made throughout the day at intervals of one minute until 5:00 P. M., every precaution being taken to secure simultaneous readings at the various points. The day was clear, warm and dry. The test proceeded from beginning to end without serious interruption of any kind.

The observations taken during the general test may be classified under the heads, A, those taken on the line; B, those taken in the station.

A. OBSERVATIONS TAKEN ON THE LINE.

This group of observations consisted of measurements made on the cars and measurements made at the stationary motors.

Each car and each stationary motor was equipped to measure the total applied E. H. P., a Weston voltmeter and a Weston or a Whitney ammeter being used, except that one voltmeter served for several stationary motors where these were near one another in a group.

The results in terms of E. H. P. are shown graphically in Plate VIII. The electromotive force and current curves have been omitted since they would show nothing beyond what has been already brought out in the plates for the special car test, and they are fully accounted for in the H. P. curves.

The curves representing the total E. H. P. for the cars and also for the stationary motors were unintentionally omitted from the plate.

The arrangement of cars that had been decided upon for the day was as follows: Cars No. 10, 15 and 17 were to make round trips and No. 13 was to ply on New street. In taking car 15 out of the barn the trolley pole was broken. This accident necessitated sending out for a short time car No. 11 which was without electrical measuring instruments. The performance of car 11 is so similar to that of 13 that it was possible to compute very closely the power taken by the unequipped car for the short time it was in service by making the assumption that the average E. H. P. for 11 and 13 are the same. The computed E. H. P. is shown by the dotted line in the group of curves for the car motors. As soon as possible car 16 was equipped and put into service in place of 11. About 9 o'clock A. M. car 15 took the place of 16.

Car No. 10 took its maximum power at 4:40 P. M., the instruments indicating 47 E. H. P. It was then heavily loaded and was

TABLE II.

Car No.	Length of car in feet.	Style of car.	Type of motor.	Rated H. P. of motor.	Average E. H. P. taken.	Max. E. H. P. taken.	Total H. P. hours.	Conditions under which maximum power was taken.					Minutes per hour that motor was not in use.	Average E. H. P. during time that motor took current.
								When.	Where.	Track.	Profile.	Load.		
10	16	Closed.	Single Reduction.	25	8.7	47.0	91.3	4:40 P. M.	Church to Main streets.	Curve	Level	Heavy	15	11.6
11	16	Closed.	Double Reduction.	16	9.9	......	......	......	......	.....	......	......	......	.....
13	16	Closed.	Double Reduction.	16	4.9	36.5	51.4	11:30 A. M.	South end New street.	Straight.	Up 3 per cent. grade.	Light.	37.5	13.1
15	22	Open.	Single Reduction.	25	10.8	50.0	113.1	9:10 A. M.	Neil to Main street.	Curve.	Level.	Average.	20	16.2
16	20	Closed.	Single Reduction.	30	11.8	45.5	......	8:40 A. M.	Neil to Church street.	Curve.	Level.	Average.	18	16.8
17	20	Closed.	Single Reduction.	25	10.4	41.5	109.2	4:00 P. M.	Neil to Church street.	Curve.	Level.	Average.	15	14.0

going east on the curve from Church street into Main street. The average for the nine hours was 7.9 E. H. P.

The H. P. taken by No. 11 being estimated, it is impossible to state what the maximum was. The average was 9 E. H. P.

Car No. 13 made round trips at 20-minute intervals, starting south as a car passed New street going west, and returned in time to make connection with the same car going east. The maximum power required by No. 13 was 36.5 E. H. P. This was at 11:30 A. M., on the start from the south end of the line where the grade is considerable. This car was at no time heavily loaded. The average was 4.5 E. H. P., the car being operated only about half the time.

No. 15 required 50 E. H. P. to start on the curve from Neil street into Main. This maximum occurred at 9:10 A. M. The average was 9.9 E. H. P. The power required for No. 16 attained a maximum of 45.5 E. H. P. at 8:40 A. M. in going around the curve from Neil into Church street. The average was 10.8 E. H. P. The maximum power taken by No. 17 was also on the curve just mentioned. It was 41.5 E. H. P. and occurred at 4 P. M. The average was 8.3 E. H. P.

The above mentioned data are brought together in Table II.

It was not deemed necessary to make any observation of the power lost in the controlling resistances, since it was possible to compute the loss. In special car test No. 2 it was found that the loss in the resistance is about 0.8 E. H. P. in starting the car in the ordinary way. The average time taken by motormen of this line to start a car, *i. e.*, to turn the controller notch by notch until the resistance is all cut out, is ten seconds. The average number of starts per car during a round trip, on the day of the test, is given in the following table:

TABLE III.

Car No.	10.	13.	15.	17.
Average starts per round trip.	17.	9.	15.	14.

Average starts per round trip for the four cars 55.

This would give a loss in the resistance of the four cars of about 0.11 E. H. P. continuously during the test, or about 1 E. H. P. for one hour in the 11 hours during which the test lasted.

It was intended to take the speed of each car, (1) in order to be able to determine whether or not the distribution of the cars along the line was satisfactory with respect to lift and propelling H. P; (2) to have sufficient data for accurate computation of the efficiency of the system. The special test of station output, however, had shown that the great variations in the load of the engine were due to all the cars starting together at the twenty minute intervals, rather than to a bad distribution with respect to grades. Further it was found impracticable to determine accurately the efficiency for the various motors at all speeds and loads. Therefore readings of speed were omitted. The location of the cars and the number of passengers at the minute intervals have not been given, since these would be of little value if the speed was not known.

There were in use for various power purposes, on the day of the test, eleven stationary motors. Two of these were in Urbana near the business center of that city; the remainder were in Champaign, all near its business center, with the exception of two at the elevator which is near the power house. In addition to the motors above mentioned there were in use several small fan motors. Data concerning the motors and the results of the measurements made on them are shown in the following table:

TABLE IV.

Type of motor.	Rated H. P.	Maximum H. P. taken.	Average H. P. taken during run.	No. hours run.	Total H. P. hours.
T. H.	(Two) 16.	21.5	12.0	3.33	40.
T. H.	15.	14.0	4.7	7.2	34.
Kester	3.	3.5	1.26	2.66	3.35
Kester	7.5	3.5	2.93	8.5	24.9
Edison	4.	1.5	1.0	2.8	2.8
C. & C.	3.	1.5	0.95	9.2	8.7
Mayo..........	1.	2.0	0.94	2.33	2.2
Kester	7.5	2.5	2.00	2.3	4.5
Belding........	6.	5.0	3.80	1.0	15.5
Kester	7.5	3.0	1.60	8.4	13.7
Jenny	5.	3.5	3.00	8.2	24.5
Fan motors....	....	....	0.46	11.	5.1

The measurements on the motors are exhibited graphically by the curves in Plate VIII. It will be noticed that most of the motors take very little power. The motors at the grain elevator, however, take considerable, the average E. H. P. during a run being about one-third of total E. H. P. taken by all the motors, if in operation at one time. The grain elevator motors are, however, in operation only a small part of the day, while several of the smaller motors operate almost continuously. The total number of E. H. P. hours for the stationary motors is about one-half the total for the car motors. It will be seen from the curves that the load for the small motors is almost uniform, while the load for the grain elevator motors changes greatly, and causes more variation in the station output than all the other stationary motors together.

The average E. H. P. for all the stationary motors during the 11 hours is 17.3. The Bevis Planing Mill started at 6.01 instead of at 6.18 and it should have been so shown in the plate. The power taken by it is shown in curve for station output. The average E. H. P. for all the motors (both car and stationary) is 52.1.

It is to be regretted that time and means did not permit of making efficiency tests of all the motors.

It was arranged that no lamp circuits should be in operation, so that power should be taken by the motors only.

B. Observations Taken at the Station.

These observations may be subdivided as follows:

(1) Observations taken at the generators.

(2) Observations taken at the engine.

(3) Observations taken in the boiler room.

(1) Observations taken at generators.

As above stated the two generators are compound wound and are connected in parallel. The output was measured by connecting a Weston voltmeter between trolley and ground bus bars and placing a Whitney ammeter in circuit with each machine. The results are graphically represented on Plate VIII.

The engine and generators were started a little before 6:00 A. M. As stated above, the Bevis Planing Mill started at 6:01 instead of at 6:18 as represented. The curve representing the output of the generators is very characteristic of power stations in which the load changes suddenly by great amounts.

The maximum power given out by the generators was 121 E. H. P. and occurred at 11:24 A. M. At this time three of the cars started suddenly and the two largest stationary motors were taking their maximum power. The power taken from the generators exceeded 100 E. H. P. several times, noticeably at the twenty-minute intervals, when the cars started simultaneously. The minimum power was 13.5 E. H. P. On several occasions the instruments indicated less than 15 E. H. P. These cases were when none of the cars were taking current, the power being taken by stationary motors only.

The maximum sudden change was 71 E. H. P., which occurred at 10:24 A. M., when the E. H. P. rose from 21.5 to 92.5. At this time all four cars started simultaneously, producing the great variation observed. The stationary motors were working uniformly at the time. The average power delivered to the line by the generators is 55.5 E. H. P.

Observations Taken at the Engine.

A Porter-Allen engine 16x16 running at 285 revolutions per minute furnishes power for driving the generators. It is run non-condensing under a boiler pressure of 110 pounds. It is situated about 100 feet from the boiler that was used during this test, the connecting pipes being well covered with a non-conducting covering. In Plate IX. is shown a cut of this engine made from a photograph taken at 3:35 P. M. on the day of the test. Arrangements are shown for taking the following observations:

1. Revolutions per minute.
2. Position of governor.
3. Steam pressure in pipe above throttle.
4. Moisture in steam pipe above throttle.
5. Indicator diagrams from each end of the cylinder every minute.

An inspection of the cut will render any detailed description of these arrangements unnecessary.

A reading of the revolution counter was taken on every half-minute while indicator diagrams were taken at the even minutes, so that the revolutions obtained in this way are the revolutions which held for the minute that the indicator card was taken.

A graduated arc set up back of the engine enabled the position of the governor to be read by the same observer that read the revolutions.

The indicator rig used was the drop lever and connecting link type without a sector, although the photograph makes it appear that a sector was used. This is due, however, to the fact that the picture was taken with the engine in motion. Two Tabor indicators were used on the engine cylinder, a string from each indicator leading straight to the drop arm of the rigging. A small strip of aluminium about $\frac{3}{8}$ of an inch wide and 4 inches long was attached to this string, and in the strip 3 holes were drilled, into either of which a hook attached to the string from the drop arm could be placed.

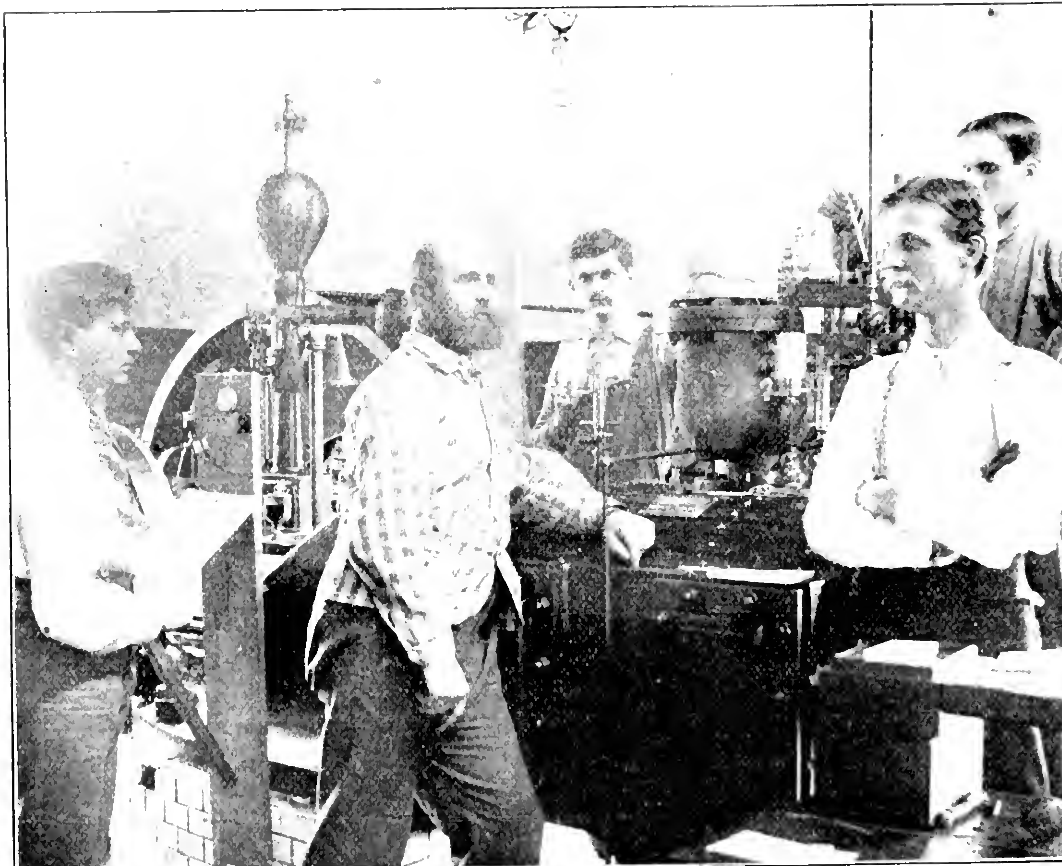


PLATE IX.

The length of the card taken was 3 inches. By placing the hook successively in the 3 holes indicated 3 diagrams could be drawn on each card without removing it each time for a new diagram. This greatly facilitated the rapid taking of diagrams, and no trouble was found in taking cards as frequently as every minute. In order that the diagram should be taken exactly on the minute, the observer at the revolution counter called "time" just as the second hand pointed to sixty.

A connection was made to the steam pipe just above the throttle valve, and to this connection, the calorimeter was attached. This instrument is shown with the observer reading the thermometer placed in the oil cup, in the top of the instrument. It is a throttling calorimeter of the type manufactured by Schaeffer & Budenburg Manufacturing Company. Observations were taken every 30 minutes from this instrument.

A Crosby indicator was attached to the extension of the same pipe and the use made of this indicator was to record the pressure in the pipe as well as to show the variation in this pressure. The method of using it was simply to turn on the steam and while the pencil was moving slightly up and down, due to variation in the pressure, the string was pulled along by hand for about ½ inch. The time was then written down above this record, and about 8 records were placed on each card. A sample of the cards thus taken is shown in Plate X., as well as sample indicator digrams taken from cylinder.

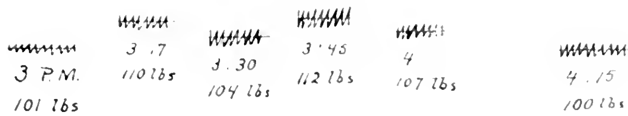
The cards taken from the steam pipe were all carefully measured and the variation in pressure recorded as well as the average pressure, which was taken to be half-way between the highest and lowest points recorded by this method.

All of the instruments seemed to be in good condition, and it is probable that the series of observations were taken as carefully as it is possible to do this kind of work.

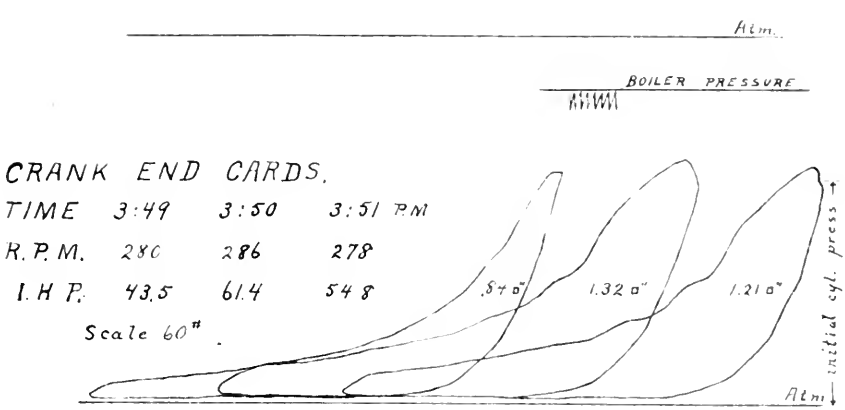
A total of about 1 300 diagrams were taken from the engine. Each of these diagrams has been planimetered by two persons, and an extensive table of results as well as a graphical record has been prepared by the mechanical engineering department. Space would not permit of the publication of this table of results and only the deductions and average values are reported. See Tables V., VI. and VII. and Plate XI.

Observations Taken in the Boiler Room.

The boiler used during this trial was that designated by the



SAMPLE CARD FROM STEAM PIPE.



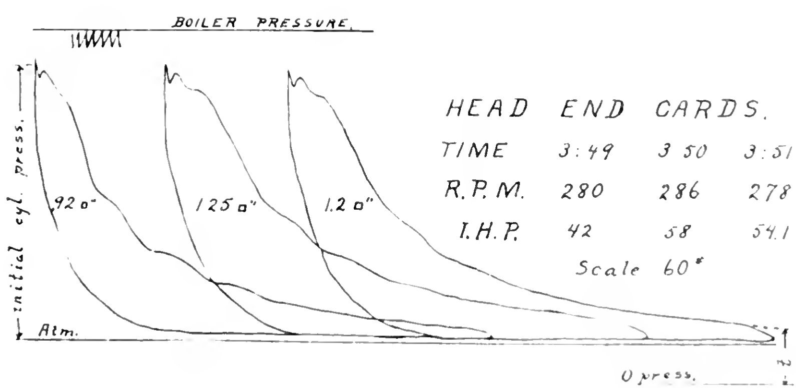


PLATE V.

power company as No. 3, being the one situated at the east end of the boiler house and furthest from the engine.

This boiler was one of the Babcock & Wilcox boilers used at the Columbian Exposition, having been erected at this plant in the spring of 1894 only a short time before it was tested.

For weighing feed water, a new 2-inch injector was set up and used for handling all the water fed into the boiler. Steam for running it was taken from the boiler tested.

A tank holding 4 barrels of water was provided and into this the suction from the injector extended. On this tank was mounted a scale carrying a barrel. Uniform amounts of 400 pounds of water were weighed and dropped into the tank below. The temperature of the water was taken while it was in the barrel on the scales.

A special box was provided for weighing the coal. Uniform charges of 300 pounds were delivered to this box and after each firing the scales were balanced.

The usual observations were made every 15 minutes during the test.

All gauges used were tested by the "Crosby weight gauge tester" and all scales were tested by a comparison with a set of U. S. standard weights belonging to the government and deposited at this university.

The coal used was "Odin Lump." An analysis is given in the following table:

TABLE V.

Moisture	6.75
Volatile matter	40.50
Fixed carbon	47.39
Ash	5.36
	100.00

The more important observations and results are represented in Plate XI.

The plate shows, in addition to the more important values of the engine and boiler test, the calculated values of engine H. P. hours, generator, and motor H. P. hours. The curves are plotted with time as abscissæ. In those for the coal burned and water evaporated the ordinates give the total quantities up to the time to which the ordinates correspond. The same holds true concerning the engine, generator and motor H. P. hours.

The average values of some of the quantities shown in the curves, together with some total values, are given in the following table:

TABLE VI.

Average steam pressure in boilers	101.2 lbs.
Average draft in inches of water	.3 in.
Average temperature of flue gases	476°.0 F.
Average temperature of steam	340°.4 F.
Average temperature of external air	86°.6 F.
Average temperature of boiler room	83°.7 F.
Average temperature of feed water	58°.0 F.
Average per cent. of moisture in steam	3.28
Total quantity of coal burned	7 900 lbs.
Total quantity of water evaporated, corrected for quality of steam	38 688 lbs.
Water evaporated per pound of dry coal	4.88 lbs.

Table VII. contains the most important results of the general test. It shows the quantities of water and coal consumed in the operation of the various parts of the system. Some facts concerning the number of passengers carried and distribution of cost are also given.

TABLE VII.

Total water evaporated	38 688 lbs.
Total coal burned	7 900 lbs.
Total engine H. P. hours	833.0
Total dynamo H. P. hours	578.0
Total motor H. P. hours	547.0
†Total car motor H. P. hours	365.4
‡Total round trips of cars, of 8.6 miles each	34.5
Total car miles run	297.
Total number of passengers carried (estimated from daily average of 1 700.)	1 100.
Passengers per car mile	4.
Passengers per round trip	32.
Water evaporated by 1 pound of coal	4.90 lbs.
Water evaporated per engine H. P. hour	46.40 lbs.
Water evaporated per dynamo H. P. hour	67.00 lbs.
Water evaporated per motor H. P. hour	70.70 lbs.
Water evaporated per car round trip	1 121.00 lbs.
Water evaporated per car mile	130.30 lbs.
Water evaporated per passenger carried	35.10 lbs.
Coal per engine H. P. hour	9.48 lbs.
Coal per dynamo H. P. hour	13.67 lbs.
Coal per motor H. P. hour	14.50 lbs.
Coal per car round trip	114.20 lbs.

†Equal 66.8 per cent. of total motor H. P.

‡Third street car reduced to round trips of 8.6 miles each

Coal per car mile	16.70 lbs.
Coal per passenger carried	4.52 lbs.
Cost of coal per ton	$ 1.80
Total cost of coal burned	7.11
Cost of coal per pound of water evaporated	0.0184c
Cost of coal per engine H. P. hour	0.8510c
Cost of coal per dynamo H. P. hour	1.2130c
Cost of coal per motor H. P. hour	1.3000c
Cost of coal per car round trip	20.6100c
Cost of coal per car mile	2.3900c
Cost of coal per passenger carried	.6460c

The Efficiencies.

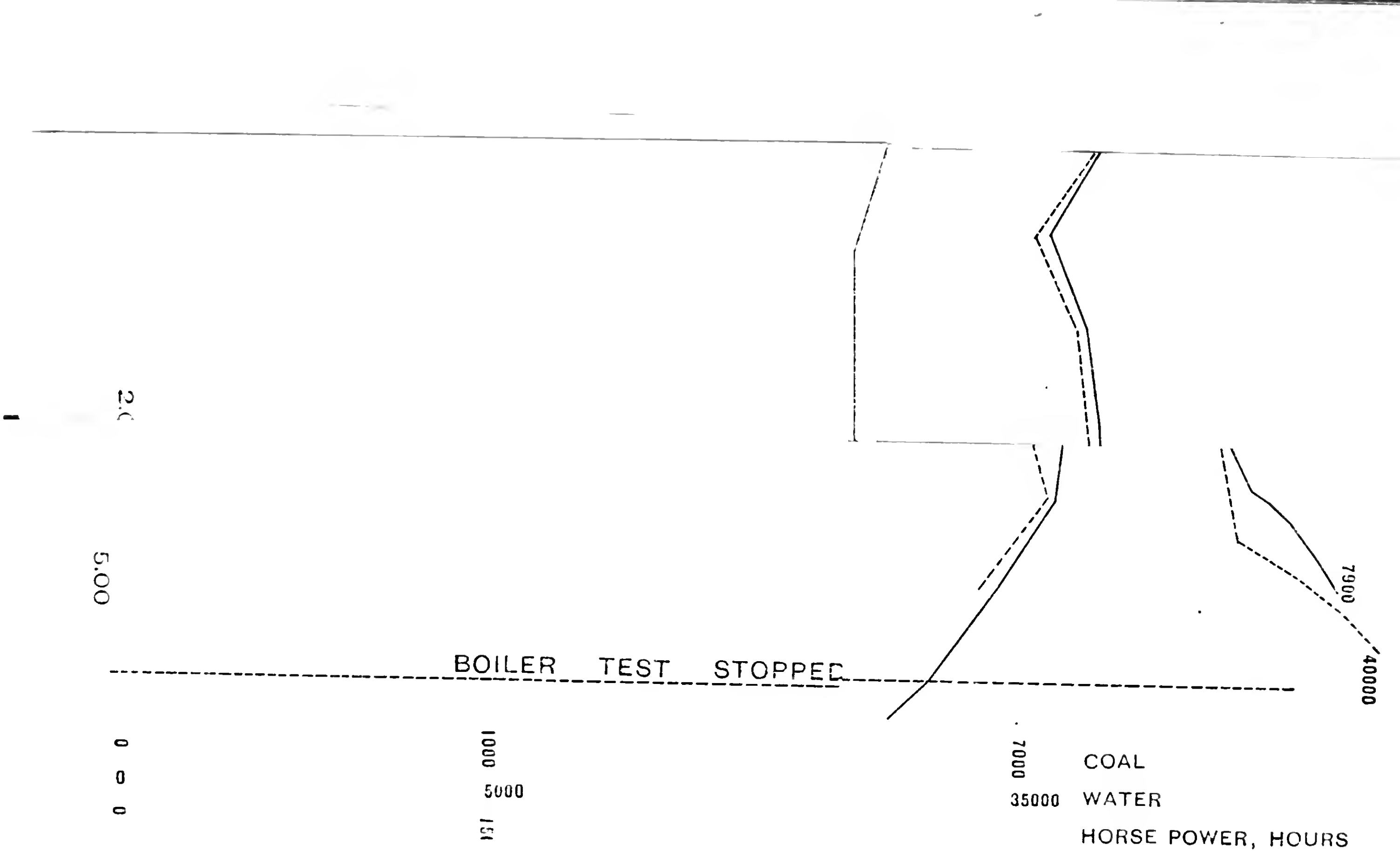
The rated capacity of the boiler used is 250 H. P. and the rate of evaporation claimed by the maker is about 9 lbs. of water per lb. of coal burned. On the basis of 11.5 square feet of heating surface per H. P. it was found that the H. P. was only 193. The quantity of water evaporated per lb. of coal burned during this test was found to be only 4.88 lbs. This indicates a very low boiler efficiency. The coal consumed is about the proper amount so far as area of grate surface and area of heating surface are concerned. The boiler was worked very much below its rated capacity. This makes the quantity of water evaporated too low with respect to the amount of grate surface and heating surface, and to the coal burned.

The low boiler efficiency may also be partly attributed to excessive variation in the load. The boiler must be ready to supply a large quantity of steam at any time, and the fires are kept to furnish this, while during a considerable part of the time only a little steam is used. Under such conditions a high boiler efficiency can not be attained.

The engine and generator efficiencies were not separately determined. From the known station efficiency, however, it is evident that they are pretty high.

The average engine I. H. P. was 79.3. The average E. H. P. delivered to the line by the generators was 55. The station efficiency, *i. e.* the ratio of E. H. P. delivered to the line by the generators to the I. H. P. at the engine, is then 69.4. This is to be regarded as a high value when compared with values obtained in tests of railways in other places, and when it is considered that very few cars are in operation at one time and these under conditions that cause excessive variations in station output.

The average E. H. P. applied at the motors was 52.1. The average station output was 55. E. H. P. The line efficiency, com-



BOILER TEST STOPPED
7900
40000
2.0
5.00
0
0
0
1000
5000
7000
35000
COAL
WATER
HORSE POWER, HOURS

DATA OF BOILER TEST AND OF ENGINE

DYNAMO AND MOTOR H.P. HOURS

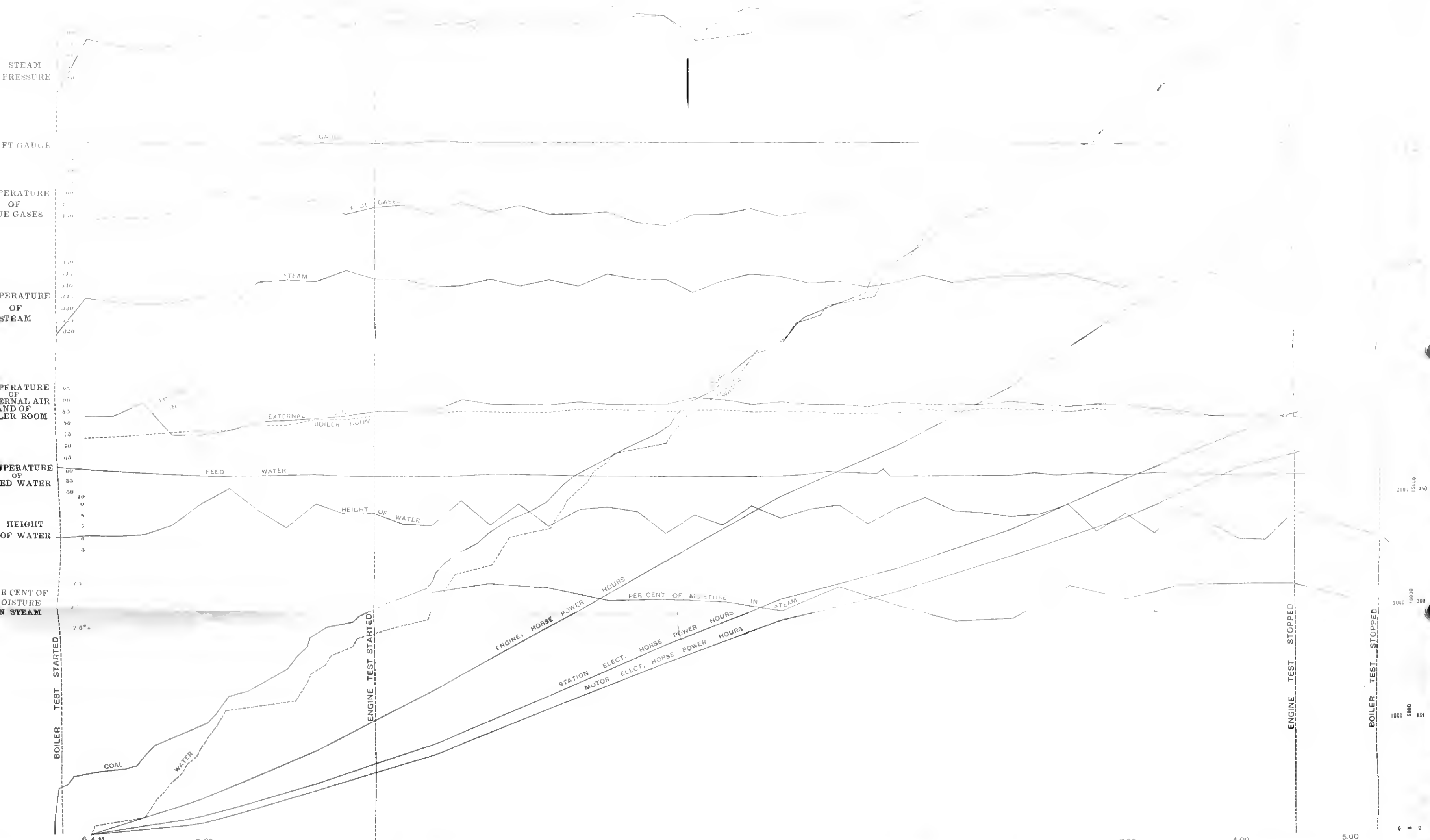


PLATE XI.

puted by finding the ratio of the average E. H. P. applied at the motors to the average station output is, therefore, 94.6.

From the known distribution of the cars along the line, and the known resistances of line and of rail and ground return which was 1 ohm for the entire circuit, most of the loss of 5.4% must be $C^2 R$ losses and very little can be due to leakage. Insulation tests made both before and after the efficiency test gave a very high insulation resistance.

The efficiency from engine (indicated) up to the motors is 65.7. The commercial efficiency for the traction system, *i. e.*, the ratio of the power delivered at the car axle, to the part of the engine I. H. P. due to the cars, can be estimated approximately by assuming that 65% of the power delivered to the motors is in turn delivered to the car axle (*i. e.*, that 35% is lost in motors and gearing). This gives a commercial efficiency of 42.7% for the traction system.

The total commercial efficiency for the entire system, *i. e.*, the ratio of the sum of the power delivered at the pulleys of the stationary motors and the power delivered at the car axles to the I. H. P. at the engine is, (if 85% be taken as the average efficiency of the stationary motors), 17.4%. Comparison with published results show this to be above the average. It speaks well for the performance of the engine and electrical part of the system. The efficiencies are brought together in the following table:

TABLE VIII.

Part of System.	Percents.
Boilers …	Low
Engine …	…
Generators …	…
Station …	69.4
Line …	94.6
Engine to motors …	65.7
Traction system, engine to car axle …	42.7
Engine to car axles and stationary motor pulleys (commercial efficiency) …	17.4

The students of the department of electrical engineering and of the department of mechanical engineering made the greater part of the readings in the general test. It is to their faithfulness and patient and intelligent observation that the success of the test is largely due. The work was carried on under the general supervision of Professor Breckenridge of the department of mechanical engineering, and of Professor Shea and Mr. Swenson of the department of electrical engineering.

To Mr. B. F. Harris Jr., president of the railway, and to Mr. H. J. Pepper, superintendent, our thanks are due for their kindness in permitting the various tests, and for the cheerful assistance given and uniform courtesy shown us.

RAILROAD CROSSING FROGS.

By Wm. D. Pence, Assistant Professor of Civil Engineering.

The measurement of the angle for a railroad crossing frog is usually a comparatively simple matter. Yet it is found that under conditions which prevail in most large railroad centers, the collection of complete data required in ordering a crossing frog may demand special skill and experience on the part of the engineer. Among the complicating circumstances encountered in most large cities are crowded railroad or street traffic, curved alinement of the tracks, and contiguity of other crossings. In preparing the order for a crossing frog, it is the custom of some engineers to provide a more or less elaborate drawing showing the details of the frog. This procedure is doubtless necessary in many instances, but in a large majority of cases it is sufficient to prepare a simple and clear center-line drawing, supplemented by a tabulated statement of the data required by the maker of the frog. In collecting the data to accompany the order for a crossing frog, the following items require due attention:

(1) *The Gage of each Track involved in the Crossing.*—In most cases the intersecting tracks will be of the same gage, but this point should be carefully tested by actual measurement. Among the most probable sources of error in this regard are the confusing of the standard gage of 4 ft. 8½ ins. with the less common gage of 4 ft. 9 ins., and the failure to observe the widening on sharp curves.

(2) *The Alinement of each Track.*—In newly located crossings, exact refinements in the matter of alinement may properly be given precedence over the question of economy in cutting rails, but in the renewal of old crossing frogs the latter consideration is usually given the more weight, particularly where connection with or close proximity to other frogs may serve to fix in a rigid manner the position of one or both of the tracks. Where the center lines are not to be disturbed in renewing the crossing, it is necessary to consider the alinement little, if any, beyond the outermost limits of the set of frogs concerned. In fact, with crossings on curved tracks the use of centers as much as 100 ft. distant from the intersection to determine the direction of the tangent line, may lead to a perceptible

misfit in the frog, owing to a lack of uniformity in the curvature within the limits taken. Ordinarily the alinement of the center lines need not be considered more than 20 or 30 ft. either way from the point of intersection. An exception to the above rule is found occasionally where the old frog has been dragged out of line on one or both lines of railroad by the "creeping" of the rails, a phenomenon which is usually, and no doubt correctly, ascribed to unbalanced traffic. The last named defect of course looks most unsightly on tangent track, but it may be sufficiently aggravated in curved tracks as well to demand periodical correction by driving the rails back or substituting rails of other lengths as may be required. In chronic cases of worn-out crossing frogs, which it must be admitted are far too common in this country, it may often be the wisest plan to re-adjust the alinement regardless of rail connections, especially if rail renewals are in contemplation on either road.

(3) *The Angle of Intersection of the Center Lines.*—The angle required is that made by the tangent lines at the point of intersection, and in the case of curved tracks this angle is, of course, equal to that between the radii to the common point. In taking the field notes, a sketch should be made showing in an unmistakable manner the position of the measured angle with relation to the cardinal points and surrounding objects and also indicating distinctly the curvature of the tracks, if the tracks are not on tangent. It is an excellent practice, and certainly a safe one, to measure supplementary angles with the transit and to check these measurements by means of a metallic or steel tape before leaving the site, the two values to agree within a minute or so. The degree of curve should also be verified by measuring the tangent offset, and centers should be established within the limits considered, for subsequent use of the trackmen in putting in the frog. These centers may also serve a valuable purpose in case of a dispute in relation to the fitting qualities of the new frog after its delivery at the site.

(4) *Rail Connections.*—This point is obviously affected by the action taken in relation to the alinement (2). In new crossings, the lengths of the wing rails may, as a rule, be fixed arbitrarily, but usually in renewing crossings the old length of rail, out to out in each direction, is taken as a ruling dimension to avoid cutting rails. The last named rule is observed with special strictness in reference to the rails on the foreign road. One reason for its observance is that it prevents or reduces possible delay to traffic when the new frog is put in place.

(5) *Rail Section.* Where the weights of rail differ in the two tracks, it is the usual custom to manufacture the crossing from rail to fit the heavier section. When the sections are widely different in height, it is good practice to insert a rail of the heavier section adjoining the frog in either direction on the road having the lighter rail in order to reduce the effect of the wheels passing over this joint. It is necessary to provide shims and perhaps special chairs and compromise splices where the difference of heights of the two rails is considerable. It is, of course, desirable to secure an exact section of the rail from which the frog is to be made, but it is often necessary and usually sufficient to give only the principal dimensions of the rail and its weight, with perhaps its brand.

(6) *Spacing of Bolt Holes.*—The bolt holes may, of course, be spaced to conform to different requirements on the two lines.

(7) *Inside Flange Gage of the Wheels.*—It is unnecessary to give consideration to this item unless one of the lines of road concerned in the crossing has rolling stock of an unusual type as regards the wheels, for the reason that the maker always constructs the crossing with the wheel flange clearance to conform to adopted standards. The minimum clearance between the wheel flanges on the motive power and cars ordinarily used on logging and similar tramways is considerably less than that on the usual type of rolling stock. The difference is not so great, however, as to prevent the use of a crossing frog ordered for such a tramway in which this point was overlooked; for, as a rule, sufficient clearance may be gained by trimming or chipping off a strip of the head of each guard rail on the tramway side of the crossing.

In most cases the engineer is not called upon to determine any angle, except that of the intersection of the center lines, which he does instrumentally. It sometimes happens, however, that a new set of frogs arrives at the site of the crossing, and owing to the dilapidated condition of the old crossing or other cause, a preliminary trial by superimposing the new over the old, leads the trackman to believe that an error has been made in the new frog. Naturally and properly the burden of the proof and responsibility falls upon the person who measured the angle and secured the data which accompanied the order for the crossing. In such cases of dispute it is highly essential that the engineer be able to compute promptly and positively the angles of the several rail intersections and the other essential dimensions of the set of frogs; for in his investigation of the matter the engineer is called upon to verify, not only his own measurements according to the centers which he is presumed to have established, but also the work of the frog maker. If one or both tracks chance to be on tangent, the latter operation is of an obviously simple character; but there is reason to believe that aside from those engaged directly in the manufacture of crossing frogs, comparatively few engineers are familiar with the more complex problem of a crossing of two curved tracks. The writer therefore ventures to transcribe from his private notes the following solution of the problem, which was envolved and frequently used in the exigences of railroad service some years ago. For the sake of completeness, the simple case of the crossing of two tangent tracks will be given.

I. Both Tracks on Tangent. Fig. 1.

Let F = the angle of intersection of the center lines.
F_1, F_2, F_3, F_4 = the respective gage-line intersection angles.
g, G = the respective gages of track.

Then, in Fig. 1, $F = F_1 = F_2 = F_3 = F_4$ . . . . . (1)

$$\mathrm{F_1\,F_2} = \mathrm{F_4\,F_3} = \frac{g}{\sin F} = g \operatorname{cosec} F \quad . \quad . \quad (2)$$

$$\mathrm{F_2\,F_3} = \mathrm{F_1\,F_4} = \frac{G}{\sin F} = G \operatorname{cosec} F \quad . \quad . \quad (3)$$

If $G = g$ $\qquad \mathrm{F_1\,F_2} = \mathrm{F_2\,F_3}$ . . . . (4)

II. One or Both Tracks on Curve. Figs. 2, 3 and 4.

With the view to simplify the solution of the problem and to facilitate the application of the resulting formulas in practice, the figures have been constructed upon the assumption that the center, B, of the flatter curve, lies always to the *right* of the center, A, of the sharper curve. The symmetrical duplications of the crossings shown in the figures above and below the line AB, serve to illustrate all possible cases of the problem and thus assist in the comprehension and use of the method deduced. With such relative positions for the centers of the two circles, the length, BF, of the longer radius may be conceived to vary between the two limits $R = r$, and $R = \infty$. The latter limit is illustrated in Fig. 2, in which the center, B, lies at an infinite distance to the right. Fig. 3 shows the case with the two tracks curved in the same direction, and Fig. 4 shows the curvature in contrary directions. By considering always the interior radial angle instead of the corresponding tangential intersection angle, the two being equal, and using the auxiliary quantity V, a set of comparatively simple formulas may be obtained, which covers the two cases alike. It should be observed in Fig. 4 that according to the basis here assumed, the angle of the intersection of the two curves in opposite directions is greater than 90°, while the angle is less than a right angle when the curvatures agree in direction.

For the sake of simplicity, the several parts of the flatter curve are represented in the figures and the work below by capital letters, and the corresponding quantities for the sharper curve are indicated by lower case letters. Thus, the outer gage-lines are represented by O′ OO″ and o′ oo″, the inner gage-lines by I′ II″ and i′ ii″, and the center lines by C′ CC″ and c′ cc″, respectively.

NOMENCLATURE.

Let R = radius of center line of the flatter curve.

R_1 = R_2 = radius of outer gage-line of the flatter curve.

R_3 = R_4 = " " inner " " " " "

r = radius of center line of the sharper curve.

r_2 = r_3 = radius of outer gage-line of the sharper curve.

r_1 = r_4 = " " inner " " " " "

F = angle of intersection of C′CC″ with c′cc″

= " included between R and r.

F_1 = " of intersection of O′OO″ with i′ii″

= " included between R_1 and r_1.

F_2 = " of intersection of O′OO″ with o′oo″

= " included between R_2 and r_2.

F_3 = " of intersection of I′II″ with o′oo″

= " included between R_3 and r_3.

F_4 = " of intersection of I′II″ with i′ii″

= " included between R_4 and r_4.

V = Cc = distance between left vertices (on the line joining the centers) of the circles which intersect in the point F.

V_1 = Oi = corresponding distance for the point F_1.

V_2 = Oo = " " " " " F_2.

V_3 = Io = " " " " " F_3.

V_4 = Ii = " " " " " F_4.

G = gage of the flatter curve.

g = " " " sharper "

The designations of the following angles were omitted from the figures to avoid confusion:

a = FAB = interior angle between r and the line AB.

a_1, a_2, a_3, a_4 = corresponding angles for the radii r_1, r_2, r_3, r_4.

b = FBA = interior angle between R and the line BA.

b_1, b_2, b_3, b_4 = corresponding angles for the radii R_1, R_2, R_3, R_4.

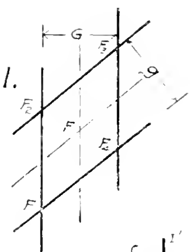


Fig. 1.

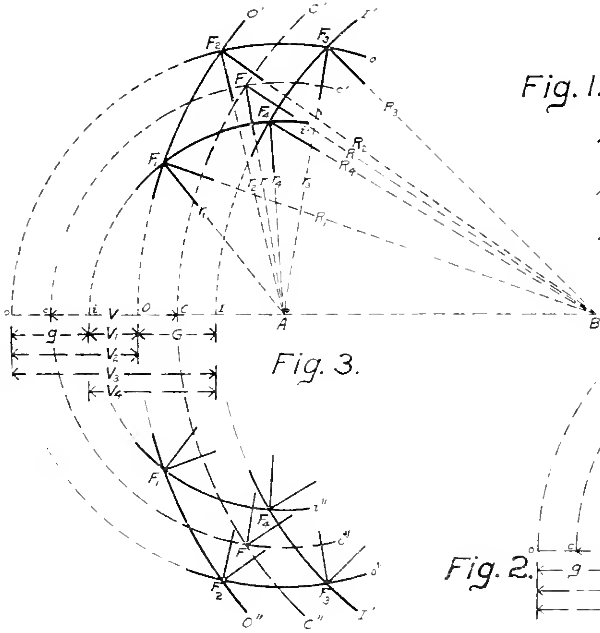


Fig. 3.

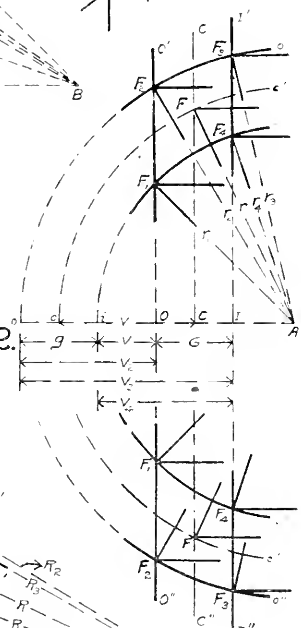


Fig. 2.

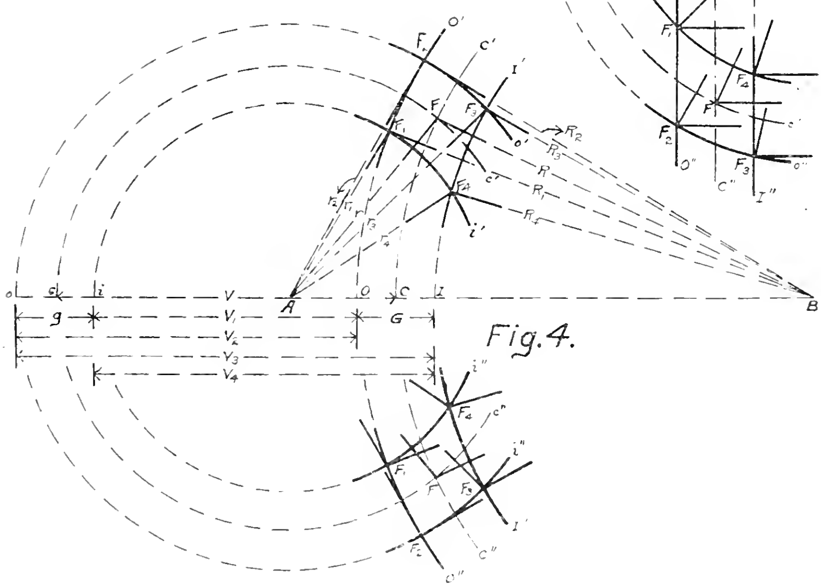


Fig. 4.

1. *One track on curve and the other on tangent.* Fig. 2.

The track C' CC'' being on tangent, gives $R = \infty$. Having determined the angle of intersection F, of the center lines, we have

$$V = r \text{ vers } F \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

and

$$\text{vers } F_1 = \frac{V_1}{r_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

$$\text{vers } F_2 = \frac{V_2}{r_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$\text{vers } F_3 = \frac{V_3}{r_3} \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$\text{vers } F_4 = \frac{V_4}{r_4} \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

The values of the respective radii r_1, etc., and distances V_1, etc., to be substituted in (6), (7), (8) and (9) are determined by inspection from Fig. 2. Table I. gives these terms for unequal gages of track, and Table II. for equal gages.

TABLE I.

VALUES FOR SUBSTITUTION IN EQUATIONS (6), (7), (8) AND (9).

Gages unequal. G = gage of tangent track; g = gage of curved track.

Angle.	Intersecting Lines.	Radius.	Auxiliary Distance.
F	C' CC'', c' cc''	$r = r$	$V = V$
F_1 (6)	O' OO'', i' ii''	$r_1 = r - \frac{1}{2} g$	$V_1 = V - \frac{1}{2}(G+g)$
F_2 (7)	O' OO'', o' oo''	$r_2 = r + \frac{1}{2} g$	$V_2 = V - \frac{1}{2}(G-g)$
F_3 (8)	I' II'', o' oo''	$r_3 = r + \frac{1}{2} g$	$V_3 = V + \frac{1}{2}(G+g)$
F_4 (9)	I' II'', i' ii''	$r_4 = r - \frac{1}{2} g$	$V_4 = V + \frac{1}{2}(G-g)$

TABLE II.

VALUES FOR SUBSTITUTION IN EQUATIONS (6), (7), (8) and (9).

Intersecting lines and radii as in Table I.

Gages of track equal. $G = g$.

Angle.	Auxiliary Distance.
F	$V = V$
F_1 (6)	$V_1 = V - g$
F_2 (7)	$V_2 = V$
F_3 (8)	$V_3 = V + g$
F_4 (9)	$V_4 = V$

Having computed the values of the several gage-line intersection angles, the distances between points of intersection are obtained by the following formulas:

$$F_1 F_2 = r_2 \sin F_2 - r_1 \sin F_1 \quad . \quad . \quad . \quad . \quad . \quad (10)$$

$$F_3 F_4 = r_3 \sin F_3 - r_1 \sin F_4 \quad . \quad . \quad . \quad . \quad . \quad (11)$$

$$F_2 F_3 = .000291^* \, r_2 \, (F_3 - F_2)' \quad . \quad . \quad . \quad . \quad (12)$$

$$F_1 F_4 = .000291 \, r_1 \, (F_4 - F_1)' \quad . \quad . \quad . \quad . \quad . \quad (13)$$

Also, the bending ordinates for the curved rails may be determined by

$$\text{mid-ordinate of } F_2 F_3 = r_2 \text{ vers } \tfrac{1}{2} (F_3 - F_2) \quad . \quad . \quad . \quad . \quad (14)$$

$$\text{" \quad " } F_1 F_4 = r_1 \text{ vers } \tfrac{1}{2} (F_4 - F_1) \quad . \quad . \quad . \quad . \quad (15)$$

2. *Both tracks on curve.* Figs. 3 and 4.

In the triangle FAB, Figs. 3 and 4, the angle F and the radii R and r are determined instrumentally. Then

By trigonometry, $\tan \tfrac{1}{2}(a-b) = \dfrac{R-r}{R+r} \tan \tfrac{1}{2}(a+b)$

in which $a + b = 180 - F$

$\tfrac{1}{2}(a+b) = 90 - \tfrac{1}{2} F$

Then
$$\tan \tfrac{1}{2}(a-b) = \frac{R-r}{R+r} \cot \tfrac{1}{2} F \quad . \quad . \quad . \quad . \quad (16)$$

and
$$\left.\begin{aligned} a &= \tfrac{1}{2}(a+b) + \tfrac{1}{2}(a-b) \\ b &= \tfrac{1}{2}(a+b) - \tfrac{1}{2}(a-b) \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

Having determined the angles of the triangle, the distance between the centers is found by

$$AB = r \frac{\sin F}{\sin b} = r \sin F \operatorname{cosec} b \quad . \quad . \quad . \quad (18)$$

By inspection of Figs. 3 and 4, it is seen that

$$F = AB + r - R \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

*Arc 1' = .00029089. Although the angle of intersection of center lines will ordinarily be measured only to the nearest minute, the computed values of angles to be used in fixing the rail intercepts should be determined at least to the nearest tenth minute, particularly when the radii are large.

TABLE III.

VALUES FOR SUBSTITUTION IN EQUATIONS (21), (22), (23) and (24).

Gages of track unequal. G = gage of flatter curve; g = gage of sharper curve.

Angle.	Intersecting Lines.	Larger Radius.	Smaller Radius.	Auxiliary Distance.	Term. $S = R - r - \frac{1}{2}V$
F	$C'CC''$, $c'cc''$	$R = R$	$r = r$	$V = V$	$S = R - r - \frac{1}{2}V$
F_1 (21)	$O'OO''$, $i'ii''$	$R_1 = R + \frac{1}{2}G$	$r_1 = r - \frac{1}{2}g$	$V_1 = V - \frac{1}{2}(G - g)$	$S_1 = S + \frac{1}{4}(G - g)$
F_2 (22)	$O'OO''$, $o'oo''$	$R_2 = R + \frac{1}{2}G$	$r_2 = r + \frac{1}{2}g$	$V_2 = V - \frac{1}{2}(G - g)$	$S_2 = S + \frac{1}{4}(G - g)$
F_3 (23)	$I'II''$, $o'oo''$	$R_3 = R - \frac{1}{2}G$	$r_3 = r + \frac{1}{2}g$	$V_3 = V + \frac{1}{2}(G - g)$	$S_3 = S + \frac{1}{4}(G - g)$
F_4 (24)	$I'II''$, $i'ii''$	$R_4 = R - \frac{1}{2}G$	$r_4 = r - \frac{1}{2}g$	$V_4 = V + \frac{1}{2}(G - g)$	$S_4 = S - \frac{1}{4}(G - g)$

By trigonometry, $\text{vers } F = 2\,\frac{(s - R)(s - r)}{Rr}$

in which $s = \frac{1}{2}(R + r + AB) = R + \frac{1}{2}V$

$s - R = \frac{1}{2}V$

$s - r = R - r + \frac{1}{2}V$

so that
$$\text{vers } F = \frac{V(R - r + \frac{1}{2}V)}{Rr} \quad . \quad . \quad . \quad . \quad . \quad (20)$$

The relation expressed in (20) is true of each of the intersections if the terms involved be assigned proper values. Hence the following may be written for the several gage-line intersections:

$$^*\text{vers } F_1 = \frac{V_1(R_1 - r_1 + \frac{1}{2}V_1)}{R_1 r_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad (21)$$

$$\text{vers } F_2 = \frac{V_2(R_2 - r_2 + \frac{1}{2}V_2)}{R_2 r_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

$$\text{vers } F_3 = \frac{V_3(R_3 - r_3 + \frac{1}{2}V_3)}{R_3 r_3} \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

$$\text{vers } F_4 = \frac{V_4(R_4 - r_4 + \frac{1}{2}V_4)}{R_4 r_4} \quad . \quad . \quad . \quad . \quad . \quad . \quad (24)$$

The respective values of the radii and the auxiliary distances to be substituted in (21), (22), (23) and (24) are given in Tables III. and IV.

TABLE IV.

VALUES FOR SUBSTITUTION IN EQUATIONS (21), (22), (23) and (24).
Intersecting lines and radii as in Table III.
Gages of track equal. $G = g$.

Angle.	Auxiliary Distance.	Term $S = R - r + \frac{1}{2}V$.
F	$V = V$	$S = R - r + \frac{1}{2}V$
F_1 (21)	$V_1 = V - g$	$S_1 = S + \frac{1}{2}g$
F_2 (22)	$V_2 = V$	$S_2 = S$
F_3 (23)	$V_3 = V + g$	$S_3 = S - \frac{1}{2}g$
F_4 (24)	$V_4 = V$	$S_4 = S$

In order to determine the distances between the points of intersection of gage-lines, and the ordinates for bending the rails, it is necessary to compute the values of the angles a_1, b_1, a_2, b_2, etc.

*Note that when the curvatures are in opposite directions, Fig. 4, the value of F exceeds 90°;—the values of the several angles in that case may be obtained by remembering that vers 90° = 1, and vers 180° = 2.

In each of the triangles F_1 AB, F_2 AB, etc., one angle and the sides are known, so that

$$\sin a_1 = R_1 \frac{\sin F_1}{AB} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25)$$

$$\sin a_2 = R_2 \frac{\sin F_2}{AB} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

$$\sin a_3 = R_3 \frac{\sin F_3}{AB} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

$$\sin a_4 = R_4 \frac{\sin F_4}{AB} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (28)$$

In like manner, $\sin b_1 = r_1 \frac{\sin F_1}{AB}$ . . . . (29)

$$\sin b_2 = r_2 \frac{\sin F_2}{AB} \quad . \quad . \quad . \quad . \quad . \quad . \quad (30)$$

$$\sin b_3 = r_3 \frac{\sin F_3}{AB} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (31)$$

$$\sin b_4 = r_4 \frac{\sin F_4}{AB} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (32)$$

And, as a check,

$$a_1 + b_1 + F_1 = 180 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (33)$$

$$a_2 + b_2 + F_2 = 180 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (34)$$

$$a_3 + b_3 + F_3 = 180 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (35)$$

$$a_4 + b_4 + F_4 = 180 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (36)$$

Then by inspection of Figs. 3 and 4,

$$F_1 F_2 = .000291 \; R_1 \, (b_2 - b_1)' \quad . \quad . \quad . \quad (37)$$

$$F_2 F_3 = .000291 \; r_2 \, (a_2 - a_3)' \quad . \quad . \quad . \quad (38)$$

$$F_3 F_4 = .000291 \; R_3 \, (b_3 - b_4)' \quad . \quad . \quad . \quad (39)$$

$$F_4 F_1 = .000291 \; r_4 \, (a_1 - a_4)' \quad . \quad . \quad . \quad (40)$$

And the mid-ordinates are as follows:

$$M \text{ for } F_1 F_2 = R_1 \text{ vers } \tfrac{1}{2} \, (b_2 - b_1) \quad . \quad (41)$$

$$\text{" " } F_2 F_3 = r_2 \text{ vers } \tfrac{1}{2} \, (a_2 - a_3) \quad . \quad (42)$$

$$\text{" " } F_3 F_4 = R_3 \text{ vers } \tfrac{1}{2} \, (b_3 - b_4) \quad . \quad (43)$$

$$\text{" " } F_4 F_1 = r_4 \text{ vers } \tfrac{1}{2} \, (a_1 - a_4) \quad . \quad (44)$$

3. *Discussion of Formulas.*

It may be shown as follows that Fig. 2 is merely a special case of the general problem: Eq. (20) may be written thus

$$\text{vers } F = \frac{V}{r} - \frac{V(r - \frac{1}{2} V)}{Rr}$$

Substituting in above the value $R = \infty$

$$\text{vers } F = \frac{V}{r} \text{ which is eq. (5) transposed.}$$

Putting $R = r$ in (19), it is found that $V = \text{AB}$, and the same value substituted in (20) gives

$$\text{vers } F = \frac{V^2}{2\,r^2} \qquad \text{But vers } F = 2 \sin^2 \tfrac{1}{2} F, \text{ so that}$$

$$V = \text{AB} = 2\,r \sin \tfrac{1}{2} F \quad . \quad . \quad . \quad . \quad . \quad (45)$$

In this case of equal degrees of curve, the two radii to the point of intersection of the center lines are the equal sides of an isoceles triangle, and the line bisecting the radial angle F is a line of symmetry to the crossing, passing through the points F_2, F and F_1, and bisecting AB at right angles.

The condition for a right angled crossing is found by placing vers $F = 1$ in (20), from which

$$V = \sqrt{R^2 + r^2} - (R - r) \quad . \quad . \quad . \quad . \quad . \quad . \quad (46)$$

If $R = r$, (46) becomes

$$V = r\sqrt{2} = 2\,r \sin 45 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (47)$$

STRENGTH OF ICE.

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Civil Engineering Course.

The comparative scarcity of published records giving experimental data concerning the strength of ice suggested the desirability of further investigation of the subject.

Experiments by Others.

Only two records of compressive tests and one of tensile tests could be found after an extended research in the files of technical periodicals and society proceedings. The first and more elaborate of these was executed by Col. Wm. Ludlow in 1880 and 1881 in connection with the construction of an ice harbor in the Delaware river, at Liston's Point, and the second tests were made by Frühling, a German experimenter, about 1885.

Col. Ludlow's experiments,* consisting of only eighteen compressive tests, gave a crushing strength varying from 100 to 1 000 pounds per square inch, with an average of about 575. The ice used by him was of poor quality, a considerable portion being frozen snow or frozen snow and ice combined. The temperature of the ice during the time of testing ranged from 25° to 31° F., while the temperature of the room varied from 29°.6 to 68° F. The distribution of pressure was equalized by placing small blocks of white pine between the faces of the cubes and the upper and lower surfaces of the press.

Col. Ludlow concludes as follows: "As preliminary inferences to be drawn from these experiments, it may be said that the maximum pressure requisite to crush ice of the clearest and most compact structure is 1 000 pounds per square inch; that ordinary clear ice, such as we get from the upper Delaware River, would, under certain conditions, resist a pressure of 700 pounds per square inch, and that ice in the condition that we should be likely to find it in the Delaware River at Liston's Point would crush with 400 or 450

*Proc. Eng. Club of Phila. Vol. IV., pp. 93-99.

pounds per square inch or less, from its gradual disintegration by exposure to the sun, air, and salt water."

Frühling's experiments* were made upon clear block ice tested at 23° F. He observes that "as the pressure was increased the cracks became more numerous until they went all through the test piece. As the pressure was further increased the height of the blocks began to diminish and their cross-section to increase until ultimately they were flattened out, never, however, giving way suddenly. The only stage in the flattening-out process at which the pressure was accurately noted was that at which the height of the block began to diminish." The pressure at which the height began to diminish perceptibly varied from 216 to 380 pounds per square inch, while the pressure at which cracks began to form varied from 60 to 200 pounds per square inch.

In the light of experiments by eminent European authorities close consideration of the results of Col. Ludlow's tests suggests forcibly that a higher crushing strength would have been obtained by him had the temperature of the air and ice agreed more closely with actual conditions in exposed localities.

As stated above, the temperature of the ice cubes in Ludlow's tests ranged from 25° to 31° F., while that of the air in the room where the tests were made varied from about 30° to 68° F. Pfaff, a German physicist, has found† "that even the smallest pressure is sufficient to dislocate ice particles if it act continuously, and if the temperature of the ice and its surroundings be near the melting point," and Andrews, a British experimenter, has shown‡ that "if the plasticity of ice at — 35° F. be taken as unity, that at 0° F. will be 2, and at 28° F. will be 8."

Experiments by The Authors.

It was with a hope of throwing some light upon these points, and of obtaining a value for the ultimate crushing and tensile strength of ice, that the following tests were undertaken:

Crushing Tests.

The crushing tests of ice executed by the writers were made with a 100 000-pound Riehle testing machine. The test pieces were

*Proc. Inst. Civil Engineers. Vol. LXXXII., pp. 391-99. Also Zeitschrift des Vereines Deutscher Ingenieure. 1885, p. 357. (May 9.)

† *Nature*, Vol. XII., p. 317.

‡ *Nature*, Vol. XLII., p. 213.

sawn from blocks of ice and their surfaces were planed down by means of a straight-edge made from a thin bar of iron. The cubes were crushed between sheets of heavy cardboard which served effectually to cushion the compressed surfaces. To prevent concentration of pressure due to non-parallelism of opposite faces of the cube or of the testing machine, the adjustable compression plate shown in Fig. 1 was used.

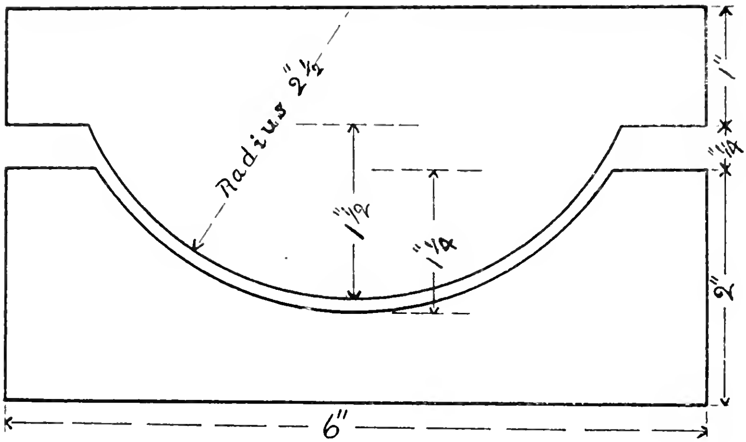


Fig. 1

This device consists of two thick circular plates, six inches in diameter, the top face of the upper and bottom face of the lower being true planes. On the lower side of the upper piece is a solid spherical segment which fits into a spherical socket in the top of the lower casting. The surfaces in contact are smoothly and accurately shaped. By thorough lubrication of the segment an exceedingly delicate equalization is secured, even under the heaviest pressures.

At the time the experiments were undertaken natural ice had not formed of sufficient thickness to afford test cubes. A cake of artificial ice 14x14x30 inches was procured. From it were prepared fourteen 4-inch and thirteen 6-inch cubes, besides a number of small slabs. This ice was manufactured in the usual manner, that is, by immersing cans filled with water in cold brine. The ice first forms on the sides and bottom of the can and gradually freezes to the center. Most of the impurities of the ice are thus concentrated at the center of the cake, together with the air contained in the water.

The natural ice was obtained from a pond near by and was quite free from air bubbles and impurities.

Ice, when subjected to pressure, is resolved into columns whose direction is normal to the surface which was in contact with the water while freezing. In natural ice these columns are parallel, hence the pressure is always applied perpendicular or parallel to them. By examining Table II. it will be seen that those pieces tested with the pressure parallel to the columns developed about 77 per cent. greater strength than those tested with the pressure perpendicular to the column. Test piece number 45 gave a very high result —2 818 pounds per square inch. This piece was remarkably clear and free from air bubles. Rejecting it, the percentage is reduced to 63.

In artificial ice the columns extend from the side toward the center and from the bottom up. In cubes cut from the corners of a cake of artificial ice the columns were found to cross or intersect at right angles, and in such cubes the fracture is always in a plane cutting the diagonally opposite edges, the one half sliding on the other. It is possible, therefore, by selecting test pieces from different parts of the original cake to obtain widely varying results for the crushing strength. The great difference between the average crushing strength of natural and artificial ice is thus easily explained.

It was found that in homogeneous ice the phenomenon of failure by crushing is similar to that of cubes of sandstone tested in a like manner, that is, a cone is forced out from each of the four vertical sides.

A few small pieces of ice were crushed at 32° F. mainly for the purpose of observing the phenomena due to crushing at that temperature. In every such case the ice gave way gradually and changed form slowly. Ice at this temperature possessed quite a degree of plasticity and exhibited scarcely any of the phenomena shown by ice crushed at lower temperatures.

It would be of interest to make a series of tests through a great range of temperature and plat the results so as to show the relation between strength and temperature.

TABLE I.

DATA ON THE CRUSHING STRENGTH OF ICE CUBES.

Experiments Made at the Testing Laboratory of the University of Illinois.

No. of Piece.	Date.	Kind of Ice.	Temperature. External Air.	Temperature. Laboratory.	Temperature. Ice at Time of Testing.	Dimensions of Specimens in Inches. Sides.	Dimensions of Specimens in Inches. Depth.	Direction of Applied Pressure with Reference to Columnar Disintegration.	Total Pressure at which cracks first appeared, pounds.	Ultimate Crushing Strength in Pounds. Total.	Ultimate Crushing Strength in Pounds. Per Sq. Inch.	REMARKS.
			F.	F.	F.							
1	Dec. 27, '94.	Artificial..	17°.6	25°.7	25°.7	4 x 4¼	4¼	Parallel.......	4000	5400	318	Gave away gradually; piece filled with iron rust and air bubles.
2	..	..	..	..	..	..	4	Perpendicular	3500	12300	724	Broke suddenly with loud report; split in diagonal plane.
3	..	..	..	..	..	4⅛ x 4⅛	4	..	4500	12000	705	Gave way gradually; broke into small pieces when struck light blow with hammer.
4	..	..	..	..	..	4 x 4¼	4	..	3300	7800	459	Broke suddenly with report.
5	..	..	..	..	..	4¼ x 4¼	4	..	3000	10500	564	Specimen from corner of block; broke suddenly with report.
6	..	..	..	..	..	4 x 4¼	4¼	Parallel.......	4800	6700	394	One side gave way before the other.
7	..	..	..	23°	23°	4⅛ x 4½	4	.. ..	2000	13700	736	At 2000 pounds a crack appeared diagonally across the piece and extending through it.
8	..	..	..	..	..	4¼ x 4	4½	.. ..	2000	12100	712	Broke suddenly with report.
9	..	..	..	..	..	3¾ x 5	4½	.. ..	4800	8000	428	Specimen from corner of block; axes of columns on one side were vertical and on the other side horizontal; diagonal line marking end of columns plainly visible.
30	Dec. 29, '94.	..	14°.9	30°.2	14°	3¾ x 4¼	3⅞	Perpendicular	5200	17200	1080	Gave way gradually.
31	..	..	..	..	..	4 x 4	4	..	7000	15400	963	One corner chipped off; crushed suddenly.
32	..	..	..	..	..	3⅞ x 4	4	..	4600	16000	1032	Center and sides crushed out; broke suddenly with report.
33	..	..	..	..	..	4 x 4	3⅞	Parallel.......	4200	5400	327	Broke suddenly on one corner with report.
34	..	..	..	..	..	3⅞ x 4⅛	4	.. ..	5200	15400	969	Gave way gradually.
35	..	..	..	..	..	6 x 6	5⅞	Perpendicular	10000	34600	962	Gave way gradually.
36	..	..	..	..	..	5¾ x 6	6	Parallel.......	7200	25700	775	Broke suddenly with loud report.
37	..	..	..	..	..	6 x 6	5⅞	Perpendicular	11200	30000	834	Broke suddenly with loud report.
38	..	..	..	..	..	6⅛ x 6	..	..	10200	25500	695	One side chipped off at 15700; broke with report
39	..	..	..	..	..	6 x 6	..	Parallel.......	8400	30400	841	Broke suddenly with report.
40	Dec. 27, '94.	..	17°.6	23°	23°	6⅜ x 6½	6	Perpendicular	12000	29800	719	Broke suddenly with report.
41	..	..	..	..	..	6¾ x 6½	5¾	..	11600	27400	623	Broke suddenly with report.
42	..	..	..	..	..	6½ x 6½	..	..	10400	28900	684	Gave way gradually.
43	..	..	..	..	..	6½ x 6¾	6	..	12000	31300	712	Broke suddenly with report.

14	Dec. 27, '94	Artificial..	17°.6	23°	23°	6¼x6⅛	6⅛	Parallel.......	12 200	17 500	156	Broke suddenly; piece failed at point where last ice was formed.
15	"	"	"	"	"	6½x6	6	"	8 400	14 600	372	One half the block failed, the other half did not crush. Failed as No. 14.
16	"	"	"	"	"	6 x6¼	6½	"	10 200	28 500	759	Broke suddenly along diagonal plane from corner of original block to opposite.
17	"	"	"	"	"	6 x6½	6½	"	6 200	24 000	645	Failed in same manner as No. 16. Line of failure plainly visible while under pressure.
40	Nov. 31, '94	Natural...	21°.2	"	12°.2	4 x4	4	Perpendicular	13 600	19 800	1 239	Broke suddenly with report.
41	"	"	"	"	"	"	3⅞	Parallel.......	13 000	23 700	1 608	Broke suddenly with report.
42	"	"	"	"	"	4 x4⅛	4⅛	Perpendicular	....	17 000	1 031	Broke suddenly without warning.
43	"	"	"	"	"	4⅛x4⅛	3⅞	Parallel.......	12 000	29 500	1 735	Broke suddenly. Cracking continued from 13 000 pounds on.
44	"	"	"	"	"	4 x3⅞	4	Perpendicular	11 200	28 600	1 841	Similar to No. 43.
45	"	"	"	"	"	4¼x4	3⅞	Parallel.	31 000	47 800	2 818	Broke suddenly with loud report. The boards under bearing surface crushed suddenly and probably caused premature failure.
46	"	"	"	"	"	4 x4⅛	3⅞	Perpendicular	....	12 000	728	Corner chipped off at 4 000 pounds. Evidently the bearing surface was imperfect.
47	"	"	"	"	"	3⅞x4⅛	4	Parallel	....	31 600	1 975	At 28 000 pounds one corner chipped off. Broke suddenly with loud report.
48	"	"	"	"	"	4 x4⅛	4	Perpendicular	...	6 000	364	One corner chipped in preparing the piece. Failed suddenly.
49	Dec. 31, '94	"	"	"	"	4¼x4	4	Parallel.......	1 300	26 300	1 649	Broke suddenly with report.
50	"	"	"	"	"	3⅞x4	4	Perpendicular	10 000	13 200	852	Broke suddenly with report.
51	"	"	23°	"	"	4 x4	3⅞	Parallel.	11 800	25 400	1 588	Broke suddenly with report.
52	"	"	"	"	"	4 x5⅞	4	Perpendicular	....	11 700	755	Broke suddenly without warning.
53	"	"	"	"	"	4 x4	3⅞	Parallel.......	22 000	30 500	1 905	Broke suddenly with report.
54	"	"	"	"	"	"	3¾	Perpendicular	7 000	16 700	1 044	Corner chipped off at 3 500 pounds.
55	"	"	"	"	"	"	3⅞	Parallel.......	11 000	23 700	1 481	Broke suddenly with report.

*The pressure was applied at an average rate of 10 000 pounds per minute.

TABLE II.

Summary of Table I.

	Pounds Per Square Inch.
Mean strength of five 4-inch cubes of artificial ice, tested at 25.7° F.	569
Mean strength of three 4-inch cubes of artificial ice, tested at 23° F.	625
Mean strength of eight 6-inch cubes of artificial ice, tested at 23° F.	617
Mean strength of all cubes of artificial ice, tested at 23° F.	620
Mean strength of four 4-inch cubes of artificial ice, tested at 14° F.	1011
Mean strength of five 6-inch cubes of artificial ice, tested at 14° F.	822
Mean strength of all cubes artificial ice tested at 14° F.	906
Mean strength of all cubes artificial ice tested	560
Mean strength of seven 4-inch cubes of natural ice with direction of pressure perpendicular to columns, tested at 12°.2 F.	1070
Mean strength of eight 4-inch cubes natural ice with direction of pressure parallel to columns, tested at 12°.2 F.	1845
Mean strength of all cubes of natural ice tested	1451

Experiments were made upon the crushing strength of slabs of ice. The results are shown in Tables III. and IV., pages 45 and 46. The phenomena and results do not materially differ from those already noted for cubes.

TABLE III.

Data on the Crushing Strength of Ice Slabs.

Experiments Made at the Testing Laboratory of the University of Illinois.

No. of Piece.	Date.	Kind of Ice.	Temperature. External Air.	Temperature. Laboratory.	Temperature. Ice at Time of Testing.	Dimensions of Specimens in Inches. Sides.	Dimensions of Specimens in Inches. Depth.	Direction of Applied Pressure with Reference to Columnar Disintegration.	Total Pressure at which Cracks first appeared. Pounds.	Ultimate Crushing Strength in Pounds. Total.	Ultimate Crushing Strength in Pounds. Per Sq. Inch.	Remarks.
			F.	F.	F.							
18	Dec. 27, '94.	Artificial.	17°.6	23°	23°	$3\frac{7}{8}$x$4\frac{1}{4}$	$2\frac{1}{4}$	Perpendicular	5 000	16 700	1 062	Resolved into columns perpendicular to direction of force.
19	..	..	..	..	..	$4\frac{1}{4}$x4	$2\frac{3}{8}$	..	2 400	7 200	436	Broke suddenly with report. Columns parallel to force.
20	..	..	..	..	..	4 x4	$2\frac{3}{8}$	..	1 400	7 500	469	Broke suddenly with report.
21	..	..	..	..	..	4 x$4\frac{3}{8}$	$1\frac{3}{4}$	..	3 300	13 200	755	Broke suddenly with report.
22	..	..	..	..	..	$3\frac{7}{8}$x$3\frac{3}{4}$	$1\frac{5}{8}$	..	2 000	20 400	915	Failed gradually.
23	..	..	..	..	..	$3\frac{1}{4}$x$5\frac{1}{2}$	$1\frac{3}{8}$	..	2 000	13 400	749	Failed gradually.
24	..	..	..	..	..	$2\frac{3}{8}$x$5\frac{1}{2}$	$2\frac{1}{8}$	..	3 000	4 800	393	Broke suddenly. Center of block full of air bubbles.
25	Dec. 28, '94.	..	12°.2	..	..	2 x3	$1\frac{7}{8}$	..	2 200	5 600	933	Broke suddenly with report.
26	..	..	..	..	..	4 x$4\frac{3}{8}$	$1\frac{3}{4}$	..	2 800	13 000	743	Broke suddenly with report.
27	..	..	..	..	..	4 x$4\frac{1}{8}$	$1\frac{5}{8}$	Parallel.......	2 200	13 300	806	Broke suddenly with report.
28	..	..	..	..	..	$4\frac{1}{4}$x$5\frac{1}{8}$	$1\frac{5}{8}$	.. ..	2 600	21 800	813	This piece came from center of block and was full of rust and air bubbles.
29	..	..	..	..	..	$4\frac{1}{4}$x$5\frac{3}{4}$	2	.. ..	4 200	13 500	551	Broke suddenly. Full of rust and air bubbles.
56	Dec. 31, '94.	Natural.	23°	..	12°.2	6 x4	$1\frac{3}{4}$	Perpendicular	2 200	35 000	1 459	Broke suddenly.
57	..	..	..		..	$5\frac{3}{4}$x4	$1\frac{7}{8}$	..	8 000	17 000	739	Broke suddenly. Flaw in piece.
58	..	..	..	..	..	1 x$5\frac{7}{8}$	$1\frac{7}{8}$	..	10 000	25 800	1 099	Failed gradually.
59	..	..	..	..	..	4 x6	$1\frac{7}{8}$	..	....	11 000	458	Broke suddenly. Specimen imperfect.
60	..	..	..		..	1 x$5\frac{7}{8}$	$1\frac{7}{8}$	..	7 000	1 700	724	Failed on one side.
61	..	..	..	..	..	4 x6	2	..	4 800	10 300	429	Broke suddenly with report.
62	..	..	..	..	..	4 x6	$1\frac{3}{4}$	..	1 000	17 800	742	Broke suddenly with report.

TABLE IV.

SUMMARY OF TABLE III.

	Pounds Per Square Inch.
Average of all natural ice slabs tested	777
Average of the four most nearly perfect slabs of natural ice	932
Average of all slabs artificial ice tested	718
Average of nine most nearly perfect slabs artificial ice tested	763

Tensile Strength.

The tests for tensile strength were made with a Riehle cement testing machine. The briquettes were made by placing the brass cement briquette molds in a shallow pan of water and allowing it to freeze. The briquettes were easily removed from the molds, by allowing a stream of water to flow over them for a short time, their cross-section not being sensibly reduced by this operation. Numbers 21, 22, 23 and 27 were shaved to a less cross-section than one square inch. By reducing the cross-section and thereby the ultimate strength, a greater and more nearly correct value of the unit tensile strength at that temperature was obtained. A large per cent. of the briquettes broke in the grips, due to cross-stresses induced by partial crushing. It would seem from the experiments that a slight difference in temperature makes considerable difference in the tensile strength of ice.

From these experiments the following conclusions may be drawn:

1. Ice, when subjected to pressure, is resolved into columns normal to the natural surface.

2. The greatest crushing strength is obtained when the direction of applied pressure is parallel to the columns and least when perpendicular to them.

3. Ice subjected to pressure at 32° F. readily changes form.

4. Variations in temperature produce a perceptible influence on both compressive and tensile strength of ice.

TABLE V.

DATA ON TENSILE STRENGTH OF NATURAL ICE.

Experiments Made at the Testing Laboratory of the University of Illinois.

No. of Piece.	Date.	Temperature. External Air.	Temperature. Ice at Time of Testing.	Section in Inches.	Ultimate Pressure in Pounds.	Tensile Strength in Pounds per Square Inch.	REMARKS.
		F.	F.				
1	Dec. 28, '94....	13°.4	19°.4	1x1	102	102	Broke in center.
2	"	"	"	"	132	132	Broke in grip. Imperfect.
3	" ..	"	"	"	179	179	Broke in center.
4	"	"	"	"	163	163	Broke in center.
5	"	"	"	"	239	239	Broke in center.
6	"	"	"	"	228	228	Broke in upper grip.
7	"	"	"	"	174	174	Broke in lower grip.
8	"	"	"	"	191	191	Broke in lower grip.
9	"	"	"	"	200	200	Broke in lower grip.
10	" ...	"	"	"	218	218	Broke in lower grip.
11	"	"	"	"	156	156	Broke in lower grip.
12	"	"	"	"	215	215	Broke in center.
13	" ...	"	"	"	165	165	Broke in center.
14	"	"	"	"	200	200	Broke in lower grip.
15	"	"	"	"	208	208	Broke in center.
16	"	"	"	"	126	126	Broke in center.
17	"	"	"	"	178	178	Broke in center.
18	"	"	"	"	221	221	Broke in lower grip.
19	Dec. 31, '94....	21°.2	23°	"	120	120	Broke in center.
20	" ...	"	"	"	110	110	Broke in lower grip.
21	"	"	"	1x $\frac{7}{8}$	167	175	Broke in lower grip
22	"	"	"	$\frac{7}{8}$ x $\frac{7}{8}$	196	256	Broke in lower grip.
23	"	"	"	1x $\frac{7}{8}$	138	158	Broke in lower grip.
24	"	"	"	1x1	120	120	Broke in upper grip
25	"	"	"	"	106	106	Broke in center.
26	" ...	"	"	"	153	153	Broke in center.
27	"	"	"	1x $\frac{7}{8}$	122	139	Broke in center.
28	"	"	"	1x1	124	124	Broke in lower grip.
29	"	"	"	"	160	160	Broke in upper grip.
30	"	"	"	"	167	167	Broke in center.
31	"	"	"	"	159	159	Broke in lower grip.
32	"	"	"	"	118	118	Broke in center.
33	"	"	"	"	118	118	Broke in lower grip.
34	"	"	"	"	120	120	Broke in lower grip.

TABLE VI.

SUMMARY OF TABLE V.

	Pounds Per Square Inch.
Average of briquettes tested at a temperature of 19°.4 F. which broke in center	184
Average of briquettes tested at a temperature of 23° F. which broke in the center	139
Average of briquettes tested at 19°.4 F. that broke in the grips	191

Average of briquettes tested at 23° F. that broke in the grips	150
Average of all briquettes tested that broke in the center .	160
Average of all briquettes tested that broke in the grips .	169
Average of all briquettes tested at 19°.4 F.	183
Average of all briquettes tested at 23° F.	146
Average of four pieces tested with a less cross-section than one square inch at 23° F.	182
Average of all briquettes tested	165

The results of five tests made by Frühling at a temperature of 23° F. gave an average tensile strength of 189 pounds per square inch. The cross-section of his specimens was 0.77 square inches.

THE BREAD-AND-BUTTER SIDE OF ARCHITECTURE.

BY C. H. BLACKALL '77.

Every year earnest, enthusiastic young men are graduated from the Department of Architecture who are looking forward to winning a position in their chosen profession. They are graduated in several senses of the word, alligned, divided into degrees, and with the freezing and the boiling point clearly defined, having aims and purposes which are real to themselves if to no one else, and are ready for the hard experiences and the keen, relentless polish which contact with the unsympathetic business world will give them and which is so necessary for their final career. And not only from this University, but from other architectural schools throughout the country, as well as from numerous architects' offices, young men by the hundred are annually turned loose on the current of business affairs. Some are full of enthusiasm, others are earnestly practical, some are poetic by nature, and some are ready to take their places as wheel horses in the hard tug of professional life ; but all have one common purpose and one very decided aim, and that is to make money—to make it artistically, with proper regard for the esthetic proprieties if they can, but to make money somehow. Disguise it as we may, impute as much earnest enthusiasm as we please to our motives, the fact remains that the man who expects to become an architect must have an opportunity to earn money, and the bread-and-butter side of architecture is one to which young men look forward with a great deal of apprehension. Their schooling may make them feel confident of their powers in solving esthetic and practical problems, they may know that they have in them the germs of talent and may feel assured beyond any doubt that they are fitted to win a place in the world, but very few can calmly contemplate the possibility of being unable to even get the oppportunity to show what they are worth. The painter or the sculptor who desires to make a mark for himself can quietly go to work in his studio, can elaborate a fine art production without the help of any one save himself, suddenly exposing it to the critical view of fellow artists, and springing Minerva-like full fledged upon the artistic world. An architect, however, no matter what his degree of talent or capability may be, must first of all have opportunity to show his worth. He can not create the opportunity, for drawings do not constitute architecture, and until he has found some one confiding enough to take chances and entrust an important building to a young man of untried capabilities, he is unable to demonstrate that he can win even his bread, much less his butter. I know of no profession which is more ennobling, if pursued rightly, which will lead to a higher degree of culture, or is more truly self-contained, holding within itself the opportunities for study and recreation, for practical industry and enthusiastic enjoyment, than architecture. And, also, there is scarcely a profession in which the rich prizes are harder to acquire or demand such a combination of talent. Every man looks forward to winning these rich prizes. Few really get them. It is worth a young man's while sometimes to sit down quietly and look at architecture from a purely mercenary view, trying to see how he can get the great opportunities and in what way his work will command the highest pecuniary rewards. The science of getting work is something which is not taught in the schools. There is as yet no Department of Applied Money Making, and while each young man generally has to work out his own lines and can not depend very largely upon the experience of others, there certainly are some general possibilities which have been made manifest as the result of experience as aids to a young man in accomplishing the very important factor of bread winning.

The young architect, when released from school, first enters the large army of draughtsmen and undergoes the ordeal of continuous office drudgery. This is a very thorough sifting process by which the servival of the fittest is aptly illustrated, for of the thousands of young men who are toiling in architects' offices, a small percentage ever reach the dignity of architect. But in the course of time, the young man whose staying powers are sufficiently strong finds some confiding friend or relative who entrusts to him the erection of some building, usually a small dwelling, rarely an important public building. Then he hires a sign painter and blossoms out as an architect. He finds the first year hard, the second year exceedingly hard, and it is only after at least two years and sometimes more, that he feels sufficiently established in his profession to be sure of remaining in it through seasons of mild depression. Then comes the real experience in getting work. To the superficial observer, the most potent factor in helping an architect to his opportunities is rich and numerous relatives. When viewed in the light of the success of some architects, a second important element seems to be bluff, pure and simple; the ability of imposing one's self on would-be clients, the faculty of making people think you are a good fellow and understand your business. A third help, which is often advised for young men, is the cultivation of social relations, bringing one's self into prominence before one's fellow beings in social intercourse. And a fourth way is by persistent advertising, either in the way of published drawings or notices in the papers through kindness of friends. Now, architecture would indeed be a mercenary profession and worthy of little real honor if individual advancement depended upon such unworthy factors as these. There is no questioning the advantage of all of these as adjuncts. Each has its proper place, each contributes to the architect's personal advancement as well as to his pecuniary advantage, and has its proper function in self development and professional growth. But architecture is more than these, and the man who is really to receive the rich prizes must have something more to recommend him than relatives, must possess more intrinsic qualities than bluff, and must have a stronger hold upon the community than can be acquired by social intercourse. He who means to rise to the top of the profession must, first and last, continually, at all times, follow the advice that was given the young man who asked a celebrated speaker as to what were the secrets of success, and was told that the first was preparation, the second was preparation, and the third was preparation. The man who depends upon extraneous or adventitious helps will sooner or later find that he is left in the race, and that the rich chances are not going to him but to the man who is thoroughly prepared, the man who is able to handle a large problem because he knows how, not because he has friends. There are plenty of opportunities everywhere, and when a young man is really ready for them he will not fail for lack of the chance. Therefore in architecture as in every other department of industry the first bread-winning requisite is thorough preparation.

Now let us consider what preparation means, and understand we are speaking now in a purely mercenary spirit and are viewing architecture simply as a means of winning bread and butter. And let it also be understood that many are called but few are chosen, and that the personal equation always counts for a great deal in an artistic pursuit. By mere volition a man may not necessarily become an architect. There is an essential spark which is found to enter into the composition of every successful architect, and achievement is pretty fairly measured by the extent to which that spark is nurtured and tended until it develops into a flame which can fire men's souls. So that preparation means more than mathematics or the handling of a jack-plane, and simply as a matter of dollars and cents, the architect who would be successful must be, first and always, an artist. If he is not, if his preparation impels him to in any measure disregard his art, he may have irreproachable business methods, he may be the best constructor in the world, and may be able to hire all the artists in christendom to lend him ideas wherewith to clothe his dry bones, but sooner or later the public will find him out, will measure him for his just worth, and when the great opportunities arise they will be given to the men who are able to do their work themselves. This is not sentiment; it is fact. Witness Violet-le-Duc, who was everything but an artist in his profession, and who, notwithstanding his brilliant success as a writer and a draughtsman, was not able to earn a living as an architect, and never had the creation of a single important building intrusted to him. Witness on the other hand the World's Fair last summer. The architects who were specially honored and given the largest commissions were not the men who had the largest social connections or the greatest amount of personal magnetism, nor were they the most successful constructors, but were a selection of the best artists that this country has produced. There is no more common mistake made by young men entering architecture than to suppose that real artistic ability, as such, does not count in a purely mercenary way, that it does not pay first and foremostly to be an artist in one's profession.

But while art is the first necessity of architectural bread-winning, there are other qualities which are very essential. The architect who expects large commissions must also have good business habits, be able to keep up the odds and ends of the tiresome minutiæ which is so inseparable from all building relations of any magnitude, must be able to keep the financial side of architecture in proper order, and be able to handle and direct his employees, whether actually in his office or indirectly employed around a building. And then, last in economic necessity, the successful architect must have a thorough scientific education. There is seldom a lack of this on the part of graduates from schools. Its absence is a very common failing with the so-called self-made men who have graduated from architects' offices. A hand-book and tables of beams and columns are not sufficient to teach construction, and a young architect who is to seriously compete for the great prizes, must know how to scientifically construct his buildings.

Then beyond these three, which are really indispensable, there comes a fourth element, sometimes and in some emergencies quite as necessary, which is always displayed in a very marked degree by the successful architect, and that is common sense; that indefinite quality which is so hard to define and yet which is so thoroughly appreciated by everyone, whether applied to pure art, to dry business methods or to practical construction. The faculty to do things as they ought to be done, to design in a reasonable, appreciative manner, to carry on business in a logical, systematic way, to construct sensibly and without waste, all these are involved in common sense as applied to architecture, besides which there is the common sense which should be developed in intercourse with clients and with men, the common sense which makes a man feel the importance of giving his client what he wants, rather than only what he thinks he wants.

Therefore, still considering architecture in a purely mercenary way, it pays to do the best work. It pays to be thoroughly prepared and equipped. Honesty is the best policy in every respect as a financial investment, and he who wins the most money in the profession and plans the most important buildings is not he to whom most has been forgiven, is not the man whose sins against good taste are pardoned because he is a good fellow, or whose badly-constructed buildings are condoned because of his relatives' influence, but is he who best serves the community. That this is fact and not theory, is becoming more apparent every year. The community is not composed entirely of fools. The general average of intelligence is quite equal to that of the average architect, and though bluff and influence may seem to count sometimes, in the long run the public will find out the difference, and with very few exceptions, looking over this country, it can be seen that the great buildings, the great opportunities, have fallen to the architects who are the best prepared in their profession.

It is not always easy, however, for the young man just out of college, or just entering architectural business life, to know how to begin his post-graduate preparation. He may have his own ideals and it may take some time to have them adjusted and straightened to the necessities of business and of practical art. Let it be remembered in this connection that the line of progress in art or science is always along the line of least resistance. If we find in dealing with the world that our way is hard, that we are not received as we think we ought to be, it behooves us to look very carefully to see if we are right ourselves, and in most cases I will venture to assume that the trouble has been on our side rather than with the world. We need the world a great deal more than the world needs us, and it is no use for us to try to impose our ideas upon others unless those ideas are right. Don't give up ideals. Don't surrender any part of one's individuality, but be sure that the ideals are real and earnest and that our individuality is not a selfish one. Be ready to give the world what it wants, not necessarily what it thinks it wants, but strive in dealing with other men to find what are their real wants, and to fit art, science and business to those necessities. Business success is not incompatible with high ideals, but is often in a direct pecuniary sense an immediate result of them.

But all natures are not alike. Some men seem to be particularly adapted for artistic pursuits, others for business, and others again are of scientific bent, but if a man has to choose between the three sides of professional life, it is financially better for him to devote himself to art first, because that cannot be hired; his second choice might be the business side, but if circumstances or personal limitations are such that one element must be neglected, the architect's bread and butter will suffer least in the long run by entrust-ing to subordinates the scientific side of his profession. There are, however, natures which can not fully develop any one of these lines, and there are others which are absolutely unable to take care of more than one. All men can not be ideal, neither can all be successful, I mean in a financial sense. Is, therefore, the pure artist to starve, and the scientist to stagnate, while business tact rakes in the shekels? Most assuredly, if the artist or the scientist sits down and bemoans his sad fate, and does not try to infuse common sense in his art or practical business in his science. Fortune always was a lazy goddess, and the architect who would win her greatest rewards must be wide-awake, keenly alive to all the possibilities of his profession, and must try with all the powers within him to be not only an artist, not only a good business man, but a good all-around architect.

The question naturally suggests itself, after all the labor and hard work of preparation, the years of preliminary toil when the architect has no career behind him and everything is in the future, are the prizes, after all, worth the effort? No, most decidedly, if any one enters the profession with the idea of acquiring a fortune, most assuredly not if a man considers architecture simply as a means of satisfying his personal wants. Yes, emphatically, if the architect is the artist he might be. There are thousands of half-way, poorly equipped and very poorly remunerated architects in this country. On the other hand, there are hundreds of bright, smart men, who have good opportunities, are able to show every year what they are worth, can gratify reasonably their esthetic tastes, and are possessed of comfortable incomes. These are the men who are to be successful architects in a pecuniary sense. They are generally also the ones who win the broader success and who at the end of their careers have the satisfaction of looking back on a life well done, a race well run, and a task accomplished in a manner which has brought its own reward.

SYSTEM IN A TECHNICAL SCHOOL SHOP.

By W. H. Van Dervoort, Assistant Professor of Mechanical Engineering.

A technical school shop to attain the greatest success must be operated under modern shop systems, and the more perfect these systems the better the results obtained. The requirements of a modern school shop do not necessitate many of the intricate systems needed in manufacturing shops where hundreds of men are employed; but many of the simpler systems are well adapted to the school shop, which, in connection with those systems specially suited to the advancement of the student, can not fail to add materially to the educational value of such a shop.

The equipment of any school shop should be kept up to date by continually adding new, improved tools. The tools of twenty years since are unfit for purposes of instruction to-day. So, too, with the instructors; they must keep up to date by reading, travel and observation.

Attention should be paid to the proper arrangement of tools in the shop. All tools of a certain class should in general be grouped together. The tools for operating on the heavier parts of machines under construction should be so placed, relative to each other, as to necessitate moving these parts the shortest possible distance. The tool room should be placed in a position as convenient as possible to all parts of the floor. These, and many other points along the same line, are important considerations in planning the arrangement of a school shop. In fact such a shop should be a model one, embodying the best modern practice in matters of arrangement as well as equipment.

A tool room is a necessity. This room should be of ample size and provided with suitable racks, shelves and drawers for holding the finer tools, stock and blue prints. All tools should be in sight when possible, and a separate place provided for each tool, so that it may readily be returned to its proper place after being used. By arranging the small tools in classes and sets, the foreman can discover at a glance the absence of any tool, and thus he takes, almost unconsciously, an inventory of tools each day.

A good rack for holding such tools as drills, reamers, taps and arbors is shown in Fig. 1. The horizontal pieces CC are supported on the inclined pieces AA; CC should be of hard wood, preferably maple, about three inches by three inches in section by any desired length, depending on the number of tools to be held. In the upper face of CC straight or taper holes are reamed to receive the shanks of the tools to be placed in the rack. On the face of CC immediately in front of each tool is stamped the size of the tool to be held in that place, and under this number is placed a brass hook to receive the workman's check when he takes that particular tool. In the figure, E represents a two-inch arbor in place and D the brass check hook. One of the pieces CC may be devoted entirely to drills,

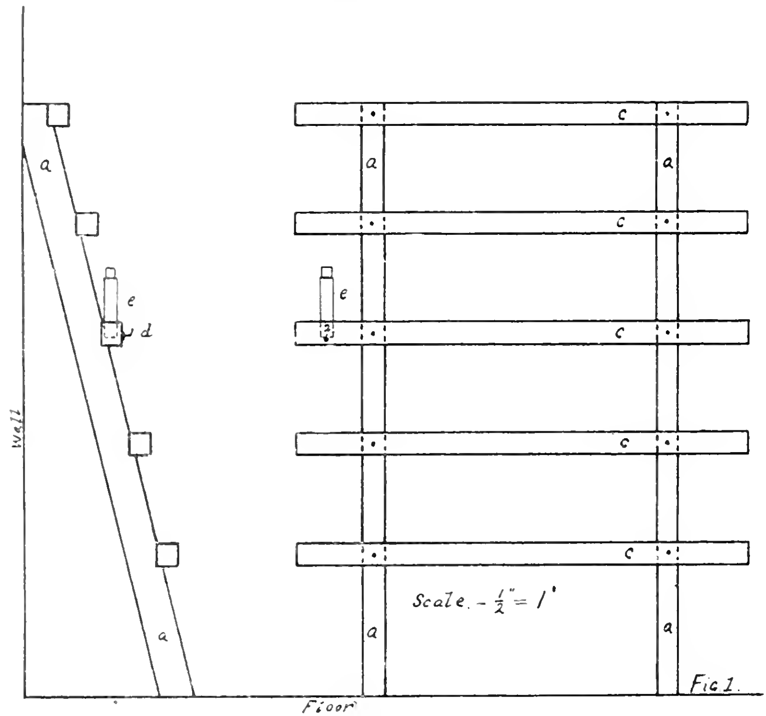


FIG. 1.

another to reamers, a third to arbors, and so on. When arranged according to size the tools look well, are not liable to injury, do not hold dust readily, and, most important of all, are convenient. By inclining the supports AA as shown the pieces CC are not immediately under each other, thus preventing a tool striking the under side of the bar above when removed from its socket.

Some system of checking out the tools from the tool room is necessary. The brass check system, common in many of our leading shops, is well adapted to the purpose. With it each student is provided with a ring of ten checks, each check bearing a number which corresponds with his number on the class roll. When the student reports for work he is given his checks, and for every tool or article taken from the room by him during the exercise, he leaves a check which is placed by the tool-room keeper on the hook, provided for the purpose, under each tool. The student is held responsible for the tool as long as his check remains in its stead. Should the instructor wish to use some particular tool that had been checked out, he can readily find, from the number on the check, who has it, and thus locate it without inquiry or loss of time. At the end of each exercise the student is required to hand in all tools and receive his check, which he places on the ring and returns to the check board.

When there is an occasional call for a tool from the room by some one not regularly connected with the shop, and when the use of the brass check is not practicable, the following blank serves the purpose well:

Mechanical Engineering Department, U. of I.
MACHINE SHOP TOOL ROOM CHECK.

Date 189

Article ....

The undersigned has received the above described article and agrees to be responsible for its prompt and safe return.

(Signed)

It is found convenient to print these on $1\frac{5}{8}$ inch by $2\frac{3}{4}$ inch Dennison's shipping tags. This blank is filled out by the person borrowing the tool and is destroyed when he returns it.

In the University mechanical engineering shops the check system has recently been adopted in the wood shop tool-room with very gratifying results. Some misgivings were entertained as to the advisability of putting all the tools in the tool room and doing away with bench cases. It is found, however, that the system works well. One man in the tool-room can easily attend to giving out tools for a class of from twenty to thirty students. The general appearance of the wood shop is much improved by the adoption of this system, and it is found that the liability of loss and injury of tools is very much decreased.

Students are detailed to tend the tool-room, each man serving about three weeks at the work during his course. It has advantages to the student from the educational standpoint, as it rapidly familiarizes him with all the small tools in the shop.

In order that a student lose no time after reporting for work, some system of giving out work is necessary, and for this purpose, the following blank is provided.

Mech'l Eng. Dep't, University of Illinois.

Date 189

Mr No

Until further assignment your work will be

....

Drawing or Blueprint No Fig No

Machine or Vise. No

REMARKS:

Retain this check and return with work when finished.

These blanks are filled out by the instructor before the exercise begins and placed under the checks, so that each student receives instruction as to what his work is to be immediately after reporting for work. The instruction on the slip is sufficiently explicit in most cases to enable the student to proceed with his work without further immediate instruction. The instructor can readily handle the balance of the students, and thus the entire class is at work within a very few minutes after the exercise begins. On completing a piece of work the student returns the blank to the instructor.

The question of systematic and equitable distribution of work is of great importance in technical school shops. To accomplish the best results, a well defined course of work should be laid out for the student to follow, and then means provided, not dependent on the memory of the instructor, to follow it. On page 59 is shown to reduced scale a form for use in the machine shop; similar forms are applicable to foundry, wood and forge shops. It represents the entire course covering three hundred and forty-five hours. Work

PRESIDENT'S OFFICE.

Mech'l Eng Shops University of Ill.

Time and work record of students in machine shop for year ending June ---189

Names and No. Division ---							
Miscellaneous		3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3
		3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3
Cutter Grinder	General Work	3 3 3	3 3 3	3 3 3	3 3 3	3 3 3	3
Grinding Machine	Internal	3	3	3	3	3	3
	External.	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3
Milling Machine	Grooving Taps Reamers etc	3 3 3 3	3 3 3 3	3 3 3 3	3 3 3 3	3 3 3 3	3
	Gear Cutting	3 3	3 3	3 3	3 3	3 3	3
	Plain Milling	3 3 3 3	3 3 3 3	3 3 3 3	3 3 3 3	3 3 3 3	3
Planer and Shaper	Angular Work	3 3 3	3 3 3	3 3 3	3 3 3	3 3 3	3
	Plain General Work	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3
		3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3
Drill	Counterboring Facing etc	3	3	3	3	3	3
	General Work	3 3	3 3	3 3	3 3	3 3	3
		3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3
Lathe	Polishing	3 3 3	3 3 3	3 3 3	3 3 3	3 3 3	3
	Boring bar Work	3 3 3 3	3 3 3 3	3 3 3 3	3 3 3 3	3 3 3 3	3
	Screw Cutting	3 3	3 3	3 3	3 3	3 3	3
		3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3
	Taper Turning	3 3 3	3 3 3	3 3 3	3 3 3	3 3 3	3
	Chuck and Face plate Work	3 3 3	3 3 3	3 3 3	3 3 3	3 3 3	3
		3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3
	Plain Turning	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3
		3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3
		3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3
		3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3
Bench Work	Tapping and Reaming	3 3 3	3 3 3	3 3 3	3 3 3	3 3 3	3
	Polishing	3 3	3 3	3 3	3 3	3 3	3
	Scraping and Filling	3 3	3 3	3 3	3 3	3 3	3
		3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3	3
	Filing	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3 3 3	3 3 3	3
	Chipping.	3 3 3	3 3 3	3 3 3	3 3 3	3 3 3	3
Names and No. Division ---							

on the principal tools forms the main heads, which are subdivided into classes of work, and under each class is given the number of hours to be devoted to that particular kind of work. The "three-hour units" are used because in this shop the exercises are of three hours duration. The student's name is written together with his class number on the left hand side of the sheet, and for convenience of observation, may be duplicated on the opposite side. The sum of all the (3)'s equals 345, the total number of hours required of each mechanical engineering student in the machine shop.

At the end of each exercise the instructor goes through the list, crossing off the time worked by each man under the class of work he has been working on. In case the student puts in two hours instead of three, a (3) would be cancelled and a (1) placed after it. In case of working four hours, cross out two (3)'s and place a (2) after them. In this way a perfect permanent record may be kept of the work done by each student, and at the end of the course each student will have done approximately the same amount of work under each class.

The sheet should be mounted on a wooden drum, and the whole enclosed, so that only one student's record may be in sight at one time. This is readily accomplished by having an opening in the casing about equal in width to the column containing a record and parallel with the axis of the drum. A duplicate heading should be pasted over the slot. The whole will somewhat resemble one of the common forms of cash registers. When so arranged it requires only a few moments of the instructor's time each day to make out the record.

The use of this system prevents the possibility of a student doing more of any class of work than an equitable distribution of his time would allow.

Much value is derived by a class in shop work from lectures given at regular intervals on Mechanical Technology. In this way an instructor gives his class much information concerning the construction and use of tools which it would be impossible for him to give individually to each man. One to two hours per week devoted to this work shows good returns.

The work in a school shop must, to command the interest of the student, be made practical. Not that we can dispense with exercise work, but that we must take our exercises from actual practical articles, and that the exercises when completed go to make up the finished machine. For example, the building of a steam engine or a wood lathe embodies chipping, filing, scraping, turning, planing, milling, drilling and in fact all the ordinary machine shop operations. The instructor in the work must have the necessary good judgment to properly select and distribute to a class the multitude of exercises which when completed and assembled form a machine of value. A student has no real interest in a piece of work which will be of no value when finished.

When possible it is much better to build a number of machines, or articles, precisely alike, as in that case the necessary special tools and jigs may be made for the rapid, systematic and accurate construction of the same.

All work should be done from accurately made drawings and blue prints. These drawings should be so numbered that any figure on any drawing may readily be referred to.

Students should be made to realize the value of an hour. In these days of close competition and narrow margins in all lines of manufacture it will not do to allow the student to fall into easy going ways. He must learn what a machine is capable of doing, and then push it to its full capacity.

MATHEMATICS AND CONSTRUCTION IN "THE ECOLE DES BEAUX ARTS."

BY JAMES M. WHITE, ASSISTANT PROFESSOR OF ARCHITECTURE.

The reputation of the Architectual Department of the Ecole des Beaux Arts at Paris is based almost wholly on its strength in design. The curriculum, however, necessarily includes a fairly thorough course in mathematics and construction, because graduates of the school are granted diplomas permitting them to practice architecture. Nominally they are also required to have had two years of office practice but in reality a few weeks suffice.

The students are divided into two classes, known as first and second, and to pass from the second to the first fifteen mentions are necessary. They are one each in mathematics, descriptive geometry, stereotomy, construction perspective, modeling and archaeology, two in drawing and six in architecture. A bright student will accomplish this work in about two years but it is possible for one who enters in March to do it in sixteen months. The first five mentions, which represent rather more than half the work, are the subject of this paper.

The instruction is given entirely by lectures which are an hour in length and usually come no oftener than twice a week in any subject. A French lecturer includes much more in a lecture than do our professors and the result is that the subject is less thoroughly grasped by the pupil. It is hoped that the reader will be able to form some conception from the number of lectures in a course and from the problems and drawings required during it and on examination of how carefully the ground is covered. The examinations will serve as the best criterion of the thoroughness attained. Merely outlines of the problems are given and without the details the reader will be apt to conceive them as simpler than they really are.

Of course any wording offers considerable opportunity for different interpretations of the amount of work expected, but there is such a spirit of competition pervading the school that the fullest interpretation usually results. In forming an opinion of the course the reader must bear in mind that all subjects are taught from the standpoint of their application to the study or practice of architecture, and everything not having a direct bearing on the subject has been eliminated from the curriculum.

The examinations are oral, but are supplemented by problems worked "en loges," which means that the student is assigned to an alcove and required to work out a problem in a specified time, varying usually from six to twelve hours.

The course in mathematics comprises about thirty-six lectures and includes the subjects of algebra, trigonometry, conic sections, analytical geometry and mechanics. The algebra includes equations as far as the solution by successive approximations of numerical equations of the third degree, decreasing geometrical progression, logarithms and interest.

Trigonometry includes the solution of plane triangles in general, the calculation of triangles by logarithms and the relation between a plane in space and its projection.

Conic sections receives much more attention than the two preceding branches. Quite a careful study is made of the curves resulting from the intersection of the cone and cylinder by a plane, and of practical methods of drawing them, and tangents to them;

also of methods of measuring surfaces and volumes frequently met with in construction.

Analytical geometry is only touched upon and is taught mainly for its application to the curves of flexure of beams. It includes the curves of the second degree except the hyperbola, equations of the line and circle referred to polar coordinates, and in geometry in space, the equation of the line and plane and the angle between two planes.

Mechanics includes only statics and simple machines. Under the first are considered parallel and concurrent forces, composition of forces, parallelogram of forces, couples, moments, general equations for equilibrium, centers of gravity and resolution of forces; under the second, the lever, balance, pulley, tackle, windlass, gears, inclined planes, the wedge, screw, and various applications.

The examination on this course in mathematics and mechanics is both written and oral. The written one usually consists of two questions, one of which is almost always the solution of a triangle and the other on mechanics. The oral is about three questions chosen at random.

As a course in mathematics it is certainly very incomplete; whether as a course specially designed for students of architecture it is also incomplete is a subject affording ample opportunity for discussion. Enough is included to suffice for the courses which are to follow, and the deficiency seems to be more in drill than in subject matter. Though the French seem to have found it sufficient to answer the actual needs of an architect, the American practice of adding a little more for the sake of the mental drill is a most excellent one.

In contrast with it is the course in descriptive geometry, which is very thorough, being the principal basis of stereotomy and perspective. The course includes fifty or sixty lectures of which about ten are a review of the part required for entrance and ten on the finding of the most common shadows.

The best conception of the course is to be obtained from the examination questions, a list of which, divided into six series, is furnished to the students. The oral examination, part of which comes at the middle of the course, is on questions from this list, one being chosen at random from each series. The first series contains about twenty-five questions on the line and plane; the second, thirty on the sphere, cone and cylinder of revolution, problems of angles, the solution of trihedral angles and regular polyhedrons; the third, thirty on cones, cylinders, pyramids and prisms; the fourth, twenty-two questions on surfaces of revolution; the fifth, twenty-five on ruled and helicoidal surfaces, and the sixth, twenty-five on shadows.

Twenty-two plates of about forty of these problems must be drawn and constitute part of the examination. The problems on the first six plates are to be chosen from the first two series, on the second six plates from series three, four and five, and the remaining ten on shadows.

One problem must be drawn "en loges," for which six hours is allowed. The problem given last year was: A cube stands with its diagonal vertical, a second cube of the same size has its diagonal coinciding with the first, but is turned through an angle of 22½°. Draw in plan and elevation the intersecting cubes and find the shadows at 45° on the solid and on the plane of projection. Pillet's text book on Descriptive Geometry is closely followed in the lectures.

The course in stereotomy is also a thorough one and includes all of Pillet's text except the scew arch. Under the division of masonry the lecturer treats of the methods and instruments used in stone cutting, the principles of jointing and of vaults, nitches, domes and cupolas; the arranging and proportioning of treads of stairs, also vaulted and suspended stairs. Under the division of woodwork, the general rules of framing are considered, the methods of assembling pieces, general principles of roofs and the special iron work of carpentry. This course also includes the methods of finding patterns of stonework and bevels of rafters, and two problems are given, the one in wood and the other in stone construction. Of those given last year the first was a small railway station which involved the design of the building, the framing plan of the roof and the principal bevels, also the framing of the stair and the patterns for the front string; the second was a building entirely in stone, to be erected in a public market square and to contain a fountain and other sources of water supply for the market. It was to be a vaulted structure with the vaulting visible both inside and out, and a decorative motive based upon the structural form of the vaults. In the center was to be a large stone basin and around the walls small basins supplied with both warm and cold water for washing purposes. Outside were to be troughs for the watering of animals. The basement was to be used for store rooms and was also to contain the apparatus for heating the water; a stone stairway was to serve as a means of communication with it. Drawings were required of the plan, facade and section, showing the jointing of the stone work, besides patterns of three voussoirs, one of which was to be from the vaulting of the stairway. A course in surveying, consisting of six or seven lectures and three days' practical field work, is appended to the above course.

The work in construction comprises twenty lectures on theoretical and thirty on technical construction. Brun's text on Construction is followed in outline, but in a condensed form, and the formulas which are given are demonstrated whenever possible by means of the mathematics already enumerated. The following outline is very general and the reader is expected to supply many headings which are necessarily preparatory to some of those enumerated. The lectures include internal and external forces acting on beams, application of formulas to all usual cases, beams of equal resistance, also beams subject to inclined pressures, columns, lattice girders, roofs, calculation of strains and deformations, curved roofs, metal ribbed vaults, expansion, friction, effect of wind, stability of masses and distribution of pressures, retaining walls, problems of stability, application to foundations in general, reservoir walls, stability of vaults and their supports, curve of the center of pressure and its application to vaulting.

The technical part includes a description of the materials of construction, methods of handling and transporting them, foundations, rules for masonry work, walls subject to thrust, buttressing, shoeing, piers and columns. Vaults are treated first historically, after which follow descriptions of different kinds, methods of construction, centerings, piers, abutments and buttresses, stone stairs, paving with flagstone, brick and asphalt, and the draining of rainwater. The lectures on wood working include descriptions of woods, methods of preservation, general principles of woodworking, assemblages, walls, floors, scaffolding, roofs, dormers, spires, towers, effect of wind and snow, roof coverings, stairs, joinery and special iron work. This is followed with lectures on metal work, descriptions of the useful metals, commercial shapes, iron walls and floors, masonry work of floors, roofs, trusses, arches, awnings, glazed roofs, water pipes, gutters, iron blinds and shutters, elevators, grilles, balconies, hardware, plumbing and gas fitting, heating and ventilating, electric bells, and lightning conductors.

Three problems are worked en loges during the lectures on theory and three general problems are required during the latter part of the course. Besides these problems there is an oral examination on each of the two parts of the course of about three questions. The nature of the problem to be worked en loges is known before hand so the student may be supplied with whatever data and formulas that may be necessary. One of these problems called for the design of a lattice I girder of equal resistance throughout and to sustain a uniformly distributed load and two concentrated loads at equal distances from the end. Given the size of the angle irons, height of web, width and thickness of cover plates and diameter of rivets. Calculate the number of cover plates required at the center and at what points they may be successively discontinued, also the spacing of the rivets for the cover plates and the lattice bars. Another problem was the design of a six panel triangular truss, sustaining dead load only, by both analytical and graphical methods.

The three required during the lectures on technical construction involve design as well as construction. The first usually includes the investigation of a vault such as: design a grand stairway leading up to a terrace, the principal landing of the stair being vaulted. Calculate the vault and its buttresses. The second in one case called for the design of one bay of a riding school, the walls to be of half timbered work, trusses 38 meters centers and 20 meters span. Submit plan, elevation, details of framing and the calculations of the principal parts. The third is called the general problem and includes about all the ordinary problems of construction which can be centered in one building. The following one will serve as a sample: Design a museum building, consisting of a central glass covered court, surrounded by galleries, three stories and basement high. On the third floor is to be a library. The basement ceiling is to be vaulted, the other floors to be of iron and masonry, the roof of the court to be of iron and glass while that of the galleries is to be of wood and metal. There are required complete general drawings, problems of the stability of the vaults and notes on the calculations. These drawings are quite elaborately worked out and rendered in color, even the construction details having the shadows all cast at 45°. The feature of design enters every problem that requires drawing, no matter what the study.

The course in perspective consists of twenty lectures and is very thorough. Three problems are required besides one en loges. The following may be considered as samples: Design a pedestal bearing a statue, the base to be about 1.5 meters across and either square or circular. Make a drawing of a public place, surrounded by arcades and with a monumental fountain in the center. No side of the square is to be parallel to the picture plane.

Make a drawing from nature of an ensemble or architectural detail, the drawing to be at least 0.25x0.35 meters. The problem given to be drawn en loges last year was the capital, architrave and frieze of the Greek Doric Order without triglyphs. The shadows were also required.

The above is, I believe, a fair representation of the work of the school not classed under the head of design, except the diploma drawing, which is a thesis design and involves details of construction and specifications. A candidate for a diploma is also required to pass quite elementary examinations in physics, chemistry and building law.

The usual problems in design do not include any calculations of construction as no construction is expected to be shown on the drawings.

SOME EXPERIMENTAL DATA ON THE DESIGN OF ELECTRO-MAGNETS.

BY WILLIAM ESTY, INSTRUCTOR IN ELECTRICAL ENGINEERING.

The design of an electro-magnet for exerting a definite pull on an armature in contact with its poles is a comparatively easy matter; but in practice it often becomes necessary to make calculations for a magnet which is to attract its armature with a given force, when the two are separated by a given distance. Although the general principle which guides us in the solution of the first case is of service in the second, still, as will be shown later, new variables enter to complicate the solution, so that no general formula can be applied.

It was for the purpose of obtaining some actual experimental data to faciliate the calculation of a special form of electro-magnet that the writer undertook this investigation while in the employ of the Thomson-Houston Electric Company at the company's factories at Lynn, Mass.

Electro-magnets in general may be classified into two groups, according to the uses for which they are designed:

(1) Magnets whose armatures can exert a powerful effort through a small distance.

(2) Magnets whose armatures exert a weaker pull, but over a considerable range.

For certain purposes an electro-magnet is required to put forth a temporary lifting power. In this case the armature is drawn to the magnet and tightly held there as long as the exciting current is maintained, and is detached only by a stronger opposing pull. The force exerted by a magnet thus in contact with an armature is considerably greater than would be the case if the magnet was acting on its armature at a distance.

The force due to an armature in direct contact with a magnet is called the *tractive* force of the magnet. On the other hand, when the force is due to the magnet acting on its armature at a distance, it is called the *attractive* force of the magnet.

The Law of Magnetic Traction was stated by Maxwell and is as follows:

$$\text{Pull (dynes)} = \frac{\mathbf{B}^2 A}{8\pi},$$

where $\mathbf{B}$ is the number of magnetic lines of force per square centimeter, and A is the polar area, or surface of contact, in square centimeters.

If English units are used the formula becomes

$$\text{Pull (lbs.)} = \frac{\mathbf{B}^2 A_{''}}{72\,134\,000.}$$

The above statement of the law of traction assumes that the distribution of the magnetic lines of force is uniform throughout the entire area, but this is rarely the case. If the density is not uniform the formula may be written

$$\text{Pull (dynes)} = \frac{1}{8\pi}\int \mathbf{B}^2\, dA.$$

But even this last formula gives no useful information about the pull of a magnet on its armature at a distance, *i. e.*, it is not a statement of the law of *attraction*.

Let us consider briefly the law of *traction* as applied to the design of electro-magnets, and then take up the various factors entering to modify any simple general statement of the law of magnetic *attraction*.

The general expression for the flux of magnetic lines in any circuit, is

$$N = \frac{\text{Magneto-Motive Force}}{\text{Reluctance}},$$

$$\text{but } M = \frac{4\pi Cn}{10}, \text{ and } R = \sum \frac{l}{A\mu},$$

$$\therefore N = \frac{\frac{4\mu Cn}{10},}{\frac{l}{A\mu}}$$

where M=magneto-motive force; R=magnetic reluctance; C= current in amperes; n=number of turns of wire on magnet; l=length of magnetic circuit in centimeters; A=cross-section of magnetic circuit in square centimeters; μ=permeability=$\frac{\mathbf{B}}{\mathbf{H}}$

Solving for the ampere-turns (Cn), we have

$$Cn = \frac{N \sum \frac{l}{A\mu}}{1.26} = N \sum \frac{l''}{A_{''}\mu}\ .3132 \text{ (in English units.)}$$

If l''=mean total path of the magnetic lines all around the closed magnetic circuit, and, since N=**B** A, or=density × area, then will

$$Cn = \frac{\mathbf{B}_{''} l''}{\mu}\ 0.3132,$$

and

$$\mathbf{B}_{''} = \frac{Cn\mu}{.3132\ l''}$$

But from Maxwell's formula—

$$\mathbf{B}_{''} = 8494 \sqrt{\frac{P\ (\text{lbs.})}{A\ (\text{sq.ins.})}}$$

Equating these two values of **B**,,, and solving for Cn, gives

$$Cn = 2661 \frac{l''}{\mu} \sqrt{\frac{P\ (\text{lbs.})}{A\ (\text{sq.ins.})}}$$

which is in a form convenient for the designer.

Here again is an ideal case; for the value of Cn given above, assumes:—that there is no leakage, and therefore perfect contact between armature and poles, and further, that the area of cross-section is the same all around the circuit, in the armature as well as in the core.

To the designer of an electro-magnet which acts on its armature at a distance, a formula like the preceding will not be of much value. Magnetic leakage increases with the air gap, and varying with the form of the magnetic circuit, will complicate the calculations. The greater the leakage, the wider the departure from the ideal formula, so that it becomes necessary to investigate the law of magnetic attraction.

The law of force governing a magnet, acting at a point some distance away from it, is commonly given in text-books as the Law of Inverse Squares. This law, though correct for certain cases of magnetic attraction, viz., where the force acts at a point, is not true for ordinary magnets.

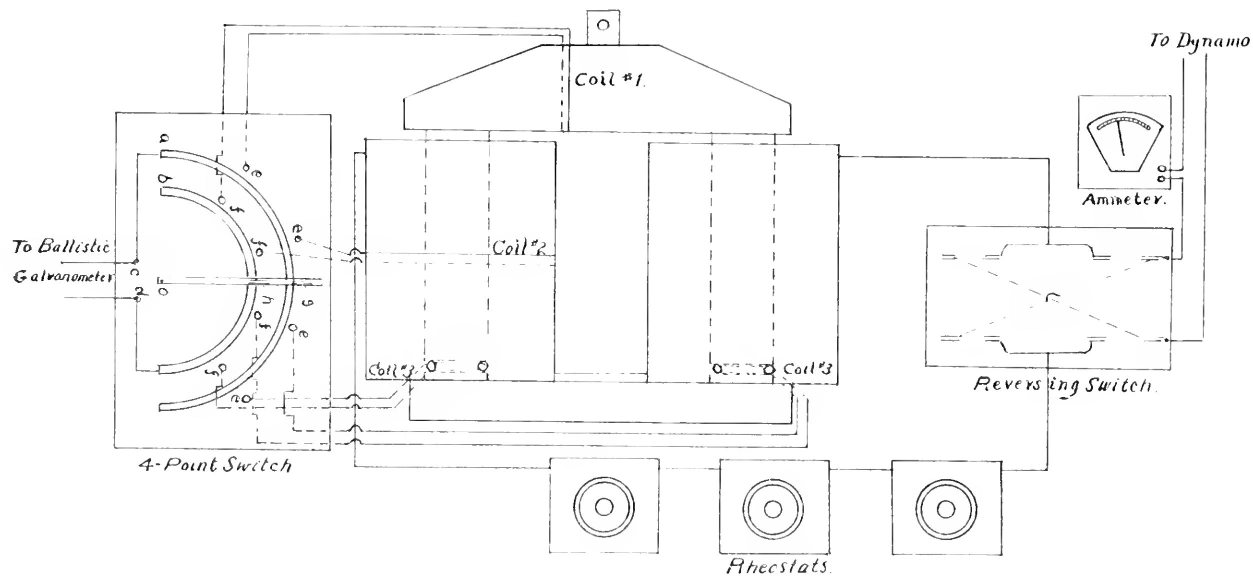
Owing to irregular leakage, the magnetic force does not emanate from mere points; hence one of the essential conditions under which the law of inverse squares holds is not fulfilled. Again, because the distance through which the force acts is not great compared to the pole from which the force proceeds, another condition on which the truth of inverse squares depends is violated.

Hence, whatever may be the law of attraction, it is not that of inverse squares.

With a given form and winding of electro-magnet, the introduction of an air gap into the circuit will, as a first effect, decrease the number of magnetic lines flowing through the circuit. The magnetic resistance to lines of force, or reluctance, of the circuit is increased, hence for the same magneto-motive force, the flux is diminished.

The second effect is a corollary to the first; if the flux is lessened the permeability of that particular iron is increased, which means that the air gap offers a greater relative resistance to the flux.

A third effect, due to the presence of an air gap, is that of *leakage*. Because the magnetic lines in passing up through the yoke have to cross an air gap before entering, and after leaving the armature on their way back to the yoke, some lines will take a shorter path and leak across from limb to limb. As the gap lengthens, more reluctance is offered, and hence more lines will leak across, and even with the armature in apparent contact with the poles, there will be some sideways leakage. Thus the number of lines which get into the armature will be less and less, the greater the gap.



To Dynamo.
Ammeter.
Coil #1.
Coil #2
Coil #3
Coil #3
To Ballistic
Galvanometer
4-Point Switch
Reversing Switch.
Rheostats.

Fig. 1.

The object of the experiments which follow is to ascertain the effect of air gaps on the magnetic flux and hence on the attractive force of the magnet.

It was proposed to take a special form of electro-magnet, and by sending through its coils different exciting currents, find the corresponding pulls of the armature, and to do this for a number of different air gaps.

In order to get the magnetic flux at different points in the circuit, and hence an indication of the magnetic leakage, test coils and a ballistic galvanometer were employed.

When the magnetic induction through any one of the test coils, whose positions are shown in Fig. 1, undergoes a change, *e. g.*, by a reversal of the primary current, a throw of the ballistic galvanometer needle will occur. This throw is proportional to the whole quantity of electricity which passes in the transient current, and this in turn is proportional to the change of magnetic induction within the coil: or

$$Q = kd,$$

where Q = the total quantity; k = the constant, and D = the deflection of the ballistic galvanometer caused by Q.

If E is the E.M.F. induced in the secondary at any instant during the change of induction, the quantity of electricity which flows in the time dt will be

$$dQ = Cdt = \frac{E}{R}\,dt$$

when C=current, and R=total resistance of the secondary circuit, including, of course, the ballistic galvanometer. The whole quantity Q which flows through the ballistic galvanometer in the time *t* is the summation of all these elementary quantities, or

$$\text{Total } Q = \int_0^t dQ = S\int_0^t \frac{E}{Rdt} = \frac{S}{R}\int_0^t Edt$$

where S equals the number of turns on the secondary. But since E by definition is the *rate of change of induction* $= \frac{dN}{dt}$, therefore $\int_0^t Edt$ is the integrated or total change of induction taking place in time t.

$$\therefore \text{Total } Q = \frac{S}{R}\int_{N_2}^{N_1} \frac{dN}{dt}\,dt = \frac{S}{R}(N_1 - N_2)$$

where N_1 is the original induction when $t = 0$, and N_2 = final induction when time = t.

Hence $S(N_1 - N_2) = RQ$; but Q is proportional to the deflection D, it produces, *i. e.* $Q = kD$, therefore

$$S(N_1 - N_2) = RQ = kRD = SN, \text{ or } N = \frac{kRD}{S}$$

where N = change of induction ($= \triangle Q$ of Ewing). If, however, the change of induction be caused by a *reversal* of the primary current, so that $N_1 = N_2$ but of opposite sign, then the total change will be

$$N_1 - (-N_1) = 2N.$$

We have thus seen that a given change of induction can be measured in terms of the deflection it produces on a ballistic galvanometer, the resistance and turns of the secondary circuit. But in order to make absolute measurements of N, we must first know how much induction it takes to produce a deflection of unit scale division, *i. e.*, we must find the constant = k of the galvanometer.

To standardize the galvanometer, *i. e.*, to find k, the following method was employed: A long magnetizing coil was uniformly wound on a brass tube whose diameter was small compared with its length. On this primary coil at the middle of its length, a short secondary coil was wound and put in circuit with the ballistic galvanometer.

CONSTANT OF BALLISTIC GALVANOMETER.

Let k = constant.

N_1 = total lines enclosed by secondary calibrating coil.

N = total change of induction (unknown) to be measured.

Q_1 = total quantity of electricity which flows in the calibrating secondary coil, caused by N_1 lines.

Q = total quantity caused by N lines.

S_2 = number of turns on secondary calibrating coil (= 890).

d = deflection of galvanometer due to N lines (= 114.8).

r = total resistance of secondary circuit (when deflection = d).
= 6.020 (galv.) + 14.25 (secondary) + 60 (res. box) = 80.27 ohms.

s_1 = number of turns per centimeters of length on primary of solenoid, (= 11.27)

a = mean area of primary(= 23.6 square centimeters.)

c = primary current (c. g. s. units) (= .2 = 2 amperes.)

S = number of turns on test coil (= 2.)

D = deflection due to unknown lines N.

R = total resistance of secondary circuit when deflection = D.
A = area of test coil.

The number of lines produced by a current c (c. g. s. units) in the calibrating solenoid is

$$N_1 = 4\pi s_1 ca.$$

The quantity of electricity which flows in the secondary on breaking the primary current is

$$Q_1 = \frac{N_1 s_2}{r} = \frac{4\pi s_1 cas_2}{r}$$

therefore $k = \frac{Q_1}{d} = \frac{4\pi s_1 cas_2}{dr}$, which is the constant sought.

To evaluate an unknown induction N having k, D, S, and R.

$$N = \frac{k R D}{S} = \frac{4\pi s_1 c a s_2}{dr} \frac{D R}{S}$$

and the density $\mathbf{B} = \frac{N}{A} = \frac{4\pi s_1 c a s_2}{dr} \frac{D R}{S A}$

For these experiments

$$N = \frac{1.26 \times 11.3 \times 2 \times 23.6 \times 890}{114.8 \times 80.27 \times 2}. \quad D R = 32.375 \text{ D R}$$

and $$\mathbf{B} = \frac{596690 \text{ D R}}{\text{ASdr}}.$$

from which formulæ the inductions given in Table II. were computed for the several test coils used in the experiments.

As d is caused by a reversal of the calibrating current, so D also corresponds to a reversal of induction in the test coil.

When N is only increasing or decreasing but not reversed, only half of the calibrating deflection can be used for comparison; that is, the numerator of the preceding fractions must then be multiplied by 2.

In applying the ballistic method to large electro-magnets, as for example to dynamo magnets, having considerable self-induction and therefore a large time constant $\frac{L}{R}$, where L is the coefficient of self-induction and R the resistance of the circuit, care must be taken to select a galvanometer having a long period, at least 15 or 20 seconds, otherwise the needle will tend to move before the induced secondary current (whose delay in rising to its maximum value is caused by the self-induction of the primary) has passed.

A practical limit to the period of a ballistic galvanometer having been reached, the following method of reducing the error due to a large time constant may be applied to magnetic measurements.

The formula, time constant (in seconds) $=\frac{L}{R}$ shows that if L remains fixed, the time constant will be reduced if R is increased.

Suppose for example that we are testing the induction in a dynamo field magnet, where R=50, magnetizing current = 1 ampere and assume L=500 henries, (when current=1.)

The time constant will then be

$$t=\frac{500}{50}=10 \text{ seconds},$$

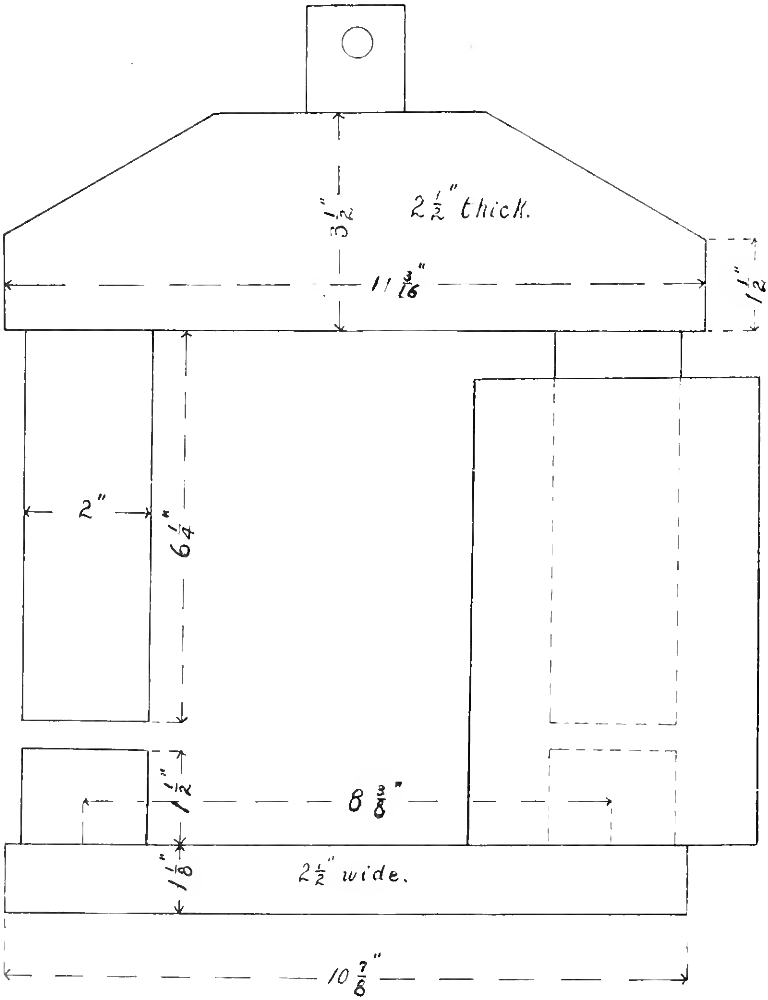
which means that the current takes 10 seconds to rise to $\left(\frac{e-1}{e}=.634\right)$ of its maximum value. See Thompson's Electro-magnet, page 222.

Now insert a non-inductive resistance of say 450 ohms in series with the magnet winding and apply 500 instead of 50 volts to the terminals. The current will be the same as before or $\frac{500}{500}=1$ ampere, but $t=\frac{500}{50+450}=1$ second, that is, we have reduced time constant from 10 to 1 second and could thus use a ballistic galvanometer having a shorter period if necessary.

The type of electro-magnet used in these experiments was one of the form termed by S. P. Thompson, "Stopped-Coil-and-Plunger." The nature of its action is intermediate between the weak long-range pull of the ordinary coil and-plunger, and the powerful short-range pull of the electro-magnet having a fixed core.

The two spools are arranged with short fixed cores extending part of the way through them, and a double movable core or armature to be sucked into the coils, and finally into close proximity with the fixed cores. This form of magnet has been largely used where a strong pull over a considerable range of action is desired for a short time.

The force with which the movable part of the core is drawn into the coil is somewhat greater, owing to the concentrating effect on the lines of force of the fixed part, than would be the case with an open coil. And when the movable part has so entered it is drawn in by



Solenoid Brake Magnet.

FIG. 2.

a pull at first fairly uniform (see Fig. 10) and then increasing greatly as the gap in the magnetic circuit diminishes.

The particular form of magnet experimented on is used by the Thomson Houston Electric Co. to act through a lever on a "toggle" arranged to apply a brake on electric cranes, elevators, and hoists. This style of magnet is well adapted to this purpose, since the brake which it operates is intended to be applied at first gradually, and then with its full strength.

One set of spools used were wound for 220 volts, and had the following dimensions:

Outside diameter (wound spool)			= $5\frac{5}{32}$ inches.
Inside	"	"	" = $2\frac{3}{32}$ "
Length (winding space)	"	"	= $7\frac{7}{16}$ "
Perimeter	"	"	= 16.20 "
Surface (cylindrical)	"	"	120.5 square inches.

Winding:—

Spool No. 1, 30 layers .032-inch wire (= No. 20 B & S) 4 476 turns = 16 lbs.

Spool No. 2, 30 layers .032-inch wire (= No. 20 B & S) 4 469 turns = 16 lbs.

Total turns = 8 945.

Inasmuch as the T.-H. standard brake magnet has cores $6\frac{1}{4}$ inches long, the minimum air gap is only $\frac{3}{8}$ inches; so, in order to try the effect of gaps less that $\frac{3}{8}$ inches, a new set of fixed cores was made, having a length of $1\frac{1}{2}$ inches instead of the normal 1 inch.

Cold resistance by bridge, Spool No. 1 = 50.383 ohms.
" " " " " " 2 = 49.683 "

The spools when in series across 220-volt mains will then take a maximum current of

$$C = \frac{220}{100} = 2.2 \text{ amperes (approx.)}$$

The heating loss is then $C^2 R = 2.2^2 \times 100 = 484$ watts, and the watts radiated per square inch of spool surface $= \frac{484}{241} = 2.+$ The temperature rise corresponding, according to Forbes' rule is $2 \times 223 = 446$ F. = 230 C. It is evident that the watts radiated per square inch of spool surface are fully four times as great as ordinary designing practice would warrant; but it should be remembered that the conditions here are very different from those ordinarily obtaining. Brake magnets are in action only intermittently, and then for brief intervals of time, so that this apparently excessive heating is entirely justifiable. During the experiments, however, the current was kept flowing in the windings an hour or more at a time, with the result that the spools would become dangerously hot, especially for currents greater than the normal 2.2 amperes. This difficulty was avoided by setting up two fan-motors, one close to each spool, thus causing strong currents of air to blow on the heated surface of both spools. This method of artificial cooling was very effective.

The form and dimensions of the magnet yoke, armature, and so forth, are shown in Fig. 2.

This magnet in practice is arranged to have its fixed core and

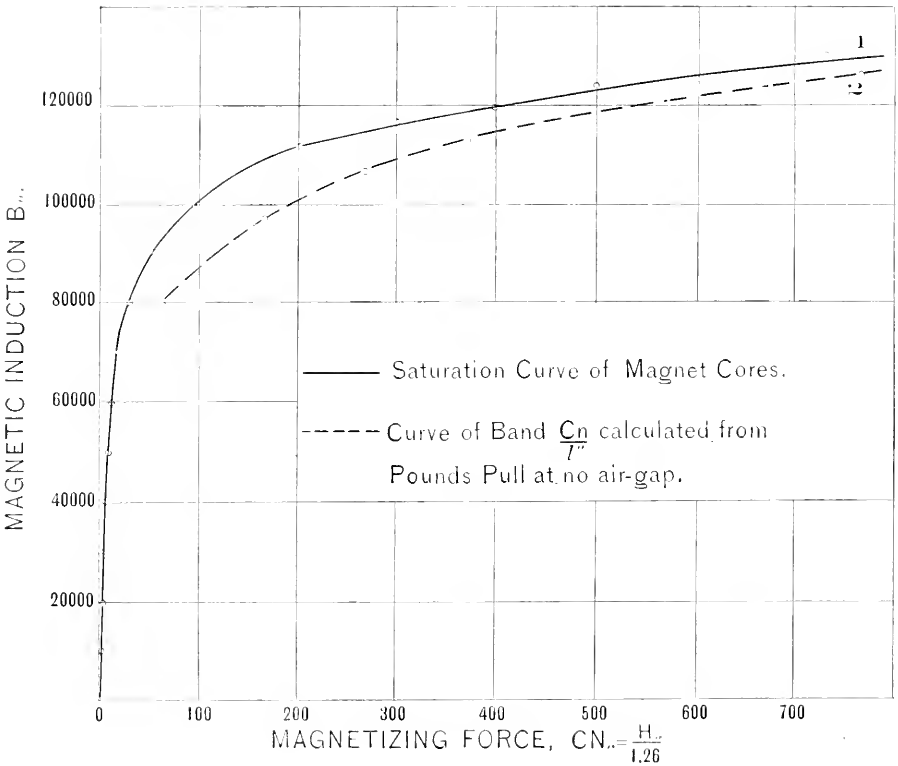


FIG. 3.

yoke uppermost, so that the movable core will be attracted upwards; but for these experiments the normal position was reversed.

The material of the yoke, armature yoke, and cores is wrought iron throughout. The weight of the movable cores with yoke, *i. e.*, the armature, was 31.5 lbs.

A saturation curve (No. 1, in Fig. 3) of the iron used in the magnet cores was obtained by using a modification of the method of Hopkinson. Curve 2 represents the relation between **B** and $\frac{Cn}{l''}$ calculated from the pounds pull for no air gap by the equation used in connection with the "permeameter" method of testing iron, viz:

$$\mathbf{B} = 1317\sqrt{\frac{\text{Pull}}{\text{area in sq. ins.}}} + \mathbf{H}\ *$$

As is to be expected, the latter curve falls below the true saturation curve, since contact between cores and poles (though they were nicely surfaced) was not perfect. Moreover, the magnetic circuit contains four joints, besides the preceding, where the upper and lower magnet cores are screwed into the movable and fixed yokes respectively; the effect of these joints being to reduce the permeability of the circuit as a whole. It might be remarked, however, that the lower curve approaches the upper more closely at the higher magnetizing forces. This is due to the fact, as Ewing has pointed out, that the pressure between the two surfaces increasing with the magnetizing force, tends to eliminate the effect of joints and to make the magnetic circuit more perfect.

DATA FOR SATURATION CURVES.

Curve 1.		Curve 2.	
$\mathbf{B}_{ii}$	$\frac{Cn}{l''}$	$\mathbf{B}_{ii}$	$\frac{Cn}{l''}$
10 000	2.0	80 000	62
20 000	2.3	97 000	165
30 000	3.0	106 500	268
40 000	6.5	112 900	371
50 000	8.5	121 400	677
60 000	11.0	126 500	766
70 000	16.5		
80 000	28.5		
90 000	53		
100 000	94		
111 500	200		
116 000	300		
119 500	398		
124 000	500		
129 000	730		

*Thompson's "Electromagnet," page 82.

APPARATUS.

For measuring the pull of the armature four spring dynamometers were used and the downward force measured directly.

Dynamometer	No. 1	read to	100 lbs.
"	" 2	" "	400 "
"	" 3	" "	1 000 "
"	" 4	" "	5 000 "

These instruments were all calibrated by standard weights or standard platform scales.

In calibrating Nos. 3 and 4 an armature truck of known weight was placed on standard platform scales and loaded with blocks of iron, and the total weight recorded. The dynamometer being tested was then attached to the truck and its contents and part of the weight removed by a chain hoist. The indication of the balance and the reading of the scales were recorded. More weight was then taken off the scales by pulling on the hoist, and the readings again recorded, the process being repeated till the truck was lifted clear of the scales.

On changing from one dynamometer to another, with the magnetizing current kept constant, the last reading on one was repeated on the next as a check.

For overcoming the magnetic attraction of the armature, a chain differential-pulley block was fastened to a beam immediately over the spools, and the dynamometer attached between the hook of the hoist and the eye in the armature. Care was taken that the pull of the dynamometer should be vertical, otherwise the friction of the movable cores on the spools would have introduced an error.

The magnetizing current was measured by a Weston ammeter having a scale reading from 0 to 5 amperes. The ammeter was calibrated by a standard Thomson current galvanometer.

To obtain the desired range of currents (.25 to 4 amperes) three electromotive forces were used, viz: 110, 220 and 500 volts.

A double-pole double-throw switch was used for reversing the current through the spools for the purpose of getting the desired readings on the ballistic galvanometer.

In order to connect the various exploring coils in succession to the ballistic galvanometer, without disconnecting their terminals, a special switchboard (see Fig 1) was employed. It consisted of a solid rectangular block of slate, having two concentric semi-circular strips of brass *a* and *b* (see Fig. 1) riveted thereto, and were connected by wires underneath to *c* and *d* whence leads were run to the ballistic galvanometer; *e* and *f* are circular contact pieces or studs to which the terminals of the several exploring secondary coils are fastened. A contact-making arm of ebonite, pivoted at *o*, is provided with sliding contact pieces or springs, which slide over the several studs; *g* serving to connect studs *e* with *a* and hence with *c*, while *h* does the same with *f* and *d*; *g* is long enough to bridge from *a* to *c*, and similarly *h* from *b* to *f*. Of course *g* and *h* are well insulated from each other. In the position shown in Fig 1, the contact arm is in a neutral position, and no exploring coil is in circuit.

The Ballistic Galvanometer was in an adjoining building, and wholly encased in a heavy cylindrical cast iron box, whose walls were two inches thick. A small aperture cut in the front permitted the beam of light from the reflecting mirror to pass through the enclosing case and fall on the ground glass screen.

The box containing the galvanometer rested upon a number of hard rubber buffers, which in turn were supported on a massive brick pier. The above arrangement, as will be seen, rendered the instrument especially free from all sources of disturbance both magnetic and mechanical.

The galvanometer, whose resistance was 6.020 legal ohms at 20 degrees centigrade, had a period of 15 seconds. In the earlier experiments an air gap coil wound on a grooved disc of hard wood about 2 inches in diameter was placed in *each* air gap (see Fig. 1,) but since they gave approximately the same induction, the two were afterwards connected in series, and the combined inductions in right and left air gaps divided by 2, giving thus the mean value of the induction.

An additional test coil around the middle of the fixed yoke would have given interesting information concerning the magnetic induction at that part of the magnetic circuit, and were similar experiments to be undertaken in the future, the writer would include such a coil.

Method of Taking Observations.

To avoid complications it was thought best to take the electrical and mechanical readings first, and afterwards to make the magnetic observations, the same conditions being reproduced as far as possible in the latter set as in the former.

For each length of air gap a series of magnetizing currents from .25 amperes to about 4 amperes was used, and the pull corresponding to each strength of current noted on the spring balance.

The current at any given point was kept constant by means of suitable rheostats, and was at all times, read in the same direction.

i. e., progressively increased or decreased. The effects of hysteresis were eliminated as far as possible by frequently reversing the current in the coils and by always reading from lower to higher values of the current and vice versa, and finally by repeating the readings, proceeding from higher to lower currents. The pull of the armature recorded was the maximum reading observed at the point when the pull applied just began to overcome the magnetic attraction. This point was well defined, especially for large magnetizing currents, the index of the balance slipping back ten or twenty pounds as soon as the armature core had moved out of the strongest field.

For varying the length of the air gap a quantity of hard wooden discs 2 inches in diameter and of thicknesses 1, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$ inches, were used to block the armature cores away from the fixed cores. The discs were carefully turned in a lathe and surfaced up and then calipered with a micrometer.

Explanation of Tables.

Table I. contains the values of the pull in pounds corrected for errors of balances and the weight of the armature which was subtracted from the gross pull, to give the net or useful pull, for currents varying from .25 to 3.85 amperes and for different air gaps varying from 0 to .5 inches.

Table II. gives the total magnetic inductions (N) in the movable yoke (calculated from ballistic readings on exploring coil No. 1, see Fig. 1,) in spool (coil No. 2,) and in air gap (coil No. 3) and values of $B_{,,}$, the density per square inch in the air gap, for air gaps varying from 0 to .5 inches, and for currents from 1.05 to 3.00 amperes.

The various inductions (N) are calculated from the formula before given: N = 32.375 D R.

Where D is the mean value of at least four galvanometer deflections, and R the particular value of the resistance in the secondary circuit, which was found to give a convenient deflection. Thus every set of four deflections observed would have its corresponding value of R, but for brevity the observed values of D and R are omitted and simply the calculated values of N given.

The several areas of the exploring coils used, are:

For Yoke	(coil No. 1)	A = 8.75 sq. ins.
" Spool	(" " 2)	A = 20.88 " "
" Air gap	(" " 3)	A = 2.76 " "

TABLE I.

Useful Pull in Pounds For Different Magnetizing Forces and Air Gaps.

Current.	.25	.65	1.05	1.45	2.05	2.25	2.45	2.65	2.85	3.00	3.25	3.65	3.85
Ampere-turns.	2 236	5 814	9 392	12 970	18 337	20 126	21 915	23 701	25 493	26 835	29 076	32 649	34 438
Air Gaps	USEFUL PULL IN POUNDS												
0.	545.0	805	940	1 055	1 160	1 180	1 210	1 240	1 265	1 270			
.125	49.5	274.	439	545	648	680		740		786			
.250	15.5	91.5	232	339	367	459		529		579			
.375	6.5	55.0	132	219	306	349		399		439			
.500	38.0	36.0	86.5	156.5	228.5		278	316	321	369			
.625	3.5	26.5	62.5	120	189	219	229	264	269	301		362	
.750	3.5	21.5	51.5	95.0	157	167*	192	210*	233	247*	269	297	
.875	3.5	17.5	44.5	71.5	136	144*	174	187*	207	223*	244		
1.000	2.5	13.5	38.5	67.5	120.5		152	168*	187	197*	219	249	261
1.125	2.0	13.5	35.0	65.5	106		140		174		204		
1.250	2.0	11.5	31.5	54.5	98.5		130.5		164		190	219	229
1.375	2.0	10.5	27.5	51.5	93.5		121		152		182	204	222
1.500	1.5	8.5	24.5	46.5	78.5		109		140		169	194	214
1.625	1.5	8.5	23.5	43.5	79.		104		129		164	189	
1.750	1.5	7.5	21.5	39.5	73.5		99		129		152	179	
2.000	1.0	6.5	18.5	34.5	65.5		93.5		126		144	169	181
2.125	1.0	5.5	16.5	31.5	60.5		88.5	102*	116	126*	141	164	177
2.250	1.0	4.5	15.5	30.5	59.		78.5		104		132	159	169
2.375	1.0	4.5	13.5	28.5	57.0		73.5		102		110	152	164
2.500	1.5	4.5	13.5	26.5	50.0		69.5		99			147	164
2.625	1.0	3.5	11.5	22.5	45.5	54.5	67.5	74*	87	94*	109	127	
3.00			9.5	17.5		38.				76.5	93.5		
3.500			6.5	13.5		32.5		15.5		60.5	71.5		
4.000			4.5	9.5		23.5		34.0		43.5		65.5	
5.000	0.	0.5	1.5	2.5		8.5		13.5		18.5	21.5	27.5	

*Not observed but interpolated from curves.

The density of lines in the air gap has been computed from the total induction thus: **B** per square inch $= \frac{N}{2.76}$ where 2.76 = area of air gap coil in square inches. The density in the movable yoke is not calculated because the cross-section is not uniform throughout, and were we to divide the total induction in the yoke by the area of exploring coil No. 1 (viz: 8.75 square inches) we would obtain the minimum yoke density, for by reference to Fig. 1 it will be seen that coil No. 1 encloses a maximum cross-section. To obtain therefore the *average* yoke density it would be necessary to divide N by the average area which may be taken = 3.75 square inches.

The density in the movable cores cannot, of course, be directly found by dividing N for the magnet spool by the area of coil No. 2 (viz. 20.88 square inches) for part of this space only is filled by iron, the rest being copper and insulation. If the mean area of one magnet spool is $A_{,}$, and the area of cross-section of one core is A, there will be $(A_{,} - A)$ **H** lines enclosed by the secondary test coil, but outside of the iron, so that the true induction within the iron is

$$N - (A_{,} - A)\,\mathbf{H}$$

where $\mathbf{H} = \frac{4\pi Cn}{10l} = \frac{1.26\,Cn}{l} = 1.26 \times$ ampere-turns per centimeter of length, whence

$$\mathbf{B} = \frac{N - (A_{,} - A)\,1.26\,Cn}{Al}$$

The above calculation of $\mathbf{B}_{,,}$ is correct only when there is a practically continuous magnetic circuit of iron, that is, when the air gap is zero. It cannot be applied when there is an air gap interposed, for **H** cannot be computed by the regular formula $\mathbf{H} = \frac{4\pi\ Cn}{10l}$, since owing to the end effect or demagnetizing tendency of short magnetic circuits (including air spaces) the value of **H** is not uniform at all points.

The 5th, 10th, 15th and 20th columns contain the values of the coefficient of leakage obtained by dividing N for the spool by N in the air gap, the mean ratios being plotted in Fig. 12.

Discussion of Curves.

Fig. 4; no Air Gap.

Inasmuch as the cores were in contact with the pole pieces, there was no room for the air gap coil (No. 3) and consequently the curves for coils 1 and 2 only appear. 1 and 2 exhibit the well

TABLE II.

Currents.	1.05 = 9 392 Ampere-Turns					1.45 = 12 970 Ampere-Turns				
Air Gaps.	N = Total Induction. Yoke. (Coil 1)	Spool. (Coil 2)	Air gap (Coil 3)	$\frac{N}{1.76} = B_{,,}$ Air Gap.	V	N = Total Induction. Yoke. (Coil 1)	Spool. (Coil 2)	Air gap (Coil 3)	$\frac{N}{2.76} = B_{,,}$ Air Gap.	V
0.	364 600	378 600				384 200	407 300			
.125	336 500	334 000	197 550	71 600	1.69	365 000	375 800	221 250	80 200	1.69
.250	305 300	296 500	136 150	49 300	2.18	346 400	246 500	161 650	58 500	2.14
.375	269 800	257 800	98 250	35 600	2.62	326 400	319 200	122 550	44 400	2.60
.500	246 200	232 300	78 250	28 350	2.97	309 600	297 200	103 000	37 320	2.89
.625	224 600	204 500	64 600	23 400	3.17	292 600	273 000	86 850	31 500	3.14
.750	206 600	190 400	53 850	19 500	3.53	275 600	255 000	75 250	27 260	3.39
.875	196 500	174 800	48 180	17 460	3.63	261 000	237 000	65 800	23 840	3.60
1.250	164 500	136 100	33 700	12 210	4.02	215 500	191 000	46 9 0	17 000	4.07
1.500	135 700	114 000	27 205	9 860	4.19	187 400	157 400	37 470	13 500	4.21
1.750	123 000	99 000	25 200	9 130		169 400	137 700	33 500	12 100	
2.125	111 000	88 500	22 200	8 040		152 200	121 700	30 500	11 050	
2.375	99 000	77 000	20 900	5 770		141 000	109 800	28 600	10 360	
2.625	90 600	69 200	19 000	6 880		125 500	97 500	25 800	9 350	
3.	77 700	57 400	17 200	6 230		108 600	79 800	24 300	8 800	
3.500	62 300	47 400	15 600	5 650		86 600	65 800	21 700	7 860	
4	48 700	40 300	14 500	5 253		69 200	55 300	20 400	7 390	
5.	29 424	32 180	13 400	4 855		40 920	41 400	19 000	6 680	

TABLE II.—Continued.

Currents.	2.65 = 23 704 Ampere-Turns					3.00 = 26 835 Ampere-Turns				
Air Gaps.	N = Total Induction. Yoke. (Coil 1)	Spool. (Coil 2)	Air gap (Coil 3)	$\frac{N}{2.76} = B_{,,}$ Air Gap.	V	N = Total Induction. Yoke. (Coil 1)	Spool. (Coil 2)	Air gap (Coil 3)	$\frac{N}{2.76} = B_{,,}$ Air Gap.	V
0.	421 000	449 200				428 100	467 400			
.125	412 000	431 000	256 500	92 900	1.69	*418 000	*451 000	*266 000	*96 100	1.70
.250	400 400	423 000	202 950	73 500	2.08	*407 000	*435 000	*207 000	*75 000	1.69
.375	396 200	414 100	164 300	59 500	2.50	413 700	436 800	176 700	64 000	2.47
.500	390 800	393 900	144 000	52 170	2.71	394 900	413 300	152 300	55 200	2.71
.625	377 700	376 500	125 800	45 600	2.99	392 100	401 200	134 100	48 600	2.99
.750	367 000	363 600	114 250	41 390	3.18	381 500	385 100	121 450	44 000	3.17
.875	359 200	346 000	102 850	37 260	3.41	375 000	372 500	110 700	40 100	3.37
1.250	329 500	304 500	78 800	28 550	3.86	349 000	332 000	86 500	31 340	3.84
1.500	304 600	267 000	65 550	23 700	4.07	325 500	291 200	72 650	26 300	4.01
1.750	291 000	246 000	60 400	21 900		312 000	268 800	67 500	24 500	
2.125	271 500	219 200	55 600	20 100		291 900	244 300	62 500	22 600	
2.375	247 000	198 200	51 600	18 690		276 000	221 000	58 100	21 050	
2.625	225 000	174 500	47 500	17 210		255 000	198 100	53 800	19 490	
3.	196 400	145 600	44 500	16 100		220 600	163 000	49 800	18 000	
3.500	156 000	118 700	40 400	14 600		180 600	134 100	45 500	16 500	
4.	126 900	101 800	37 400	13 550		143 000	117 100	42 600	15 430	
5.	75 950	83 000	34 500	12 500		86 520	93 400	39 500	14 310	

* Not observed, but interpolated from curves.

known characteristics of saturation curves, first, a rapid rise along a straight line nearly, then a gradual bending increasing more

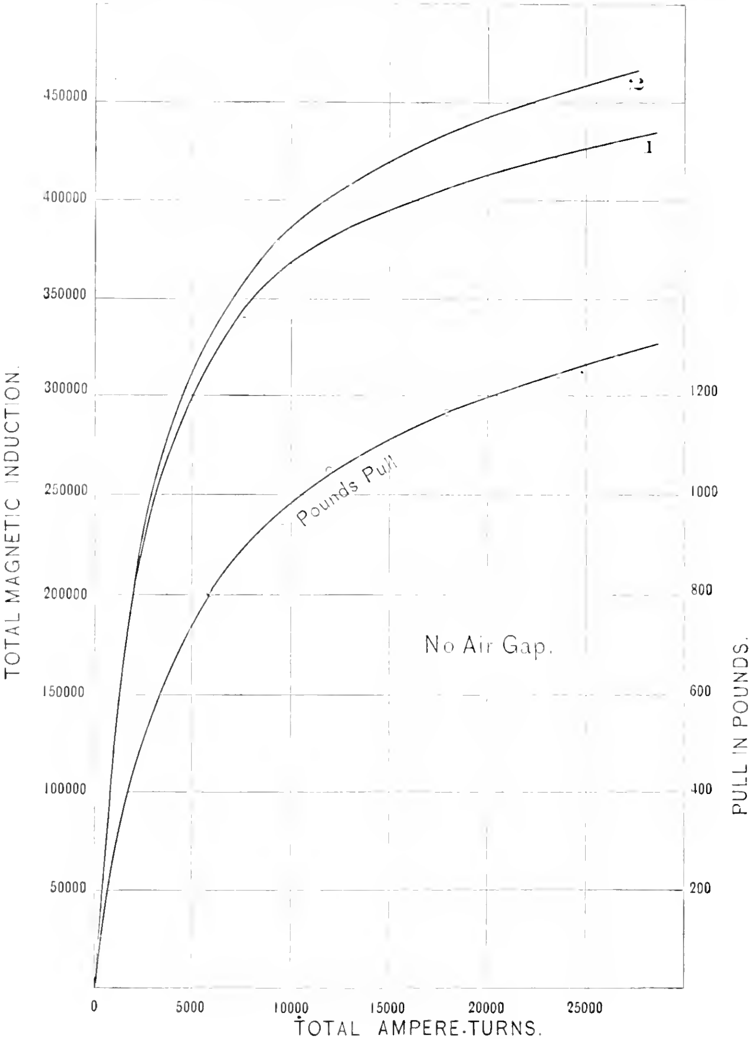


FIG. 4.

rapidly as the density of the iron is forced up, and for the higher magnetizing forces running off in a straight line again.

Curve 2 is higher than curve 1 throughout, as is to be expected, for the leakage is not sufficient to increase the induction through 1 at the expense of 2.

The curve of ampere-turns and pull resembles somewhat the saturation curves 1 and 2, but the bend is more exaggerated and occurs earlier. This is due to the fact that the curve of pull represents a function of $\mathbf{B}^2_{\prime\prime}$ and hence of N^2. As the length of the air gap increases and the ratio, $\frac{\text{Air Reluctance}}{\text{Iron Reluctance}}$ becomes greater, the curves 1, 2, and 3 all become straight lines. And because pull varies as a function ($\mathbf{B}^2$) we shall find that the curve of pull becomes a hyperbola.

It will be noticed that the maximum pull obtained was 1 270 pounds with a magnetizing force of 27 300 ampere-turns, while to get half that pull the ampere-turns needed were 3 700, or only about $\frac{1}{8}$ of 28 000.

It might be added incidentally that commercial considerations would suggest that the cores be worked at a point below the bend.

The density of lines ($\mathbf{B}_{\prime\prime}$) in the core calculated by the formula

$$\mathbf{B}_{\prime\prime} = \frac{N - (A_{\prime} - A)\,\mathbf{H}}{A}$$

runs up to about 134 000 lines per square inch, showing that the core is saturated, even deducting a liberal percentage of leakage.

Fig. 5: $\frac{1}{8}$-inch Gap.

With an air gap now in the circuit we have a true saturation curve no longer, because the effect of both the air and the iron reluctances are combined. The total reluctance of the circuit is now

$$\frac{l_1}{A_1\,\mu_1} + \frac{2l_2}{A_2\,\mu_2}$$

in which the first fraction is the iron reluctance, l_1 = mean length of iron circuit, A_1 = average area of iron circuit, and μ_1 = the permeability; $\mu_1 \propto \frac{1}{\text{density}}$ and the second fraction is the air reluctance ($2l_2$ = length of two air gaps; A_2 = area; $\mu_2 = 1$).

As the length of the gap increases, for the same densities, the effect of the first fraction will be less and less and finally become nil at air gaps of about 4 inches, but as we shall see, the relative positions of curves 1, 2 and 3 for the different air gaps depend on varying amounts of leakage.

$\frac{\text{Total lines}}{\text{Useful lines}}$ = coefficient of leakage, and this cannot be constant in a given magnetic circuit because the amount of leakage depends on the relative permeance $\frac{1}{\text{reluctance}}$ of the path through the iron and the stray paths outside. The permeability of the air being constant at 1, and μ for the iron varying inversely as the density, we should expect to find greater leakage with higher excitation. Again, for a given air gap, when the density is low the iron reluctance is small compared to the air reluctance (constant,)

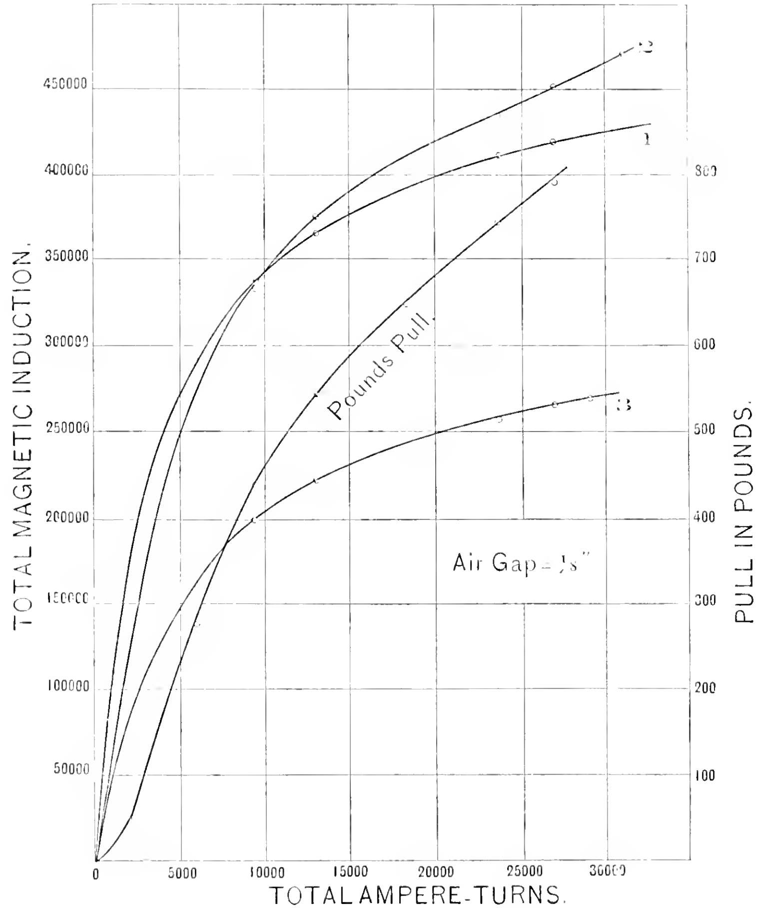


Fig. 5.

therefore the "neutral line," or place of maximum magnetization, will move away from the air gap toward the yoke. For high densities the iron reluctance is considerable, and the ratio between the air and iron reluctances is therefore less, and the neutral line will shift backward toward the air gap. A high density in the iron then has the same effect as an additional air gap.

Applying these principles to the discussion of the plots we see that for $\frac{1}{8}$-inch gap, curve 1 is higher than curve 2 at low densities, but that the two curves cross at about N = 325 000 after which point 2 is higher. The reason is plain. With low magnetizing forces, as we have seen, the neutral line has shifted upwards towards

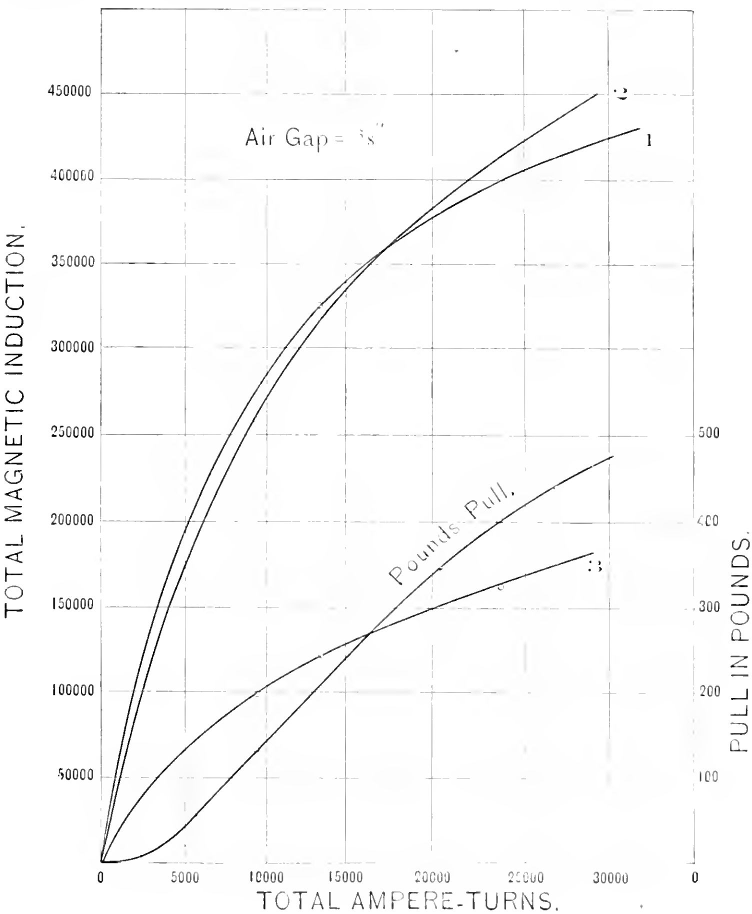


Fig. 6.

the yoke. Coil 2 therefore will not catch all of the lines induced by the spool, for the position of coil 2 is fixed. Had the coil No. 2, however, been moved up on the spool till the neutral line was reached, it would have included more lines than coil No. 1. At high densities, on the contrary, the iron reluctance bearing a greater relative proportion to the air reluctance than at low densities, the neutral line moves back again toward the air gap. This latter fact accounts for coil No. 2 becoming higher than No. 1 at 8 500 ampere-turns.

The curve of pull for $\frac{1}{8}$-inch gap is apparently steeper than the

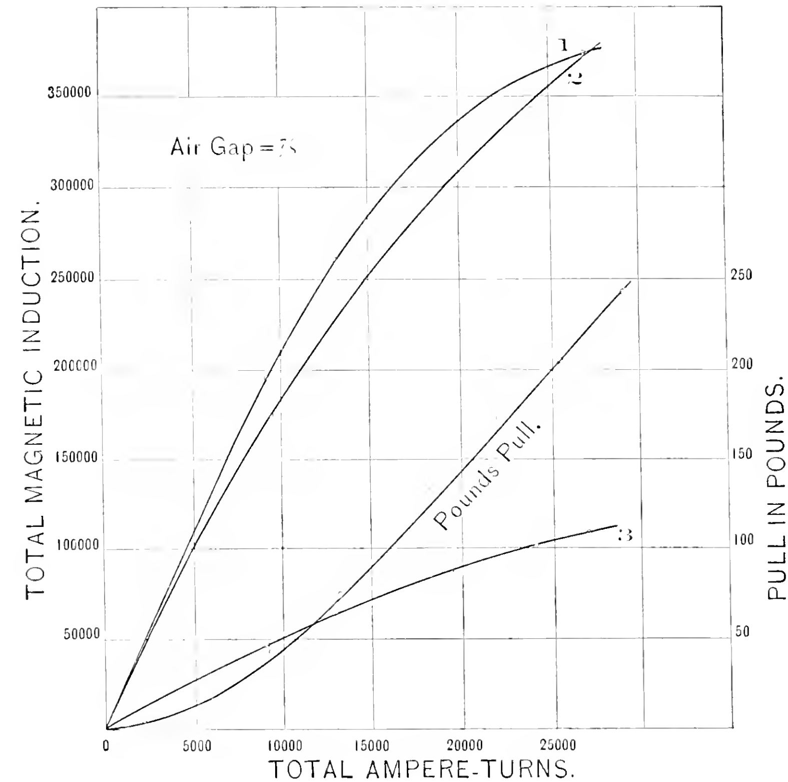


FIG. 7.

same curve for no gap, but in reality it is less steep, because the scale of ordinates has been doubled. A noticeable feature about this curve is the sudden curvature at its commencement, and the later change from convexity to concavity. This is due to the fact, already stated, that the curve of pull, being proportional to $\mathbf{B}^2$, will become a hyperbola when the curves of induction for the same air gap become straight lines. By reference to Fig. 8 for 2⅝-inch air gap this state of things, as will be seen, has been realized.

Fig. 6: ⅜-inch Gap.

There are the same characteristics present in this set of curves, as for the preceding. We note in addition that the crossing point in curves 1 and 2 is higher up the curves, and that the slope of all the curves is decreasing.

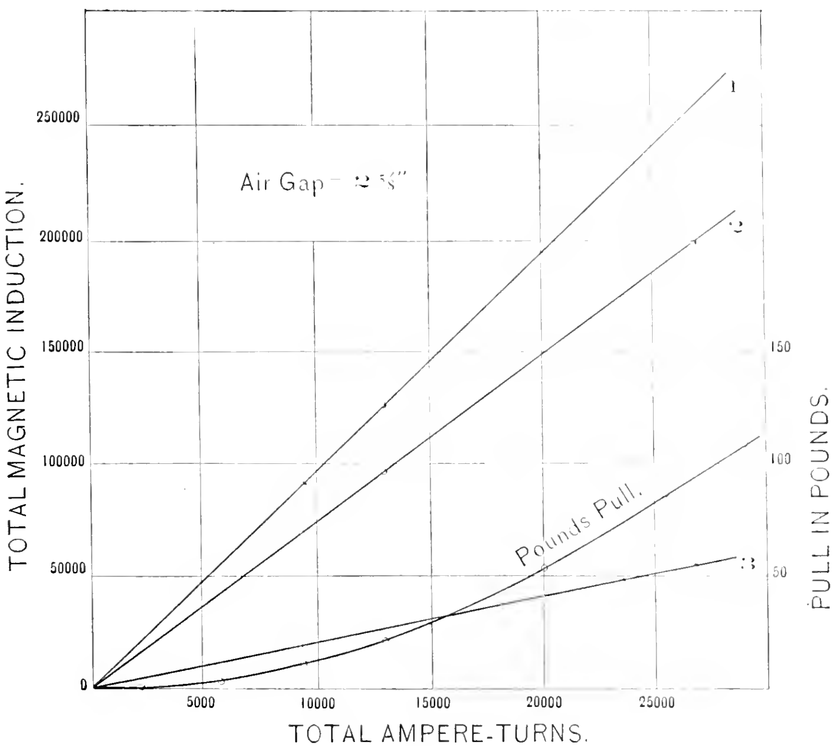


FIG. 8.

The curves for ½-inch, ⅝-inch and ¾-inch air gap, if plotted, will show the general tendencies remarked above, but to an increasing degree.

Fig. 7: ⅞-inch Gap.

Here for the first time curve 1 is higher than 2 throughout its entire length. The iron reluctance, even for the higher densities, is small compared with the air reluctance, so that the neutral line has shifted upwards and has remained practically at the top of the spool. The leakage of magnetic lines has also increased, so that the coil No. 2 has less induction through it than has No. 1.

Fig. 8; 2⅝-inch Gap.

Curves 1, 2 and 3 are now straight lines, the effect of the iron being almost nil. The leakage around coil 3 has been increasing the while, and the smaller inductions through all three coils cause them to rake over more and more.

Fig. 9; 5-inch Gap.

This was the last and longest gap used in the experiments, and the movable cores are now within an inch of the top of the spool.

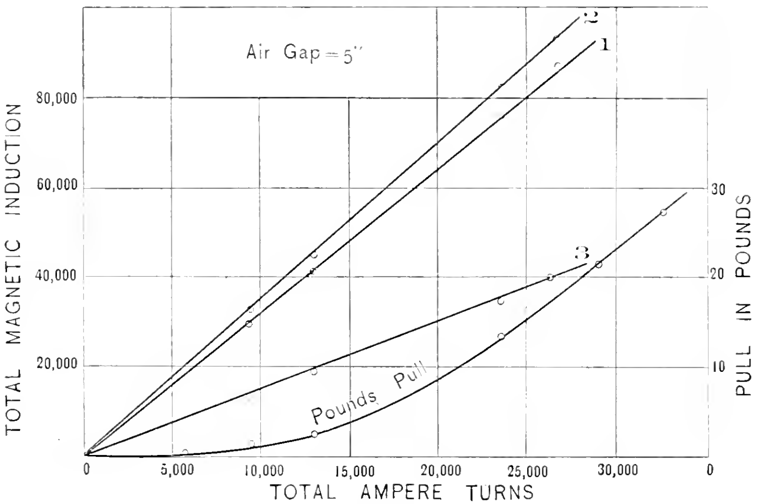


FIG. 9.

The most interesting feature of this plot is the relative position of curves 1 and 2. With a 4-inch air gap, No. 1 was higher than No. 2, but here the situation is reversed. Somewhere between 4 inches and 5 inches the curves crossed. The effect of a 5-inch gap is similar to the effect that would be produced had the movable cores been entirely withdrawn and removed. In this case some of the lines would have passed through coil 2, and bending around would have returned to the fixed yoke, thus completing a closed circuit. So with a gap 5 inches long, more lines will pass through coil 2 than through coil 1, for the leakage between coil 2 and the upper yoke is almost as great as though no iron were present. In short, the pres-

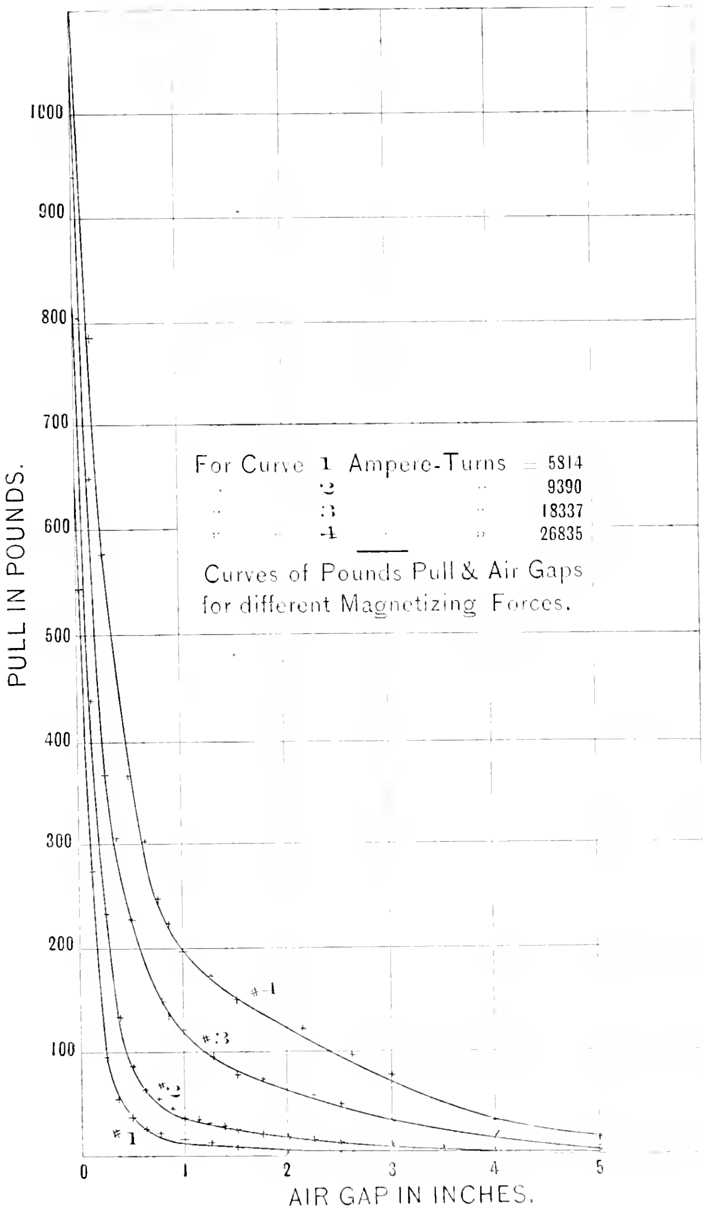

For Curve 1 Ampere-Turns = 5814
" 2 " 9390
" 3 " 18337
" 4 " 26835
Curves of Pounds Pull & Air Gaps
for different Magnetizing Forces.
PULL IN POUNDS.
1000
900
800
700
600
500
400
300
200
100
0
1
2
3
4
5
AIR GAP IN INCHES.
#1
#2
#3
#4

FIG. 10.

ence of the iron armature and yoke does not appreciably lessen the spreading of the lines after passing through the spool coil.

Fig. 10; Curves of Gaps and Pulls.

These four curves show the effect on the attractive force of varying the air gap, the magnetizing current being kept constant at .65, 1.05, 2.05, and 3.00 amperes for curves 1, 2, 3, and 4, respectively.

The general form of these curves suggests the rectangular hyperbola. If they were genuine hyperbolæ, they would be asymptotic to the axes, which would mean that for an infinite air gap the pull would be zero, and also that for zero air gap the pull would be infinite. As a matter of fact the curves intersect both axes with finite intercepts. The intercept on the axis of air gaps is limited by the sensitiveness of the balance used to measure the pull, while the other intercept depends on the contact between core and pole-piece.

In the foregoing discussion it has been assumed that the air gap was zero when the surfaces were in contact, but of course this is not strictly true. The conditions under which with zero air gap the pull will be infinite are given below. In the general formula

$$\text{Magnetic flux} = \frac{\text{Magneto-motive Force}}{\text{Reluctance}}$$

we may have an infinite pull (since Pull $\propto \mathbf{B}^2 \propto N^2$) when 1. Magnetic flux $= \infty$. 2. Magnetomotive Force $= \infty$. 3. Reluctance $= 0$.

since reluctance $= \frac{l_1}{A_1 \mu_1} + \frac{2l_2}{A_2 \mu_2}$, to reduce it to zero, one of the three conditions following must be fulfilled: 1. l_1 and $l_2 = 0$. 2. A_1 and $A_2 = \infty$. 3. μ_1 and $\mu_2 = \infty$. Should any one of the last three cases be true, we would have $\rho = 0$ in $N = \frac{M}{\rho}$; therefore N would $= \infty$, hence $\mathbf{B}^2$ and hence Pull would be infinite.

It might be added that the tendency of higher degrees of magnetization is to flatten out the curves.

Fig. 11; Curves of Pull and Density in Air Gap.

Here the pull in pounds is plotted as a function of the density in the air gap. The full line curves are first plotted from the data sheets on $\frac{1}{8}$-inch, $\frac{1}{4}$-inch, $\frac{3}{8}$-inch, $\frac{1}{2}$-inch, $\frac{3}{4}$-inch, and $2\frac{1}{8}$-inch air gaps.

As is to be expected, the full line curves are discontinuous because the sideways leakage from the pole pieces is increasing with every increase of air gap. The induction through the air gap coil (No. 3) then is decreasing and hence, also the density.

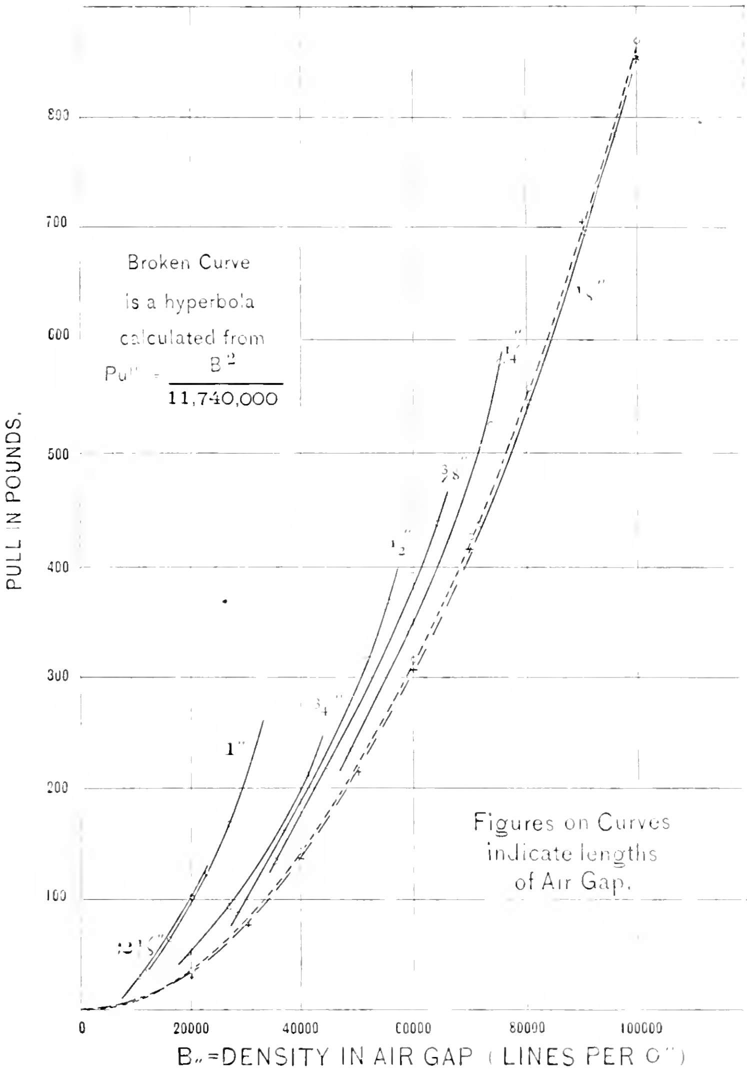


FIG. 11.

The dotted curve lies to the right of the full curves for this reason, that on account of the leakage referred to above, we are getting a certain pull with a less density apparently than is actually the case, and this discrepancy becomes more marked for the lower full curves (with larger air gaps) than for the upper.

The equation to the hyperbola represented by the broken line curve in Fig. 11 is Pull $= \frac{B^2_{\prime\prime}}{11\,740\,000}$, which is evidently a rectangular hyperbola whose equation is $y = Kx^2$. The points for the hyperbola are obtained by taking the densities of the points along the curve of $\frac{1}{8}$-inch gap, squaring them and dividing the result by the corresponding value of the pull, using the mean of these ratios to obtain the points for the lower portion of the broken curve. For example, at $B_{\prime\prime} = 96\,000$, the pull = 785 pounds. Since the equation to the curve is Pounds = K B^2, we have $\frac{(96\,000)^2}{785} = 11\,740\,000 = \frac{1}{K}$

Similarly at $B = 85\,000$, the pull = 615.

$$\therefore \frac{1}{K} = 11\,740\,000.$$

and again at $B = 80\,000$, the pull = 545, and $\frac{1}{K} = 11\,740\,000$ as before. The value of the constant $\frac{1}{K}$ is thus found for different points along the curve of $\frac{1}{8}$-inch gap, and the mean value taken.

It is of interest to compare the two hyperbolæ; the one represented by a broken line having, as stated above, the equation $P = \frac{B^2_{\prime\prime}}{11\,740\,000}$; while the other, represented by the dotted line, is plotted from the equation $P = \frac{B^2_{\prime\prime}\ A\ \text{inches}}{72\,134\,000} = \frac{B^2_{\prime\prime}}{11\,482\,000}$ (since A = 6.284 square inches).

DATA FOR HYPERBOLÆ.

$B_{\prime\prime}$ for air gap.	$B^2_{\prime\prime}$	$P = \frac{B^2}{11\,740\,000}$	$P = \frac{B^2}{11\,482\,000}$
100 000	100×10^8	852.	871.
90 000	81×10^8	690.	705.4
80 000	64×10^8	545.	557.4
70 000	49×10^8	417.	426.8
60 000	36×10^8	307.	313.5
50 000	25×10^8	213.	218.0
40 000	16×10^8	136.	139.4
30 000	9×10^8	76.7	78.4
20 000	4×10^8	34.1	34.8
10 000	1×10^8	8.52	8.71
0	0	0	0

The dotted curve then, as will readily be seen, is the theoretical curve of the pull in pounds for different densities, being in fact, plotted from Maxwell's formula given at the beginning of this article. It will be noticed how closely the theoretical and the experimental curves agree for small air gaps of $\frac{1}{8}$-inch and under; for longer gaps, as already pointed out, the agreement becomes less and less close on account of the increased leakage, of which the air gap coil per se takes no account.

If then it is desired to know what densities will be required to produce a given pull at different air gaps, say up to 1 inch, we may

apply the formula Pull$=\dfrac{B^2}{11\,740\,000}$,

thence the density $= B_{''} = 3\,426\sqrt{\text{Pull}}$.

In Fig. 12 a curve showing the relation between length of air gap in inches, and corresponding coefficients of leakage, is plotted.

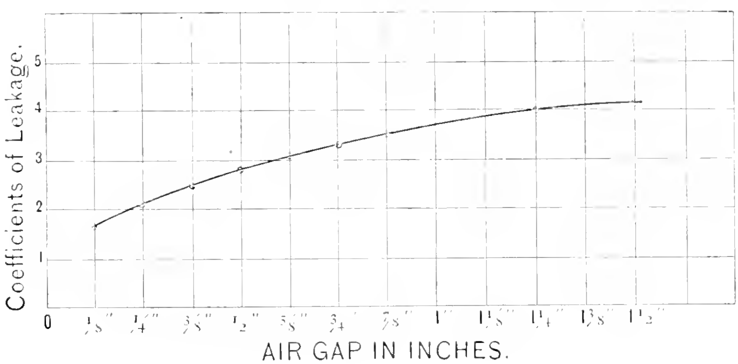


Fig. 12.

The coefficients of leakage were obtained by taking the mean of the values $\dfrac{\text{N in spool}}{\text{N in air gap}}$ for four or more magnetizing forces. This ratio is in reality too large to represent the true value of v for the leakage of lines from the core in the observed values of N in the air gap.

As already stated, the normal minimum air gap used with this brake magnet in practice is $\frac{3}{8}$ inch, for which from the curve the coefficient of leakage is 2.5. In order to compare this experimental value of v with the theoretical value, the writer has calculated the leakage coefficient for several cases by S. P. Thompson's method as given on page 177 of the "Electromagnet."

Coefficient of leakage = v =

$$\frac{\text{total magnetic flux in magnet core}}{\text{useful magnetic flux through armature}},$$

but these fluxes are proportional to their respective permeances, (permeance is the reciprocal of reluctance). If u = permeance of useful paths through armature, gaps, yokes, etc., and w=permeance of waste leakage paths, then we may write $v = \frac{u+w}{u}$.

The value of u is easily found for a given case, but it is w that gives difficulty. However, S. P. Thompson has greatly simplified the task and has given values of w per unit length of parallel cylinders for different ratios of $\frac{b}{p} = \frac{\text{least distance apart of cylinders}}{\text{perimeter of 1 cylinder}}$.

To apply the method to the case in hand we have $b = 6\frac{3}{8}$ inches, $p = \pi 2$ inches $= 6.28$ inches

$$\frac{b}{p} = \frac{6.375}{6.283} = 1.01.$$

Table XIV. for $\frac{b}{p} = 1$, reluctance per inch length of cylinder = 0.2003 and permeance = 4.777. But length of parallel cores = $6\frac{1}{4}$ inches, hence reluctance becomes $\frac{.2003}{6.25} = .032$; and permeance = 29.856. This last value should be divided by 2 as the average difference of magnetic potential over the leakage surface is only about half that at the ends of the poles. The true value of w then = 14.9. The value of u is found by estimating the reluctances of the several parts of the magnetic circuit, taking the reciprocal of their sum. The total permeance of the useful paths thus calculated is u = 12.4.

The calculated value of $v = \frac{u+w}{u} = \frac{12.4+14.93}{12.4} = \frac{27.33}{12.4} = 2.2$, which is in fair agreement with the experimental value, viz., 2.5. It should be added that the value of v calculated as above is only approximate, for the method assumes that leakage occurs in but one plane, while in reality leakage takes place out of the plane considered. This method then makes v smaller than is actually the case.

The foregoing results, though directly relating to a special type of electro-magnet may nevertheless be applied to the design of different sizes of magnets having the same general form as the one described, provided the iron used gives approximately the same saturation curve and that the ratio of $\frac{b}{p}$ is 1 or thereabouts.

As to the relative length of the movable and fixed cores it might be thought that the results would depend on their ratio, but a number of experiments were made expressly to determine this point and it was found that even for the case where the fixed cores were equal in length to the movable cores, virtually the same results were obtained.

If by the aid of the data given herewith the design of a new magnet can be more successfully predetermined and rendered less a matter of trial and guess work, than before, the object of the writer will have been attained.

WASHINGTON FIR.

BY G. W. BULLARD '82.

An architect is to some extent an educator and a pioneer. At times his better judgment leads him to specify a new article in his work, though it requires some courage to do so. Changes from materials long used to those that are new and unknown to a community, are not made suddenly. The dealers are slow to invest in a stock of materials not specified by the architects and that are unknown to the consumer. To help bring about such a change, it is necessary to convince those most interested that the character and quality of the new material are all that is desired.

When the writer came from Illinois to the new State of Washington nearly five years ago, the use of Washington fir as a building material in the Mississippi valley was practically unknown. The lumber commonly used in that locality was, and is still, largely of white and yellow pine. So scarce has clear white pine become that it is no longer an inexpensive finishing wood, and as a result, hard woods are now used in finishing the best buildings. Yellow pine is unsatisfactory as a finishing lumber, consequently there is now a much felt want prevailing for an inexpensive framing and finishing lumber in the middle western states.

Knowing the superior quality of Washington fir, the writer prepared the drawings and specifications for the new Engineering Hall to have it used in the construction of the building. Government tests have shown this wood to have a strength greater than oak, and more than twice the strength of white pine. For this reason it is not only the best wood that can be used for heavy floor beams, but is, approximately, as inexpensive as any other wood. While the lumber costs more on the building site than white pine, the fir beams were specified one-fourth less in size than if white pine had been used. The beams of the latter wood would have to be built up of two-inch joists spiked together, which would add considerable expense for labor, while the fir beams are put in of solid pieces, thus saving an item of material and labor that made the cost no greater than that of white pine, and secured a stronger and better building. It may be of interest to the reader to know that the splendid timbers in the floors of this building were furnished with four sides surfaced, at the low price of eight dollars per thousand feet at the mill, and yet the writer knows this was not the lowest bid for furnishing the material. The contractors preferred to secure the lumber from a Tacoma mill, so the architect could inspect it before shipping. It is but justice to say that the above price is less than the same material can be bought for in this city or state. To furnish lumber for a state building in Illinois was an opportunity that Washington lumbermen never before had, and the competition was very close, and the bids low in price.

There are but few architects in the middle west who know that choice strictly clear Washington fir lumber can be put on the market at Chicago and St. Louis at prices lower than clear eastern white pine; that it makes a finishing wood as firm and durable, and almost as rich in grain and color as oak; that it can be worked almost as easily as white pine. As a finishing lumber for residences, office and business buildings, it is practically equal to oak and other hard woods. It is far superior to yellow pine and receives a natural finish equal to any wood.

It was a great pleasure to the writer to plan a building for the Engineering College of the University in which he was educated. It was also a pleasure to use so excellent and noble a wood in its construction as the Washington fir. By using it in this building a pioneer and educational work has been started that will lead to its use in many buildings in Illinois and adjoining states. It is the writer's desire that the young men who study architecture or engineering in this building may have a practical knowledge of the excellent qualities of this wood from a personal observation of its use in comparison with other woods. This wood will fill a much felt need in that locality, and will be much used as a building material as soon as the dealers and the consumers learn to know its price and quality, but it remains largely with the architects and the engineers to bring the people to a knowledge of it.

Much might be said further pertaining to this wood, but I will only add that this wood is used for deck floors on the United States war ships on the Pacific Coast, and is being used by a number of the leading eastern railroads as a framing timber. It is also used largely by fire apparatus manufacturers for making ladders. Besides the many car-loads shipped to the eastern part of the Union, there are ships being loaded at this port with lumber for not only all Pacific Coast ports, but for Australia, New South Wales, China, Japan, South Africa and other distant lands.

THE PROXIMATE ANALYSIS OF COAL.

BY S. W. PARR, PROFESSOR OF APPLIED CHEMISTRY.

For the purposes of the engineer, especially in boiler tests and relative work, it is necessary to have the data to be obtained by a Proximate Analysis of the coal and ashes. This includes the determination of moisture, volatile products, fixed carbon or coke, and the ash.

According to the standard methods, the following, in brief, is the outline of procedure: For the moisture, the finely ground sample is dried for one hour in an air bath at 105° to 110° C. For the other constituent, a fresh sample is taken, about a gramme in quantity, and in a platinum crucible with the cover on, heated for 3½ minutes over a Bunsen burner and followed immediately with the highest temperature of the blast lamp for an equal length of time. The loss in weight, less the moisture obtained, equals the volatile combustible matter. The fixed carbon is next burned off by removing the crucible cover and heating in the flames of a Bunsen burner with access of air, till all the carbon is burned off. The loss of weight equals the carbon; the residue is ash.

Owing to the cost of platinum and its rapid deterioration under the conditions imposed, as well as the impossibility of supplying platinum crucibles for extended class work, it became necessary to

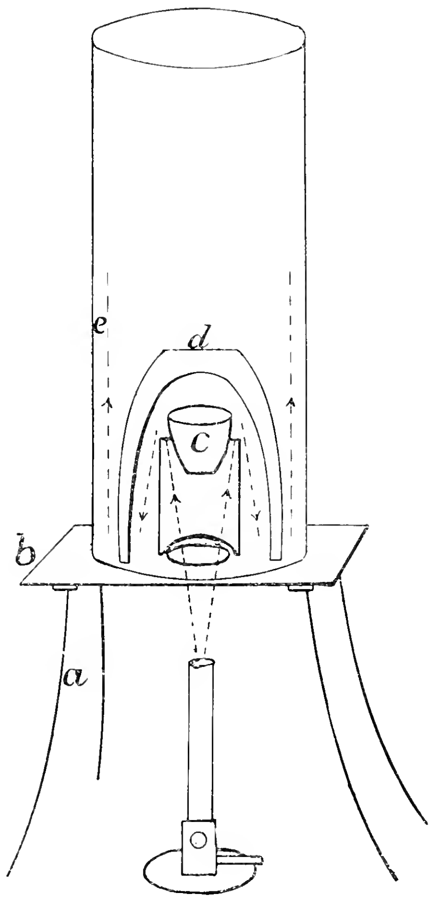


Fig. 1.

devise some substitute if possible and make such modifications as would produce concordant results which conform to those obtainable by the regular method. It was thought that satisfactory results would be obtained with the ordinary porcelain crucibles, provided a sufficiently high temperature, corresponding to that obtained with the blast lamp and platinum crucible, could be reached.

To this end, the principles of the Hempel furnace shown in Fig. 1 were adopted as follows: (*a*) is an ordinary iron stand or tripod and resting upon it is the plate (*b*) about 10 or 11 American gage in thickness with a $1\frac{1}{2}$-inch hole in the center. Over this hole is placed a sheet iron or fire-clay cylinder or tube having three bearings at the upper edge upon which may rest the porcelain crucible (*c*). Over this is inverted an ordinary assayer's crucible (*d*) of such size and shape inside as shall allow of free circulation of the hot gases and having sections cut away at the edge, so as to allow the escape of the gases, thus giving the inverted crucible three short legs on which to stand. Over all is placed the sheet iron pipe (*e*) about 18 inches in height and about 4 inches in diameter, depending somewhat on the size of the crucible (*d*). The effect of this arrangement, as may readily be seen from the cut, is to compel the flame and hot gases from the Bunsen lamp to return upon themselves and so heat the walls and surrounding parts as to prevent radiation away from, but rather direct it towards crucible (*c*). The effect further of the chimney (*e*) is to make a draft and secure a good circulation, this making it easy with proper burner and gas supply to raise the crucible and contents to a heat quite equal to that obtained by the use of platinum and the blast. It should be noted, however, that much depends upon the character of the Bunsen flame. A tripple burner giving flames that would reach to a height equal, say to that of the top of the crucible (*c*), proves perhaps the most satisfactory. With proper adjustment of such a burner it is easy to secure a white heat and this should be accomplished if the results are to be trustworthy. In any event it is well to put the whole apparatus near the edge of the desk so the crucible can be viewed from beneath, and the flames regulated to suit the case. Two necessary variations from the standard method are at once obvious, first the time element and second the reducing, rather than oxidizing atmosphere, for that part of the operation which burns off finally the fixed carbon.

For the first modification it was at first supposed that about double the usual time would produce the same distilling effect as the customary 7 minutes with this platinum crucible, but that time gives results somewhat low unless the parts of the furnace are well heated up before the crucible with the coal is inserted. Repeated experiments in which time of heating was exactly 15 minutes were made and checked by parallel determinations in platinum in the ordinary way with quite satisfactory results as indicated below. It should be noted especially, however, that the arrangement was such as to easily and readily give to the crucible a white or very bright red heat.

The second modification is necessary in burning off the fixed carbon. Here the use of the furnace is impossible because an oxidizing atmosphere is essential. The complete Hempel arrangement of parts provides for the conducting into the crucible of a current of superheated air and it was thought possible to effect the combustion by this means. A more satisfactory way, however, is to remove the outer parts and conduct directly into the crucible a slow current of oxygen from a glass tube of two or three centimeters internal diameter or sufficently large to avoid a jet of gas, the purpose being to avoid carrying away any light particles of ash.

The gas should pass through an ordinary wash bottle so that its flow may be easily watched and regulated. This method of burning off the coke proves far more expeditious and satisfactory than the customary one of heating the platinum crucible in a current of air. Of course a good flame should strike the crucible, keeping it at a good red heat while the oxygen is being conducted into it, otherwise the process will be a long one. Occasional stirring may expedite matters, but care must be taken to avoid loss. Below are given some results obtained with comparisons by the standard method.

The column marked A gives percentages obtained by the usual method with platinum crucible and the blast lamp. Column B gives the results as obtained by the methods above described:

Coals.	*Volatile Matter.*		*Fixed Carbon.*		*Ash.*	
	A	B	A	B	A	B
DuQuoin	42.06	42.88	44.60	43.72	13.34	13.40
Odin Lump . . .	45.38	44.42	42.31	43.30	12.31	12.28
Moweaqua Lump . .	44.17	44.41	42.01	41.62	13.74	13.97
Niantic Nut . . .	38.66	38.62	40.55	40.18	20.79	21.20
Odin Ash*	15.27	16.52	....	....	....	....
DuQuoin Ash . . .	7.77	7.06	....	....	....	....
Moweaqua Ash . . .	8.36	8.29	....	....	....	....
Odin Ash	14.69	15.01	....	....	....	....
Niantic Ash	8.67	7.85	....	....	....	....

*Taken from the furnace of a boiler that was being tested.

NOTES ON CEMENT LABORATORY WORK.

By I. O. Baker, Professor of Civil Engineering.

It is thought the following notes on the work in the Cement Laboratory will be of some interest to students as a record of their work, to instructors as information concerning the methods employed in instruction, and to practical engineers as showing the degree of accuracy attained. The work was done without the remotest thought of its being made public. Owing to the temporary condition, the work was done under serious disadvantage, which is sufficient reason for not publishing the results and at the same time is the excuse for so doing. In the new Engineering Hall just completed are two commodious rooms which are fitted up as cement and masonry laboratories, and the University of Illinois now offers most excellent facilities for this class of work. It is to advance this work that this article is written.

In this as in all technical work the proper ideal is to give the student just enough practice to fix clearly in his mind principles and methods. It is not expected that he shall become an expert in mere manual manipulation, that comes only after long experience and can be maintained only by continued practice. This principle should not be forgotten in judging of either the absolute value or the uniformity of the following results. They are valuable only as showing what can be done under the particular conditions.

The work in the cement laboratory is a part of the instruction in masonry construction, each student giving each week five periods of one hour each to the recitation room work and one period of two hours to the laboratory work. The major part of the laboratory work is given to testing cement. A few days preceding the laboratory work, the student is given a sheet containing the instructions for the particular problem; and after performing the work, a written report is submitted to the instructor. Owing to the crowded condition of the laboratory two students work together, but each submits his own report. The following pages contain a copy of the instructions for each exercise and also a summary of the several reports. There were twenty in the class, but all the work of one pair of students has been misplaced, and owing to the peculiarities of the details of the program, all of the students did not have all of the problems here reported. The cement was bought on the market, and except the Portland had then been in the laboratory a year.

Problem I.

Test Fineness of Cement.

1. Weigh out 100 grammes of Portland cement. If there are any lumps in it, crush them with the fingers or a trowel. Then pass the cement through the No. 50, No 80, and No. 100 sieves, and weigh the portion left on each, and also that passing the last.

Repeat the preceding operation for three other brands of cement.

2. Tabulate the results so as to show the per cent. retained by each sieve, and also the error of the experiments.

The scales used nominally weighed to tenths of grammes, but really only about to fifths. The students did not all use the same sieves, and those of like numbers were not exactly of the same mesh. The sieves were used separately and not in an enclosed nest. The results are given in Table I., page 114.

Problem II.

Weight of Cement.

1. Determine the weight per cubic foot of four samples of cement, by sifting each into a standard measuring box.

2. Compute the weight per bushel of each cement, and tabulate the weights per cubic foot and per bushel.

The cement was shaken through a No. 20 sieve into an enclosed tube at the bottom of which was a cubical box having a capacity of approximately one tenth of a cubic foot. Each student measured the box for himself. The results are given in Table II., page 115. It will be noticed that the results are somewhat divergent, which is partially accounted for by the fact that the apparatus was not fastened to the floor and that in shaking the cement through the sieve the cement in the measuring box may have been jarred and thus have been shaken down.

Problem III.

Per Cent. of Water for Neat Cement Mortar.

1. Determine by experiment the proper per cent. of water to be used in mixing neat cement mortar for experimental purposes. Weigh out, say, 200 grammes of cement, and add the estimated amount of water (see foot note on page 58 of Baker's Masonry Construction and also the first paragraph of section 95). Work the mortar thoroughly and vigorously with a

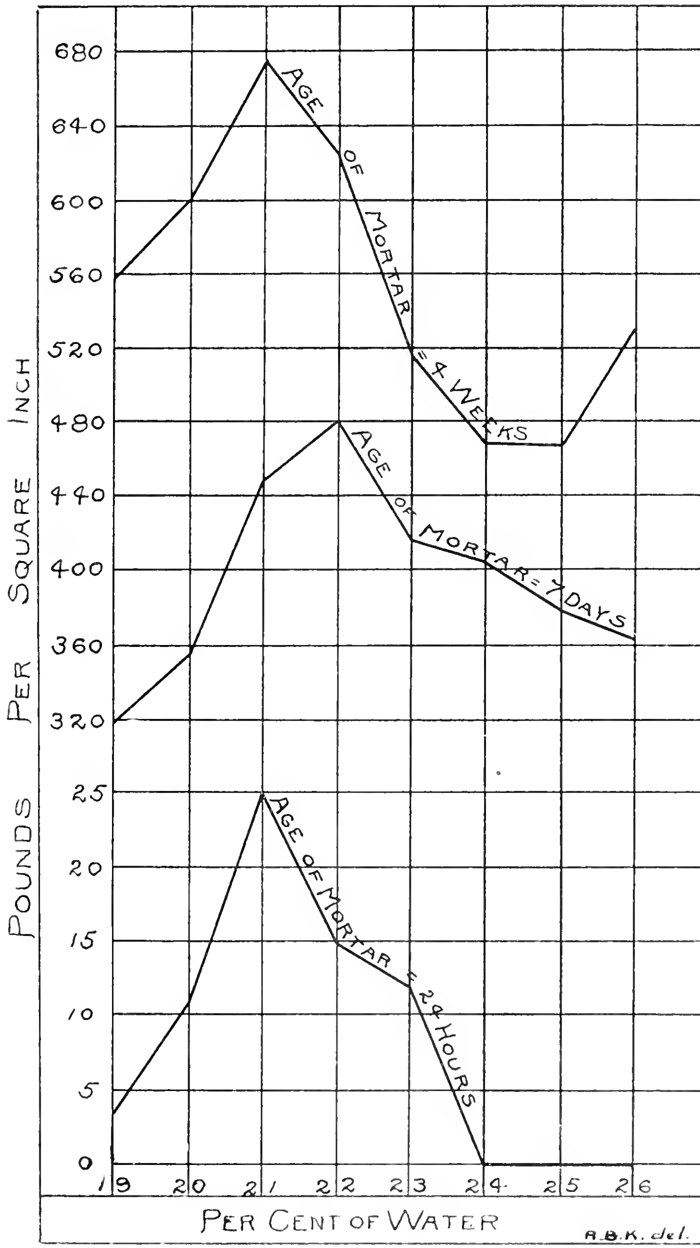


FIG. 1.

TENSILE STRENGTH OF NEAT PORTLAND CEMENT Mortar with Various per cents. of Water trowel on a slate table for three to five minutes. The inexperienced operator is very likely to use too much water and too little work.

To determine whether the mortar is of proper consistency, apply the four tests mentioned in section 99, page 71, of the text book. If the mortar is too dry and has not begun to set, more water may be added, as a fur-

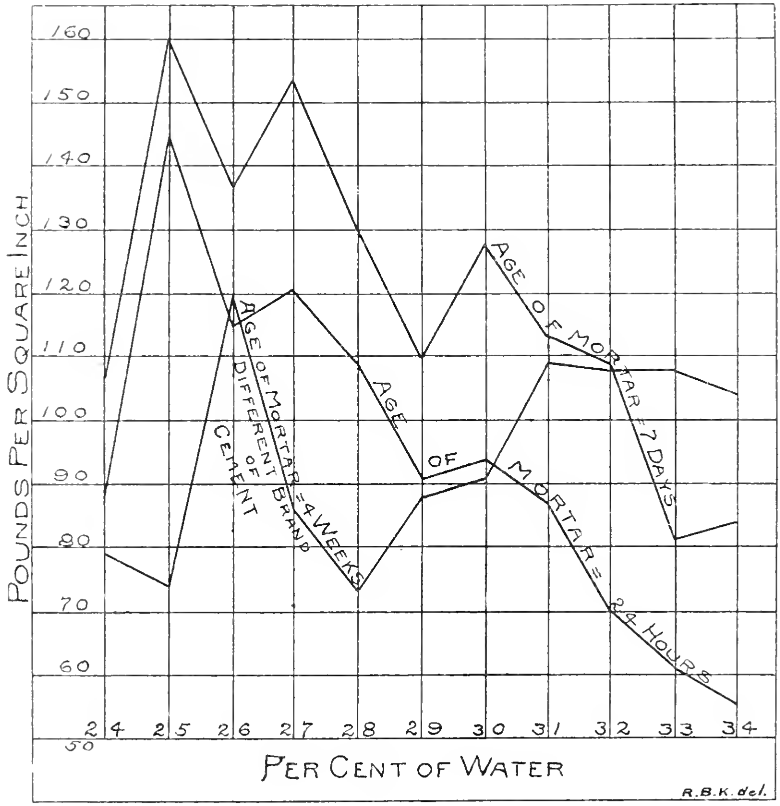


FIG. 2.

TENSILE STRENGTH of NEAT LOUISVILLE CEMENT MORTAR with Various per cents. Water.

ther preliminary test: but for the final test weigh out a new portion of cement.

How definitely can the proper portion of water be determined, *i. e.*, what is the estimated probable error of the experiment?

2. Tabulate the results, and state the estimated probable error.

The results are given in Table III., page 115.

PROBLEM IV.

Soundness of Cement.

1. Make two pats of neat cement mortar, having a diameter of two or three inches, a thickness at the center of about a quarter of an inch, and thin edges. Mold the pats on a sheet of glass. Cover one with a wet cloth.

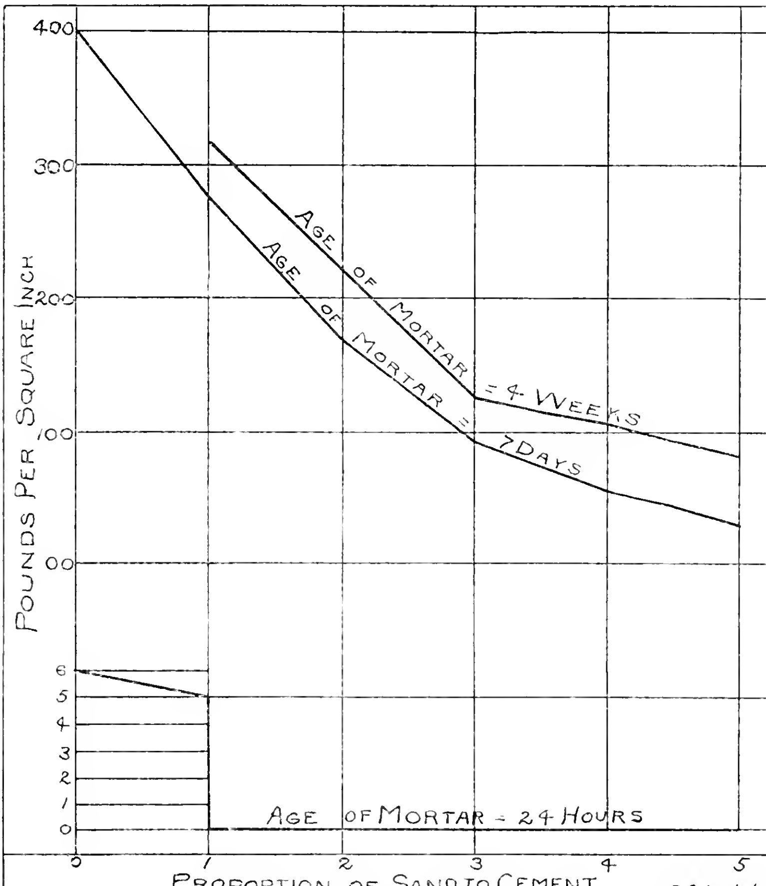


FIG. 3.

TENSILE STRENGTH OF PORTLAND CEMENT Mortar with Various Proportions of Standard Sand.

and allow it to set in the air. When sufficiently set to bear it, place the other cake in water.

2. On returning to the laboratory for succeeding class exercises, carefully examine the pats, and make note of the conclusions to be derived from the experiment.

The results of Problem IV. are not of a nature to permit their tabulation. Apparatus is provided for making hot test for soundness, but the crowded condition of the room then used as a laboratory did not permit an attempt to use it.

Problem V.

Test of Activity of Cement.

1. Weigh out 500 grammes of Louisville cement, mix a mortar of the proper consistency (see Prob. III.) using water of from 65° F. (18.6° C.) to 70° F. (21.1° C.), and noting the temperature of both the air and the water. Note the time of adding the water. Make two pats, one of which shall be upon a sheet of glass; and also fill the metal ring with the mortar by pressing it in with the fingers or the point of the trowel.

Place the pat on glass, in water having a temperature of 65° F. to 70° F., and allow the other to remain in the air. Note the time respectively when the two Gilmore wires are supported.

Note the time when the standard German needle ceases to penetrate the mortar in the ring, and also the time when the needle is just supported.

2. Tabulate the results, and state the time for the Gilmore test, and also for the German test, elapsing from adding the water until the cement began to set, and also until it had "fully set." State the estimated probable error of the several intervals.

The temperature of the room was usually between 60° and 70° and hence no other note is here made of it. The time available for a class exercise was too short to permit the determination of all the data asked for. The results are shown in Table IV., page 116. The paucity of the results was partially due to the crowded condition of the laboratory. The most noticeable thing about the experiments is the wide difference in the results; for example, compare lines 3 and 4 of Table IV. This shows that the test is not very precise.

Probeem VI.

Tensile Strength of Neat Cement Mortar.

1. Mold six neat briquettes of each of four brands of cement. Before beginning see that the molds are clean and well oiled. Note the per cent. of water used and the intervals elapsing from the time of adding the water until the first and last briquettes are molded, respectively. Cover the briquettes with several thicknesses of damp cloth.

After 22 hours the attendant in charge of the laboratory will place the briquettes in water. Break the briquettes when seven days old.

2. Determine the tensile strength with a cement testing machine, using rubber-tipped grips. Note the approximate time of applying the stress. Tabulate the results, and show the strength of each briquette, and the mean for each brand and also its probable error.

The results are given in Table V., page 117.

In conection with the results for Problem VI. it is necessary to remind the reader that the purpose of their publication is to show the variation in the results obtained in any one experiment and also the difference in values obtained by different experimenters. Ordinarily one man filled all the molds, but sometimes each filled part.

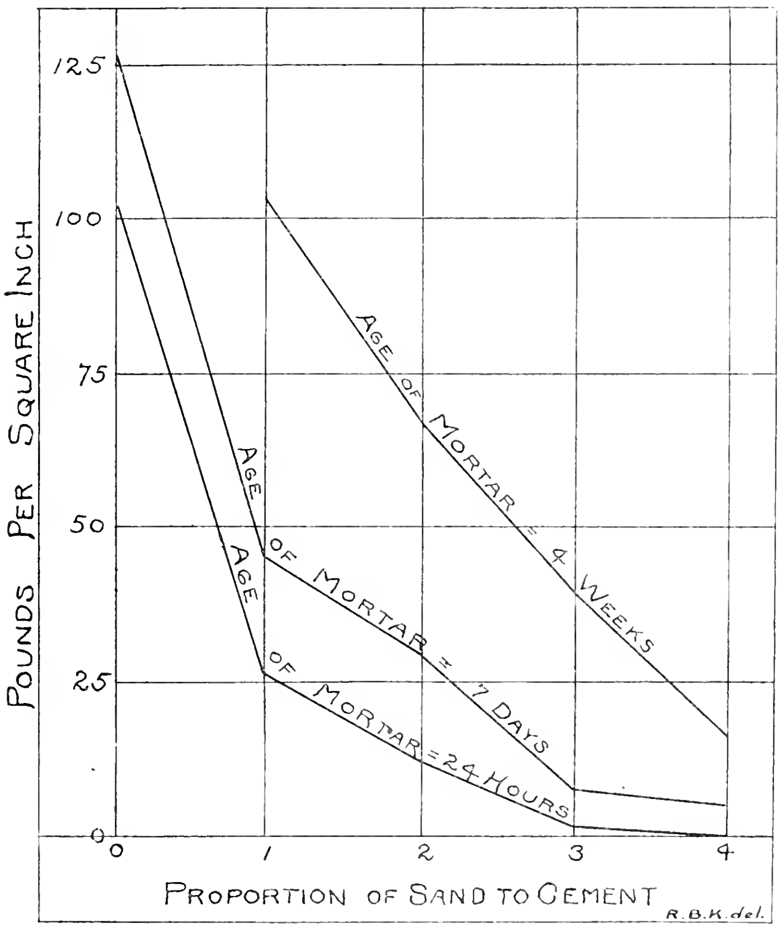


Fig. 4.

Tensile Strength of LOUISVILLE Cement Mortar with Various Proportions of Standard Sand

The probable errors in the last line of the table, are the probable errors of the averages adjoining, and not the averages of the probable errors above.

Problem VII.

Tensile Strength of 1 to 3 Cement Mortar.

1. Use German Portland cement and sifted river sand, and mould five briquettes by hand and five with either Boehme's hammer apparatus* or Russell's lever machine.† Record the temperature of the water and of the air, and the time from adding water (1) until beginning to mould the first briquette, and (2) until the completion of molding the last briquette.

Cover the briquettes with a damp cloth, and when twenty-two hours old the attendant will place them under water.

Break them when seven days old.

2. Report all the facts and show the mean for each method of moulding and also the probable error of each mean. Specially mention any important fact connected with the experiments.

The results for Problem VII. are given in Table VI., page 118. After commencing the experiments it was discovered that the Russell machine needed repairing, and the repairs were not completed in time for many of the students to use this machine.

Problem VIII.

Effect of Fineness of Sand on Tensile Strength of Cement Mortar.

1. Use German Portland cement and make five briquettes with each of the following kinds of sand: (1) German standard crushed quartz, (2) standard river sand, (3) river sand passing a No. 20 sieve and not passing a No. 50, (4) same passing a No. 50 and not a No. 75, (5) same passing a No. 75 and not a No. 100, and (6) same passing a No. 100 sieve. Be sure that the sand is clean.

Record the temperature of the water and of the air, and the time from adding water (1) until beginning to mold the first briquette, and (2) until completing the molding of the last briquette.

Break the briquettes when seven days old.

2. Report all the facts and show the mean for each kind of sand and the probable error of each mean. Specially mention any important fact observed in making the experiments.

The results are shown in Table VII., page 119.

Problem IX.

Effect of Cushions on the Crushing Strength of Stone.

The details of the "instructions" are too long for reproduction here. Different sections of the class tested cubes of stone with different pressing surfaces. The cubes tested each year were all prepared at the same time from the same block of Indiana limestone,

*For an illustrated description, see Engineering News, Vol. XVII., p. 260.

†For an illustrated description, see Trans. Amer. Soc. Civil Engineers.

by sawing and rubbing. The surfaces were perfectly flat. The specimens were nominally 2-inch cubes; but they were carefully measured and the actual dimensions were used in computing the results. All the specimens were crushed between self-adjusting parallel steel surfaces, the "cushion" being placed upon these surfaces. With the wood cushions, apparently the relative direction of the fibers at the top and bottom of the specimen makes no appreciable difference in the strength.

Miscellaneous Problems.

In addition to the preceding problems, which all members of the class have, each student has one or more problems which are somewhat of the nature of original research. Figs. 1, 2, 3 and 4 pages 107, 108, 109, and 111 show the results of some of these problems.

Several observations concerning the experiments suggest themselves, but limitations forbid a further discussion.

Tables referred to in this article are given on following pages.

TABLE I.

Results for Problem I.

Fineness of Hydraulic Cements.

Reference Number.	Students' Initials.	German Portland.					French Portland.					Black Diamond Louisville.					Utica.				
		Per cent. retained by sieve No.			Per cent. passing sieve No. 100	Per cent. of error.	Per cent retained by sieve No.			Per cent. passing sieve No. 100	Per cent. of error.	Per cent. retained by sieve No.			Per cent. passing sieve No. 100	Per cent. of error.	Per cent. retained by sieve No.			Per cent. passing sieve No. 100	Per cent. of error.
		50	80	100			50	80	100			50	80	100			50	80	100		
1	B. & C.	0.1	2.8	6.3	90.0	0.8	0.5	4.5	6.1	86.8	1.2	22.3	11.5	5.9	58.1	2.2	9.5	11.0	8.7	66.0	1.8
2	B. & L.	0.0	2.8	9.6	89.7	0.7	0.2	4.2	8.1	87.5	0.0	21.6	13.1	6.1	63.9	0.1					
3	B. & M	0.0	1.9	5.3	93.0	0.0	0.1	3.8	6.5	89.1	0.2	18.1	10.1	4.5	67.0	0.3	6.5	11.1	6.5	71.5	0.9
4	B. & Q.	0.2	2.1	1.8	91.9	1.0	0.2	1.1	5.9	89.3	0.2	22.1	11.0	3.9	61.9	1.1	6.9	10.7	5.9	71.7	1.8
5	H. & H.	0.0	4.0	9.0	87.0	1.0	0.2	4.8	10.2	83.5	1.3	19.9	11.1	1.7	63.9	0.4	7.0	18.9	21.2	48.8	1.1
6	K. & S.	0.1	2.5	5.0	92.0	0.1	0.1	4.6	3.9	90.7	0.1	19.1	10.8	3.8	66.0	0.3	6.5	11.5	6.5	74.2	1.3
7	S. & S.	0.0	2.2	7.7	91.1	0.9	0.2	3.9	5.9	90.2	0.2	21.7	9.7	5.0	63.0	0.6	6.2	11.3	5.9	75.3	1.4

TABLE II.

RESULTS FOR PROBLEM II.

Weight of Hydraulic Cement in Pounds per Cubic Foot.

Ref. No.	Students' Initials.	German Portland.	French Portland.	Black Diamond Louisville.	Utica.
1	B. & C.	76.3	74.6	59.0	57.9
2	B. & L.	73.0	73.0	58.1	57.5
3	B. & M.	75.5	70.2	58.3	59.1
4	B. & Q.	74.7	70.2	58.4	56.4
5	H. & H.		74.0	59.6	62.7
6	K. & S.	79.9	74.3	63.8	57.7
7	M. & R.	73.0	68.6	57.1	55.1
8	S. & S.	75.4	71.1	59.7	57.7
	Mean,	75.4	72.0	59.2	58.0
10	*Probable error of single result,	2.3	3.1	2.0	2.2

*For an explanation of this term, see Baker's Engineer's Surveying Intruments, page 368.

TABLE III.

RESULTS FOR PROBLEM III.

Per Cent. of Water for Neat Cement Mortar.

Ref. No.	Students' Initials.	German Portland. Per cent. water.	German Portland. Per cent. prob. error.	French Portland. Per cent. water.	French Portland. Per cent. prob. error.	Black Diamond Louisville. Per cent. water.	Black Diamond Louisville. Per cent. prob. error.	Utica. Per cent. water.	Utica. Per cent prob. error.
1	B. & C.	22.5	½		½	33.0	¾		
2	B. & L.	22.5	1	25.0	1	33.5	1		
3	B. & M.	22.0	½	25.0	½	33.0	¾	33.0	¾
4	B. & Q.			27.0	¼	33.5	½		
5	H. & H.	21.5		22.5		33.0		34.0	
6	H. & S.	22.5	¾	25.0	¾	33.0	¾	33.5	¼
7	K. & R.	22.0	½	24.0	½	33.0	½	33.5	½
8	S. & S.	22.0	¼	26.0	¼	33.0	½	33.0	½

TABLE IV.

Results for Problem V.

Activity of Black Diamond Louisville Cement.

Ref. No.	Students' Initials.	Standard German Test.				Gilmore's Test.			
		In Air.		In Water.		In Air.		In Water.	
		Began	Set.	Began	Set.	Began	Set.	Began.	Set.
1	B. & C.	31	43			42	44	43.5	54
2	B. & L.		37					42	55.5
3	B. & M.	25	35			35	45		
4	B. & Q.	35	41			13	16		
5	H. & H.	29	22	39	49				
6	K. & S.	24				28	47		
7	S. & S.	26.5	33			36	48		

TABLE V.

Results for Problem VI.

Tensile Strength of Neat Cement Mortar Seven Days Old.

Ref. No.	Students' Initials.	German Portland. Per cent. water	Strength in lbs. per sq. in.	Prob. error in lbs.	French Portland. Per cent. water.	Strength in lbs. per sq. in.	Prob. error in lbs.	Black Diamond Louisville. Per cent. water.	Strength in lbs. per sq. in.	Prob. error in lbs.	Utica. Per cent. water	Strength in lbs. per sq. in.	Prob. error in lbs.
1	B & C	22	512.0	10.9	25	505.0	9.3	33	40.0	1.2	33	118.0	4.5
2	B & L	22.5	477.0	7.8	25	370.8	7.3	33.5	55.8	1.9		81.2	1.6
3	B & M	22	529.8	11.2	25	439.4	10.7	33	47.0	2.8	33	105.3	2.7
4	B & Q	24	443.5	7.7	22.5	256.8	10.7	33.3	32.8	2.7	33	100.33	8.2
5	H & H	22	536.0	6.5	26	372.5	19.2	33	30.8	4.6	33	68.7	6.4
6	K & S	22.5	464.1	14.0	25	392.5	10.0	33	30.5	1.6	33.5	103.1	2.6
7	M & R	22	475.7	8.6	25	425.0	12.5	33	37.6	1.4	33.5	107.5	3.6
8	S & S	22	398.3	21.5	25.5	463.8	12.3	33	45.0	2.3	33	80.1	3.9
		Average	479.6	*11.3		411.9	*12.5		39.9	*2.2		95.5	*4.0

*Indicates plus or minus.

TABLE VI.

Results for Problem VII.

Effect on Tensile Strength of Different Methods of Molding.

Mortar, 1 part Portland Cement, 3 parts Standard Sand, and 0.4 part of Water.

Ref. No.	Students' Initials.	Hand Molded.		Machine Molded. Bœhme Hammer Apparatus.		Machine Molded. Russell Lever Machine.	
		Strength lbs. per sq. in.	Prob. Error	Strength lbs. per sq. in.	Prob. Error	Strength lbs. per sq. in.	Prob. Error
1	B. & C.	46.0	0.3	127.0	2.4		
2	B. & L.	48.0	17.0	176.0	34.0		
3	B. & M.	62.8	7.6	175.6	1.3		
4	B. & Q.	84.0	0.9	112.0	7.5		
5	H. & H.	54.7	3.7	148.0	3.7		
6	K. & S.	88.0	1.0	169.8	2.7	66.0	1.5
7	M. & R.	76.4	3.2	173.8	9.0		
8	S. & S.	59.8	10.9	186.0	2.5		
9	H. & D.	54.6	6.0			43.8	2.3
	Mean,	63.8	*3.2	158.5	*6.4	54.9	*7.3

*Indicates plus or minus.

TABLE VII.

Results for Problem VIII.

Effect of Fineness of Sand on the Tensile Strength of Neat Cement Mortar.

The table gives the Tensile Strength in Pounds per square inch, and the probable error in Pounds.

Ref No.	Students' initials	German standard crushed quartz.	Prob. error.	Standard river sand.	Prob error.	Sand passing No. 20 sieve and not passing No. 50.	Prob error.	Sand passing No. 50 sieve and not passing No. 75.	Prob error.	Sand passing No. 75 sieve and not passing No. 100.	Prob. error.	Sand passing No. 100 sieve.	Prob error
1	B & C	73.2	1.1	82.6	13.7	70.1	3.2	53.6	0.6	20.0		54.0	
2	B & L	100.6	8.5	97.8	11.2	90.0	8.4	61.4	5.5	42.8	1.1	42.8	0.6
3	B & M	97.8	4.0	93.4	1.9	94.4	1.2	61.8	2.1	32.5	2.0	35.6	1.5
4	B & Q	89.6	1.9	63.6	1.6	36.2	1.2	41.8	1.1	36.8	1.5	41.2	2.6
5	K & S	108.2	8.0	114.8	1.7	63.0	5.4	41.2	4.0	34.0	2.7	32.0	2.0
6	M & R	140.0	1.1	90.5	2.6	96.8	2.8	50.0	1.9	45.0	1.0	20.8	0.6
7	S & S	70.6	3.4	89.5	3.1	88.8	2.2	70.4	2.1	54.8	2.0	41.8	2.0
	Average	81.5	*5.25	90.3	*3.0	77.1	*5.7	54.6	*3.2	39.3	*2.9	35.7	*2.9

*Indicates plus or minus.

TABLE VIII.

Results for Problem IX.

Effect of Cushions on Crushing Strength of Stone.

Ref. No.	Kind of Cushion.	Results in 1893. Crushing strength lbs. per sq. in. Individual Specimen.	Results in 1893. Crushing strength lbs. per sq. in. Mean.	Results in 1893. Per cent of strength	Results in 1894. Crushing strength lbs. per sq. in. Individual Specimen.	Results in 1894. Crushing strength lbs. per sq. in. Mean.	Results in 1894. Per cent of strength
1	Steel,	4 500			6 361		
2		4 400			4 964		
3		3 950			4 725		
4		4 800	4 412	100		5 350	100
5	Strawboard,	4 982			6 096		
6	1-16 in. thick,	3 050			5 842		
7		4 975			5 331		
8		6 137				5 756	107
9		4 355	4 700	107			
10	Wood, 1-4 in.	3 937			5 247		
11	thick,	3 625			6 107		
12	1893—hard,	6 000			5 615		
13	1894—soft,	3 500	4 264	96		5 656	106
14	Leather, 3-16	4 945			4 705		
15	in. thick,	3 750			3 992		
16		4 325			4 104		
17		2 950					
18		4 175	4 029	91		4 267	79
19	Lead, 1-8 in.				4 347		
20	thick,				5 000		
21					4 817	4 731	88

TESTS OF THREE BABCOCK & WILCOX BOILERS AT THE CHAMPAIGN ELECTRIC LIGHT AND POWER CO.'S STATION.

By R. A. Wood, Assistant in Mechanical Engineering.

After the test of the Champaign Electric Light and Power Co.'s plant on May 17, 1894, by the department of mechanical engineering, Professor L. P. Breckenridge thought it desirable to make thorough tests of the plant under various conditions, and accordingly arrangements were made with the company for the following tests. These tests were made after the close of the spring term.

The observations were made under the direct supervision of the writer, by Messrs. Busey, Junkersfeld, Williams, Funston, Capps and McRae of the class of '95.

The eight tests are divided into three series. Series A consists of comparative efficiency tests of the three boilers which comprise the plant; series B consists of economy tests of five different kinds of coal; and series C is to determine which of the two different grate areas under the same boiler gives the higher evaporative efficiency.

The Plant.

The plant consists of three Babcock & Wilcox boilers numbered from west to east, 1, 2 and 3. They are connected to the same steam main and also to a common horizontal flue leading along the floor to the stack. Usually the feed water is pumped through an exhaust steam feed water heater and introduced into the boiler at the front end of the drums. In these tests an injector was used.

The boilers supply steam for an 18x18 Porter-Allen engine which furnishes power for the street railway and small stationary motors, two Ideal engines, one 12x12 and one 14x14, and one 12x18 Russell engine. The last three supply power for electric lighting. A detailed description of the three boilers is given in Table V., and below are tabulated the principal dimensions in which the three boilers differ.

Number of Boiler.	*1*	*2*	*3*
Horse power*	242	226	226
Number of shells	3	2	2
Diameter of shells (in.)	30	36	36
Length of shells (ft.)	15.16	17.08	17.08
Grate surface (sq. ft.)	54	51	38.5
Heating surface (sq. ft.)	2 216	2 464	2 464
Area of draught between tubes (sq. ft.)	20	15.5	15.5
Ratio of grate to heating surface	1 to 44.7	1 to 44.4	1 to 58.7
Ratio of grate to water space	1 to 4.6	1 to 5.6	1 to 7.5

Originally there was no difference between boilers No. 2 and No. 3, but the length of furnace of No. 3 had been reduced eighteen inches by means of an extra wall built in front of the bridge wall, thereby reducing the grate area from 51 square feet to 38.5 square feet. Nos. 2 and 3 had been in use only two months, while No. 1 had been used for one year. One of the principal differences between boiler No. 1 and the other two is in the length and arrangement of the tubes. In No. 1 there are 126 4-inch tubes 15 feet 8 inches long, arranged 7 tubes high and 18 tubes wide. Nos. 2 and 3 each contain 108 tubes 17 feet 6 inches long, arranged 9 tubes high and 12 tubes wide.

In No. 1 there was a double bridge wall, the front one being laid on the back end of the grate bars. The first test of this boiler was made with this supplementary bridge wall in position, giving a grate area of 54 square feet; but in the second list of series C it was removed, thereby giving an area of 65 square feet.

Description of Instruments and Methods Used.

The scales used for weighing water and coal were carefully calibrated at the end of the tests by means of U. S. standard weights. Both scales were found to be practically correct.

The steam gauges in regular use on the boilers were used. They were calibrated by means of a Crosby weight gauge tester and corrections made in the pressures for the errors in reading.

The draft gauge consisted of a U tube containing water with one end open to the atmosphere and the other connected at a point just

*Rated at ten square feet grate area per horse power.

above the opening from the setting into the horizontal flue leading to the stack.

The thermometers were high grade instruments made by H. J. Green of Brooklyn, N. Y.

The pyrometer used to measure the temperature of the escaping gases was a Queen instrument containing compressed nitrogen above the mercury. The pyrometer and draft gauge were both inserted at the same place in the brick work. The part of the pyrometer exposed to the escaping gases was 36 inches long.

The calorimeter was of the throttling type and for all of the tests was attached to the horizontal steam main between the engine and the boiler nearest to the engine, and about three feet from the connection of that boiler to the main. The collecting pipe was ½ inch in diameter, closed at the end, and extended horizontally into the steam pipe five inches. In the pipe were a number of holes ⅛ inch in diameter, whose combined area was about one square inch.

The injector was a Pemberthy and was run almost continually while the boiler under test was generating more than 150 horse power, but below that rate numerous startings and stoppings were necessary. The water line in the boilers was not allowed to vary more than one inch. Steam for operating the injector was drawn from the steam main and was supplied by the boiler being tested.

Method of Starting and Stopping Tests.

The method of starting and stopping tests was as follows: Just before starting the test the fire was cleaned and allowed to burn low and as the test began the fire was closely inspected, the amount of coal on the grate estimated, the steam and water gauges read and the height of water in the feed tank recorded.

In closing the test, the amount of coal on the grate, the amount of water in the feed tank and in the boiler and the reading of the steam gauge were all made to conform as nearly as possible to the conditions under which the test was started,

Observations.

Observations were made every twenty minutes with the exception of calorimeter observations. These were made every hour.

Coal Measurement.

Coal was weighed in a box placed on platform scales, 300 pounds of coal being weighed at a time. The fireman shoveled directly from this box into the furnace. The coal remaining was re-weighed after each firing and thus a record was kept of the rate of firing, and accuracy insured as to the total amount of coal used in any test.

A sample of coal collected from each wheelbarrow load as it was dumped into the weighing box, was weighed, dried on the top of the boilers for twelve hours and then again weighed in order to determine the amount of moisture contained in the coal.

Water Measurement.

Water was drawn from the city water-pipes into a barrel whose capacity was about 450 pounds and which rested on a pair of platform scales. The water was then allowed to run into the feed tank which held about 3½ barrels and from there injected into the boiler. All valves in the feed and blow-off connections were carefully examined in order to detect any leaks which would introduce errors into the results. As the water was allowed to run into the lower tank a record was made of the weight and of the time at which the outlet valve in the weighing barrel was opened.

RESULTS.

Series A.

The result of the tests in series A was the selection of boiler No. 2 as being the most efficient with the kind of coal used, Pana Slack.

This boiler showed an evaporation of 7.51 pounds of water at and from 212 for each pound of combustible burned and developed 14.9 horse power for each dollar's worth of coal used.

Referring to Table I., it may be noticed that the temperature of flue gases is lower in the test with No. 2 boiler than in the other tests. This may be due to the fact that less coal per square foot of grate area was burned. There was also a greater amount of moisture in the coal. But on the other hand there was a greater percentage of ash which would tend to lower the economy.

TABLE I.

SERIES A: TO DETERMINE THE MOST EFFICIENT BOILER, USING PANA SLACK COAL.

Number of boiler	3	2	1
Date . . . . . 1894, June	11th	12th	13th
Total heating surface (sq. ft.) .	2 264.00	2 264.00	2 416.00
Total grate surface (sq. ft.) . .	38.50	51.00	54.00
Ratio grate to heating surface .	1 to 58.70	1 to 44.40	1 to 44.70
Coal burned per sq. ft. of grate surface per hour (lbs.) . . .	19.50	12.36	13.70
Temperature of flue gases (deg.)	504.00	480.00	494.00
Percentage of ash	20.70	23.60	19.40
Percentage of moisture in coal .	10.00	10.50	7.00
Percentage of moisture in steam	4.00	2.90	2.80
Water evaporated per pound of combustible at and from 212° F. (lbs.)	*5.63*	*7.51*	*6.07*
Number of H. P. obtained for $1.00 for 24 hours	*13.40*	*11.90*	*12.90*
Percentage of H.P. developed below rating (10 sq. ft. grate=1 H. P.)	*55.30*	*49.50*	*51.90*

Series B.

The principal results of the tests of five grades of coal are arranged in Table II. and for convenience of comparison are plotted in Fig. 1.

Other conditions being equal the curve representing the number of horse power for 24 hours developed for one dollar is the one which decides as to the relative economy of the different coals.

The prices quoted were the combined cost of coal, freight and of handling at the time the tests were made.

Pana Slack at $0.92 per ton gives 14.9 horse power for 24 hours. It is to be noted that as the size or price of coal increases in classes A, B, C, and D, the economy decreases, and in A, B, and C, the number of pounds of water evaporated per pound of coal and per pound of combustible actually decreases as the price and size of coal increase.

It will be seen by reference to Table VI. that the capacity at which this boiler was operated is far below its rating. It was impossible under the conditions of draft, firing, and so on, to obtain much more than fifty per cent. of its rated capacity with Pana slack.

The test of June 29-30 was made at night, at which time for about two of the 10.18 hours the boiler was forced to its greatest capacity, and from the rate of feeding water it was roughly estimated

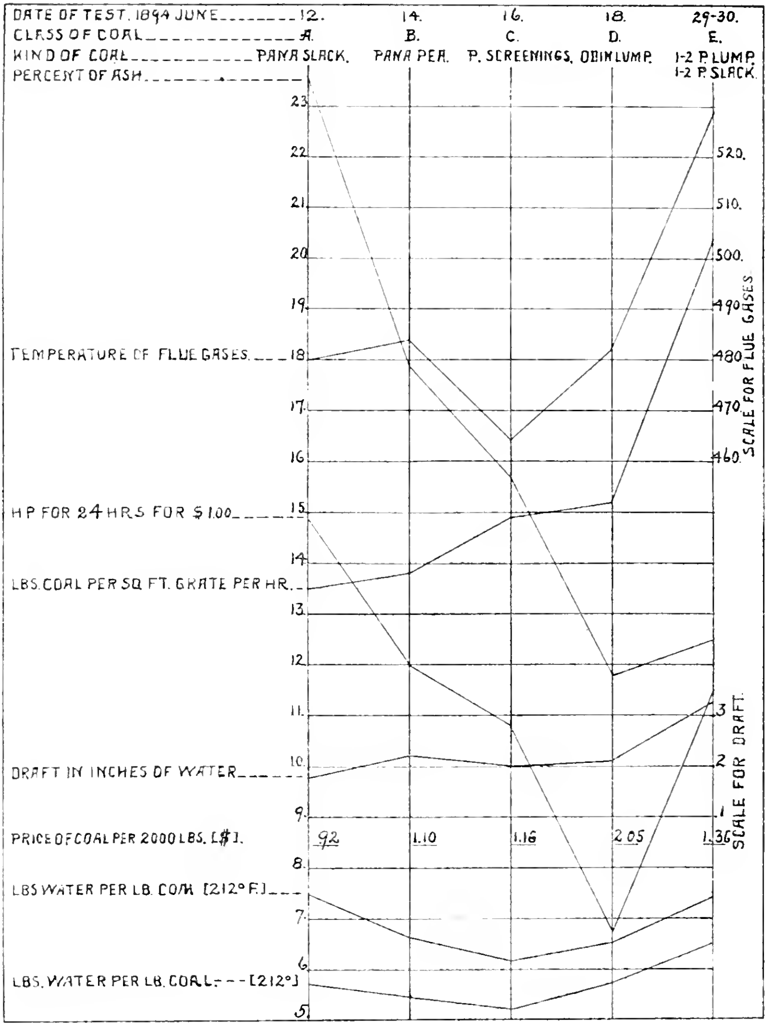


FIG. 1.

that it was developing 220 horse power, the average for the entire test being 196, or 13.3% below rating.

The percentage of ash which is plotted in Figure 1 allows for the moisture, determined by drying a sample of coal in an open pan on top of the boiler for 12 hours, and for all material that passed through the grate bars.

TABLE II.

SERIES B: TO DETERMINE THE MOST ECONOMICAL KIND OF COAL, USING BOILER NO. 2.

Date of Test, 1894, June	12th	14th	16th	18th	29-30th
Class of Coal . . .	A	B	C	D	E
Name of Coal . . .	Pana Slack.	Pana Pea.	Pana Scr'gs.	Odin Lump.	$\frac{1}{2}$ P. Lump $\frac{1}{2}$ P. Slack.
Width of air spaces (in.)	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{9}{16}$
Per cent. of ash . .	23.600	17.90	15.70	11.80	12.500
Coal per sq. ft. grate surface per hr. (lbs)	13.500	13.80	14.90	15.20	20.400
Temperature flue gases (deg.)	480.000	484.00	464.00	482.00	529.000
Draft in in. of water	.178	.22	.20	.21	.325
Water evaporated per lb. of coal at and from 212 F (lbs.) .	5.710	5.43	5.20	5.73	6.510
Water evaporated per lb. of combustible at and from 212 F. (lbs.)	7.470	6.62	6.18	6.51	7.430
Price of Coal per 2 000 lbs. at boiler ($)	.920	1.10	1.16	2.05	1.360
No. H. P. obtained for $1.00 for 24 hrs. . .	*14.900*	*12.00*	*10.80*	*6.75*	*11.500*

Coal A contained the highest percentage of ash. This was due in a large measure to the air spaces being 9-16" wide, to hand firing, and to thin fires. It was found impossible to carry thick fires, with the low draft pressure.

The coal analysis, Table IV., shows that a large proportion of what passed through the grate bars was combustible. The large percentage of ash, shown in Table I. as 23.6, and the analysis of that ash, which shows that it contained 19.49 per cent. of volatile matter and 14.83 per cent. of fixed carbon, would both tend to lower the evaporation. But in spite of these drawbacks, Pana slack did better than Pana pea coal or Pana screenings, in pounds of water evaporated per pound of coal. When we consider pounds of combustible and horse power developed for 24 hours for $1.00, its advantage is more apparent.

One object of the night test June 29-30 was to increase the efficiency by working the boiler more nearly up to its rated capacity. In this regard the test was a failure, for while the average horse power was 196, 13.3% below rating, the evaporation at and from 212 per pound of combustible was 7.43, which is practically the same as when on June 12 the average horse power was 114, or 49.1% below rating.

Series C.

These two tests show in favor of the small grate area, viz: using 54 square feet instead of 65 square feet. The evaporation of water at and from 212 was 6.07 pounds and 5.51 pounds respectively.

The rate of combustion and the horse power developed were about the same in both tests. The analysis of coal shown in Table IV. shows no radical difference, and since care was taken to keep all other conditions as nearly the same as possible, it is fair to decide in favor of the smaller grate area.

The lower temperature of escaping gases with the small grate area without doubt conduced to the higher evaporation obtained. A higher temperature of escaping gases might be expected, since the horse power developed by the boilers was about the same in each case, but it will be noticed that the number of pounds of coal burned per square foot of grate surface was about the same in each case. This gave approximately the same amount of heat liberated per square foot of grate area, but a difference in the total amount of heat, due to the difference in grate areas.

Tables V., VI., and VII., which are appended at the close of this article, give the results of series A, B, and C in full.

TABLE III.

SERIES C: TO DETERMINE THE RELATIVE ECONOMY OF TWO DIFFERENT GRATE AREAS WITH THE SAME CLASS OF COAL, PANA SLACK.

Date of test . . . . 1894, June	13th	19th
Area of grate (sq. ft.)	54.00	65.00
Ratio of grate to heating surface	1 to 44.70	1 to 37.20
Force of draught in inches of water	.23	.26
Temperature of escaping gases, F. (deg.) .	491.00	516.00
Percentage of ash	19.40	29.00
Water evaporated at and from 212° F. per pound of dry coal (lbs.)	4.90	3.91
Water evaporated at and from 212° F. per pound of combustible (lbs.)	6.07	5.51
Coal burned per sq. ft. of grate surface per hr. (lbs,)	11.20	14.89
H. P. obtained for $1.00 for 24 hrs.	12.90	10.26
H. P. developed ($34\frac{1}{2}$ lbs. at and from 212° F.)	169.00	110.00

TABLE IV.

Analysis of Coal.

Kind of Coal....	Pana Slack.		Pana Pea.		Pana Scr'ngs.		Odin Lump.		Pana Slack.		Pana Slack.		Pana Slack.	
Class of Coal...	A		B		C		D		A		A		F	
When used, 1894, June	12th		14th		16th		18th		11th		13th		29-30th	
	Coal per ct.	Ash per ct.	Coal per ct.	Ash per ct.	Coal per ct.	Ash per ct.	Coal per ct.	Ash per ct.	Coal per ct.	Ash per ct.	Coal per ct.	Ash per ct.	Coal per ct.	Ash per ct.
Moisture	4.70	.98	5.00	.34	5.79	.37	6.13	.34	4.70	......	4.07	1.09	5.59	5.59
Volatile Matter	33.69	19.49	38.88	7.83	37.79	8.31	40.20	11.88	33.69	......	33.69	19.85	30.55	11.56
Fixed Carbon...	41.17	14.83	40.25	6.44	38.69	7.65	42.20	20.16	41.17	......	41.17	14.97	43.14	26.68
Ash............	20.44	64.70	15.87	85.39	17.73	83.67	11.47	67.62	20.44	......	20.44	64.09	20.72	56.17
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00		100.00	100.00	100.00	100.00

TABLE V.

Series A: To Determine the Relative Economy of Boilers 1, 2 and 3.

	Items.			
1.	Date of tests .... 1894, June	11th	12th	13th
2.	Duration of tests (hrs.)	10.5	10	10
	DESCRIPTION OF BOILERS.			
	(Number)	3	2	1
(a)	Type of boiler	Water tube	Water tube	Water tube
(b)	Diameter of shells (in.)	Two-36	Two-36	Three-30
(c)	Length of shell (ft.)	17.08	17.08	15.16
(d)	No. of tubes. Vertical	12.00	12.00	18.00
	No. of tubes. Horizontal	108.00	108.00	126.00
(e)	Diameter of tubes (in.)	4.00	4.00	4.00
(f)	Length of tubes. Vertical (ft.)	4.66	4.66	4.75
	Length of tubes. Horizontal (ft.)	17.50	17.50	15.66
(g)	Length of furnace (ft.)	5.50	7.00	5.00
(h)	Width of furnace (ft.)	7.33	7.33	10.83
(i)	Kind of grate bars	Plain stationary	Plain sta.	Plain sta.
(j)	Width of air spaces (in.)	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{9}{16}$
(k)	Ratio of area of grate to area of air spaces	1.87 to 1.00	1.87 to 1.00	1 to .46
(l)	Area of chimney (sq. ft.)	28.00	28.00	28.00
(m)	Height of chimney above grate (ft.)	125.00	125.00	125.00
(n)	Length of flues connecting to chimney (ft.)	34.00	44.00	60.60
(o)	Area of flues connecting to chimney (ft)	18.00	35.50	12.00
(p)	Least draft area (sq. ft.)	12.00	12.00	10.00
	GOVERNING PROPORTIONS.			
(a)	Grate surface (sq. ft.)	38.50	51.00	54.00
(b)	Heating surface. Water (sq. ft.)	2 264.00	2 264.00	2 416.00
	Heating surface. Steam (sq. ft.)	.00	.00	.00
	Heating surface. Total (sq. ft.)	2 264.00	2 264.00	2 116.00

TABLE V.—CONTINUED.

	(c) Area of draught through or between tubes (sq. ft.)	15.50	15.50	20.00
	(d) Ratio of grate to heating surface	1 to 58.70	1 to 44.40	1 to 41.70
	(e) Ratio of least draught area to grate	1 to 3.20	1 to 4.25	1 to 5.40
	(f) Ratio of least draught area to total heating surface	1 to 188.60	1 to 188.60	1 to 211.60
	(g) Water space (cu. ft.)	289.00	286.00	250.00
	(h) Steam space (cu. ft.)	130.00	133.00	116.00
	(i) Ratio grate to water space	1 to 7.50	1 to 5.60	1 to 4.63
	(j) Ratio grate to steam space	1 to 3.37	1 to 2.60	1 to 2.15
3.	Grate surface (sq. ft.)	38.50	51.00	54.00
4.	Water heating surface (sq. ft.)	2 264.00	2 261.00	2 116.00
5.	Superheating surface (sq. ft)	.00	.00	.00
6.	Ratio of water heating surface to grate surface	18.7 to 1.00	45.4 to 1.00	41.7 to 1.00
	AVERAGE PRESSURES.			
7.	Steam pressure in boiler by gauge (lbs.)	90.00	89.10	95.70
8.	Absolute steam pressure (lbs.)	104.69	103.79	110.39
9.	Atmospheric pressure (lbs.)	14.69	14.69	14.69
10.	Force of draught in inches of water	.21	.18	.23
	AVERAGE TEMPERATURES, FAHR.			
11.	Temperature of external air (deg.)	90.00	91.00	90.00
12.	Temperature of fire room (deg.)	89.00	90.00	94.00
13.	Temperature of steam (deg.)	331.00	330.00	335.00
14.	Temperature of escaping gases (deg.)	504.00	480.00	494.00
15.	Temperature of feed water (deg.)	59.00	59.30	59.00
	FUEL (KIND)	Pana Slack.		
15½	Cost of coal per 2 000 lbs. at boilers (dollars)	0.92	0.92	0.92
16.	Total amount coal consumed—includes wood × 0.4 (lbs.)	8 003.00	7 687.00	8 261.00
17.	Moisture in coal (per cent.)	.10	10.50	7.00
18.	Dry coal consumed (lbs.)	7 203.00	6 880.00	7 683.00
18½	Total refuse dry (lbs.)	1 495.00	1 626.00	1 497.00
19.	Total refuse dry (per cent.)	20.70	23.60	19.40
20.	Total combustible—item 18 less item 19 (lbs.)	6 508.00	5 260.00	6 186.00

TABLE V.—CONTINUED.

21.	Dry coal consumed per hour (lbs.)	686.00	688.00	768.00
22.	Combustible consumed per hour (lbs.)	620.00	526.00	619.00
	RESULTS OF CALORIMETRIC TESTS.			
23.	Quality of steam (dry steam taken as unity)	96.00	97.10	97.15
24.	Percentage of moisture in steam	4.00	2.90	2.85
25.	Number of degrees superheated	0.00	0.00	0.00
	WATER.			
26.	Total weight of water pumped into boiler and apparently evaporated (lbs.)	31 899.00	33 857.00	32 341.00
27.	Water actually evaporated, corrected for quality of steam (lbs.)	30 623.00	32 868.00	31 419.00
28.	Equivalent water evaporated into dry steam from and at 212° F. (lbs.)	36 656.00	39 311.00	37 639.00
29.	Equivalent total heat derived from fuel in British thermal units	35 398 699.00	3 796 710.00	36 350 909.00
30.	Equivalent water evaporated into dry steam from and at 212° F. per hour (lbs.)	3 491.00	3 931.00	3 761.00
	ECONOMIC EVAPORATION.			
31.	Water actually evaporated per lb. of dry coal from actual pressure and temp. (lbs.)	4.25	4.78	4.08
31½.	Equivalent water evaporated for $1.00 from and at 212° F. (lbs.)	11 065.00	12 113.00	10 652.00
32.	*Equivalent water evaporated per lb. of dry coal from and at 212° F. (lbs.)*	*5.09*	*5.71*	*4.90*
33.	*Equivalent water evaporated per lb. of combustible from and at 212° F. (lbs.)*	*5.63*	*7.51*	*6.07*
	COMMERCIAL EVAPORATION.			
34.	Equivalent water evaporated per lb. of dry coal with one-sixth refuse at 70 lbs. gauge pressure from temperature of 100° F. (= item 33 × 0.7249) (lbs.)	4.08	5.44	4.40
	RATE OF COMBUSTION.			
35.	Dry coal actually burned per sq. ft. of grate surface per hr. (lbs.)	17.80	13.50	14.20

TABLE V.—CONTINUED.

36.	Consumption of dry coal per hr., coal assumed with one-sixth refuse. Per sq. ft. of grate surface (lbs.)	19.50	12.36	13.70
37.	Per sq. ft. of water heating surface (lbs.)	.33	.28	.30
38.	Per sq. ft. of least area for draught (lbs.)	62.50	52.53	71.30
	RATE OF EVAPORATION.			
39.	Water evaporated from and at 212° F. per sq. ft. heating surface per hr. (lbs.)	1.54	1.73	1.55
40.	Water evaporated per hr. from temp. of 100° F. into steam of 70 lbs. gauge pr. Per sq. ft. of grate surface (lbs)	78.84	67.10	60.61
41.	Per sq. ft. of water heating surface (lbs.)	1.34	1.48	1.35
42.	Per sq. ft. of least area for draught (lbs.)	253.00	285.00	327.00
	COMMERCIAL HORSE POWER.			
43.	On a basis of 30 lbs. water per hour evaporated from a temperature of 100° F. into steam of 70 lbs. gauge pressure (= 34½ lbs. from and at 212° F.)	101.00	114.00	109.00
43½	*No. of H. P. obtained for $1.00 (per 24 hrs.)*	*13.40*	*11.90*	*12.90*
44.	H. P.—Builders' rating at 10 sq. ft. per H. P.	226.00	226.00	242.00
45.	Per cent. developed below rating	55.30	49.50	54.90

TABLE VI.

SERIES B: TO DETERMINE THE RELATIVE ECONOMY OF DIFFERENT KINDS OF COAL, USING BOILER NO. 2.

	Items.					
1.	Date of test. 1891. June	12th	13th	16th	18th	29–30th
2.	Duration of tests (hrs.)	10.0	10.0	10.0	10.0	10.18
	AVERAGE PRESSURES					
7.	Steam pressure in boiler by gauge (lbs.)	89.100	91.30	95.90	98.50	95.000
8.	Absolute steam pressure (lbs.)	103.790	105.99	110.59	113.19	109.690
9.	Atmospheric pressure (lbs.)	14.690	14.69	14.69	14.69	14.690
10.	Force of draught in inches of water	.178	.22	.20	.21	.325
	AVERAGE TEMPERATURES, FAHR.					
11.	Temperature of external air (deg.)	91.000	88.30	85.50	71.00	
12.	Temperature of fire room (deg.)	90.000	87.30	81.00	70.00	88.200
13.	Temperature of steam (deg.)	330.000	331.00	335.00	337.00	334.000
14.	Temperature of escaping gases (deg.)	480.000	484.00	461.00	482.00	529.000
15.	Temperature of feed water (deg.)	59.300	60.80	60.00	59.50	60.700
	FUEL (KIND)	Pana Slack.	Pana Pea.	Pana Screen.	Odin Lump	See Remark
15½	Cost of coal per 2 000 lbs. at boilers (dollars)	0.920	1.10	1.16	2.05	1.360
16	Total amount coal consumed—includes wood × 0.4 (lbs.)	7 687.000	7 431.00	7 840.00	7 761.00	10 602.000
17.	Moisture in coal (per cent.)	10.500	5.40	2.90	0.00	0.000
18.	Dry coal consumed (lbs.)	6 880.000	7 030.00	7 613.00	7 761.00	10 602.000
18½.	Total refuse dry (lbs.)	1 626.600	1 261.00	1 197.00	918.00	1 328.000
19.	Total refuse dry (per cent.)	23.600	17.90	15.70	11.80	12.500
20.	Total combustible—item 18 less item 19 (lbs.)	5 260.000	57.69	6 416.00	6 843.00	9 274.000
21.	Dry coal consumed per hour (lbs.)	688.000	703.00	761.00	776.00	1 011.000
22.	Combustible consumed per hour (lbs.)	526.000	577.00	612.00	681.00	911.000
	RESULTS OF CALORIMETRIC TESTS.					
23.	Quality of steam—dry steam taken as unity (per cent.)	97.01	97.01	97.53	96.80	98.00
24.	Percentage of moisture in steam	2.90	2.90	2.47	3.20	2.03
25.	Number of degrees superheated	0.00	0.00	0.00	0.00	0.00

TABLE VI.—CONTINUED.

	WATER.					
26.	Total weight of water pumped into boiler and apparently evaporated (lbs.)	33 857	32 927	33 960	38 137	58 799
27.	Water actually evaporated, corrected for quality of steam (lbs.)	32 868	31 963	33 111	37 208	57 623
28.	Equivalent water evaporated into dry steam from and at 212° F. (lbs.)	39 311	38 228	39 634	44 539	68 915
29.	Equivalent total heat derived from fuel in British thermal units	37 962 632	36 916 186	38 274 385	43 010 300	66 608 923
30.	Equivalent water evaporated into dry steam from and at 212° F. per hr. (lbs.)	3 931	3 823	3 963	4 454	6 775
	ECONOMIC EVAPORATION.					
31.	Water actually evaporated, per lb. of dry coal from actual pressure and temp. (lbs.)	4.78	4.55	4.35	4.79	5.41
31½.	Equivalent water evaporated for $1.00 from and at 212° F. (lbs.)	12 413 00	9 871.00	8 966.00	5 590.00	9 573.00
32.	Equivalent water evaporated per lb. of dry coal from and at 212° F. (lbs.)	5.71	5.43	5.20	5.73	6.51
33.	Equivalent water evaporated per lb. of combustible from and at 212° F. (lbs.)	7.47	6.62	6.18	6.51	7.43
	COMMERCIAL EVAPORATION.					
34.	Equivalent water evaporated per lb. of dry coal with one-sixth refuse at 70 lbs. gauge pressure from temperature of 100° F. (= item 33 × 0.7249) (lbs.)	5.11	4.80	4.84	4.72	5.39
	RATE OF COMBUSTION.					
35.	Dry coal actually burned per sq. ft. of grate surface per hr. (lbs.)	13.50	13.80	14.90	15.20	20.40
36.	Consumption of dry coal per hr., coal assumed with ⅙ refuse: Per sq. ft. grate surface (lbs.)	12.36	13.60	15.10	16.10	21.40
37.	Per sq. ft. water heat'g surface (lbs.)	00.28	00.30	00.34	00.36	00.48
38.	Per sq. ft. least draught area (lbs.)	52.53	57.80	64.20	68.10	91.00

TABLE VI.—Continued.

RATE OF EVAPORATION.					
39. Water evaporated from and at 212° F. per sq. ft. heating surface per hr. (lbs.)	1.73	1.69	1.75	1.97	2.99
40. Water evaporated per hr. from temp. of 100° F. into steam of 70 lbs. gauge pressure — Per sq. ft. grate surface (lbs.)	67.10	65.20	67.70	75.90	115.00
41. Water evaporated per hr. from temp. of 100° F. into steam of 70 lbs. gauge pressure — Per sq. ft. water heating surface (lbs.)	1.48	1.46	1.52	1.71	2.60
42. Water evaporated per hr. from temp. of 100° F. into steam of 70 lbs. gauge pressure — Per sq. ft. least draught area	285.00	277.00	288.00	322.00	191.00
COMMERCIAL HORSE POWER.					
43. On a basis of 30 lbs. water per hr. evaporated from a temperature of 100° F. into steam of 70 lbs. gauge pressure (= 34½ lbs. from and at 212° F.)	111.00	111.00	115.00	129.00	196.00
43½. Number of H. P. obtained for $1 (per 24 hrs.)	11.90	12.00	10.80	6.75	11.50
44. H. P.—Builders' rating at 10 sq. ft. per H. P.	226.00				
45. Per cent. developed below rating	4.91	50.20	12.00	12.00	13.30

REMARKS.

Coal burned June 29-30: ½ Pana lump @ $1.80 and ½ Pana slack @ $0.92; average cost, $1.36 per ton.

TABLE VII.

Series C: To Determine the Relative Economy of Two Different Grate Areas, Using Boiler No. 1.

	Items.		
1.	Date of tests ......1891, June	13th	19th
2.	Duration of tests (hrs.)	10	10
	AVERAGE PRESSURES.		
7.	Steam pressure in boiler by gauge (lbs.)	95.70	86.00
8.	Absolute steam pressure (lbs.)	110.39	100.69
9.	Atmospheric pressure per barometer (lbs.)	14.69	14.69
10.	Force of draught in inches of water	.23	.26
	AVERAGE TEMPERATURES, FAHR.		
11.	Temperature of external air (deg.)	90.00	84.00
12.	Temperature of fire room (deg.)	91.00	83.00
13.	Temperature of steam (deg.)	335.00	328.00
14.	Temperature of escaping gases (deg.)	491.00	516.00
15.	Temperature of feed water (deg.)	59.00	59.00
	FUEL (KIND.)	Pana Slack.	
15½.	Cost of coal per 2 000 lbs. at boilers (dollars.)	0.92	0.920
16.	Total amount coal consumed (includes wood × 0.4) (lbs.)	8 261.06	10 588.000
17.	Moisture in coal (per cent.)	7.00	8.600
18.	Dry coal consumed (lbs.)	7 683.00	9 678 000
18½.	Total refuse dry (lbs.)	1 497.00	2 815.000
19.	Total refuse dry (per cent.)	19.40	29.000
20.	Total combustible—item 18 less item 19 (lbs.)	6 186.00	6 871 000
21.	Dry coal consumed per hr. (lbs.)	768.00	968.000
22.	Combustible consumed per hr. (lbs.)	619 00	687.000
	RESULTS OF CALORIMETRIC TESTS.		
23.	Quality of steam—dry steam taken as unity (per cent.)	97.15	97 050

TABLE VII.—Continued.

24.	Percentage of moisture in steam	2.85	2.950
25.	Number of degrees superheated	0.00	0.000
	WATER		
26.	Total weight of water pumped into boiler and apparently evaporated (lbs.)	32 311.00	32 634.000
27.	Water actually evaporated, corrected for quality of steam (lbs.)	31 419.00	31 671.000
28.	Equivalent water evaporated into dry steam from and at 212° F. (lbs.)	37 639.00	37 878.000
29.	Equivalent total heat derived from fuel in British thermal units (lbs.)	36 350 909.00	36 578 781.000
30.	Equivalent water evaporated into dry steam from and at 212° F., per hr. (lbs.)	3 764.00	3 788.000
	ECONOMIC EVAPORATION.		
31.	Water actually evaporated per lb. of dry coal from actual pressure and temperature (lbs.)	4.08	3.270
31½.	Equivalent water evaporated for $1 from and at 212° F. (lbs.)	10 652.00	8 500.000
32.	Equivalent water evaporated per lb. of dry coal from and at 212° F. (lbs.)	4.90	3.940
33.	Equivalent water evaporated per lb. of combustible from and at 212° F. (lbs.)	6.07	5.510
	COMMERCIAL EVAPORATION.		
34.	Equivalent water evaporated per lb. of dry coal with one-sixth refuse at 70 lbs. gauge pressure from temperature of 100° F. (= item 33 × 0.7249) (lbs.)	4.40	3.990
	RATE OF COMBUSTION		
35.	Dry coal actually burned per sq. ft. of grate surface per hr. (lbs.)	11.20	11.890
36.	Consumption of dry coal per hr., coal assumed with one sixth refuse. Per sq. ft. of grate surface (lbs.)	13.70	12.670
37.	Consumption of dry coal per hr., coal assumed with one sixth refuse. Per sq. ft. of water heating surface (lbs.)	.30	.310
38.	Consumption of dry coal per hr., coal assumed with one sixth refuse. Per sq. ft. of least area for draught (lbs.)	71.30	82.100
	RATE OF EVAPORATION.		
39.	Water evaporated from and at 212° F. per sq. ft. heating surface per hr. (lbs.)	1.55	1.570
40.	Water evaporated per hr. from temperature of 100° F. into steam of 70 lbs. gauge pressure. Per sq. ft. of grate surface. (lbs.)	60.61	50.680
41.	Water evaporated per hr. from temperature of 100° F. into steam of 70 lbs. gauge pressure. Per sq. ft. of water heating surface. (lbs.)	1.35	1.360
42.	Water evaporated per hr. from temperature of 100° F. into steam of 70 lbs. gauge pressure. Per sq. ft. of least area for draught. (lbs.)	327.00	329.000

TABLE VII.—CONTINUED.

COMMERCIAL HORSE POWER.

43.	On a basis of 30 lbs. water per hr. evaporated from a temperature of 100° F. into steam of 70 lbs. gauge pressure (= 34½ lbs. from and at 212° F.)........	109.00	110.000
43½	No. of H. P. obtained for $1 (per 24 hrs.)........	12.90	10.260
44.	H. P., Builders' rating at 10 sq. ft. per H. P........	242.00	242.000
45.	Per cent. developed above or below rating........	54 90	54.500

HINTS RELATING TO THE PRACTICE OF RAILROAD SURVEYING.

BY A. C. SCHWARTZ '74.

The writer is not assuming to instruct the engineer of experience, although the practical knight of the tripod may scan these pages not altogether without interest and perhaps with profit. Their perusal may bring to his memory pleasant and peculiar circumstances in his own experience, and by a comparison of ideas with those of others, it often occurs that there is suggested to the mind better and improved methods of practice.

These words are addressed more particularly to the young engineer and to him who is considering the matter of preparing himself for the practice of the engineering profession. If they shall prove a benefit to the latter, by assisting him in the choice of a profession, or to the former by contributing to his success and advancement in practice, the highest expectations of the writer will have been fully realized.

Being limited to the space of an ordinary magazine article, we can sketch but briefly a few of the experiences and methods of practice, of these itinerant rovers of the forest and plain, and cannot even mention the various problems and difficulties that the engineer may expect to meet in the location and construction of an important line of railroad, much less attempt to give instructions for their solution.

The determination upon the choice of a profession is a very important matter. The future of the young man depends upon it. Success in life is less certain and failure is more probable if a choice is made of a profession for which the person is not adapted in mind, in disposition and in temperament. Each profession requires some special mental qualification; and each, in its practice, has its attractions and objections which should also receive consideration. It often occurs that the young man sees the former and is allured by them, while he does not discover, until too late, the latter.

One determines to be a physician. His success in the study of anatomy, physiology and materia medica gives him great encouragement. At the dissecting table he is as indifferent with the scalpel as the butcher is with his cleaver. But at the bedside of suffering humanity he becomes nervous and excited, and discovers what he did not know before, that he is not suited in temperament for the practice of medicine. Another endeavors to be an artist, but, after he has produced heaps of rubbish, he finds that his invention is only of the order out of which mechanics are made. He who hears only the martial music and sees only the dignity of command, but does not consider the engagement and its dangers, the forced march with its exposures and privations and the humility of dumb obedience to superiors, will likely be dissatisfied with military life.

The young man should learn as much as possible of the requirements and environments of his contemplated profession, and when he has become familiar with these, let him equate them with himself. The first requirement of all, then, is "Know Thyself."

All agree that the engineer should have an aptness for mathematics. But it is quite doubtful if the practical engineer in the field ever again knows as much about mathematics as he did on the day of his graduation. I would not, however, subordinate the study of mathematics in an engineering course. How much is retained will depend upon what the daily practice requires.

The writer was much astonished to find that engineers, almost without an exception, used the natural, instead of the logarithmic functions. But he was more astonished to find that after a few years he, also, gradually dropped the use of logarithms until he has entirely discarded their use. The only reason that can be given for this practice among engineers is that the greater part of their calculations is of such a nature that the use of logarithms is not practicable, and after a time they cease to use the tables, even when they could be used to advantage.

Quickness and accuracy in the ordinary use of figures is a necessity. He who cannot accurately add ten columns of ten figures each within sixty seconds, should, by no means, call himself quick, and he certainly can not call himself an expert. The study of algebra, geometry and trigonometry should be done with the greatest care and thoroughness. The student should become familiar with their application to the solution of practical problems. He who has not the faculty of original and independent demonstration will not be long in practice before he will have to call upon others for assistance, or will be compelled to resort to fudging, and thus expose himself to ridicule by attempting a practical solution of his problems in the field, instead of making a mathematical demonstration in the office. When his blundering has been discovered, he will be called upon for an explanation, which will usually end with the information that his services are no longer required; or, he is humiliated by being offered a position commensurate with his ability. The principles of mechanics and strength of materials should be kept well in mind, so as to be able to make a ready application of them to building construction. Preference will be given to the graphical methods of the determination of stresses on account of their general application, simplicity and convenience, as well as for the intelligent representation to the eye that they afford.

But the engineer must be something more than a mathematician. A knowledge of the sciences will be useful in his practice and will contribute much to his pleasure. A sound body is as necessary as a well trained mind. He must have energy, and possess endurance under long continued exposure and hard labor. Good judgment and well developed powers of observation are necessary. He must be certain of his opinions and quick in perception. He must be willing to exchange luxury, comfort and society for hardship, toil and isolation. He must accept a pile of brush as a substitute for a spring mattress and a pair of cow-hide boots for a pillow. The tarantula, scorpion and centipede will be frequent bed-fellows. Even the skunk has come, an uninvited guest, to share the engineer's couch. Choice cuts of porterhouse and delectable pastries may be unknown to his palate for months, while he makes a forced acquaintance with slap-jacks, beans and dried apples.

The experiences of the engineer are as varied as the views of a kaleidoscope. Encouragement and disappointment, security and uncertainty, safety and danger, are so closely associated as to be strongly contrasted. While you are in the enjoyment of one you may discover the approaching shadow of the other. He who thinks that on account of some valuable service rendered, he has made himself solid with his company, may have his confidence suddenly shaken. He may also find that superior intelligence is not always the stepping stone to advancement. There is always more or less unscrupulousness in corporation management and this quality in a person has been too often recognized by preferment. Expect advancement and strive for it, but do not prepare a disappointment by being over assured. The warning, "Let him that thinketh he standeth take heed lest he fall," may be quite appropriately applied to civil engineers.

The writer at one time received a telegram from an official, instructing him that if a certain land owner from whom the right of-way had not been obtained, interfered with the construction, to "shoot the stuffing out of him." Then, when he did not learn of a funeral within the time reasonably expected, he inquired why his orders had not been obeyed. But since the days of speculative railroad building are past, all departments of the service are being conducted upon more legitimate business principles and with a much greater show of respectability.

The engineering profession offers one of the most attractive fields to the energetic young man. So extensive is its scope, so varied its demands, so great its opportunities for invention, that it is always interesting in its practice. There is no tiresome repetition. Each day brings some new problem for solution. Its requirements are about equally balanced between the mental and the physical. The exercise of one affords relief and relaxation to the other.

Many are attracted to the engineering profession on account of the opportunities for travel which it affords. No tale of the traveler has ever been told that did not incite a desire in the mind of some hearer to experience something of adventure and sight-seeing. When an engineering party is to be organized there is never a lack of applicants for the positions to be filled, even when the proposed survey leads through countries where roving bands of hostile savages may be expected.

The sublime and the ridiculous are often viewed from the same point of observation. The engineer may stand enraptured as he views the towering cliffs, chiseled with nature's bold hand, and the rushing, foaming waters leaping and bounding among the rocks as they hurry through the magnificent gorge of the grand canon, and while his soul is being filled with ecstasy at the awe-inspiring scene before him, he is suddendly attracted by a cry of alarm. It is caused only by a pack mule, laden with blankets and other camp equipage, having fallen from the trail blasted in the rocks fifty feet or more above the water's surface, and it now floats rapidly downward upon its back, vainly endeavoring to adjust its pedal extremities as nature had intended them.

Again, he ascends the serpentine trail as it winds among the trees and around projecting ledges of rocks, until he reaches the mountain's summit. Upon this divide of the waters of the oceans he views the towering peaks and the deeply cut channels of two great water sheds. He is just in time to behold the indescribable scene of a gorgeous sunset. The illumined and gilded clouds, the heavens with tinted blended hues more delicate than ever given to the canvas by the most reverenced limner, the mountain sides with their foliage showing every shade of the red, the green and the gold, and presenting every effect of light and shadow, which is ever shifting and changing: all tend to fill the soul with enraptured awe. Surrounded by this evidence of creative power and these scenes of nature's art, he seems to stand in the very presence of Divinity. The highest opinions he has ever held of himself or formed of man quickly vanish, and he faintly realizes the state of that inspired one who inquired, "What is man that thou art mindful of him?" Then, suddenly, the scene changes. The face of the mountain grows darker, black clouds show their ominous heads over the distant ridge and peer around the obstructing peak. The low mutterings of thunder are heard; the clouds advance; the roaring and the darkness increase, until every mountain side and intervening gorge is reflecting and echoing the sound, and all nature is veiled in the blackest gloom. Now, the lightning's vivid flash frequently illumines some towering peak as it seems to play at hide and seek among its capping rocks, in bright and blinding scintillations. But, with thought of the duties of to-morrow, this pioneer of civilization, with weary limbs, now wraps himself in his blankets and, sheltered by the spreading branches of a neighboring pine, the sighing of the wind and the tranquil noise of the falling rain soon lulls him to a sound repose. Such was the experience of the writer, with his muleteer as only companion, on Marshall's Pass, in the autumn of 1877.

There are also occasions which may suggest some lines from a favorite author. He was pleased with the thought of the poet who wrote of the beautiful dew drops hanging like clusters of sparkling jewels from the forest foliage. But he has different feelings as he goes crouching through the willows and these precious jewels drop down his shivering spine until they fill his iron-shod, cowhide boots. His thoughts are recorded only upon his conscience and in the ears of his companions.

When a man prepares himself for a special service he expects to make that a means of support. The engineer is only fairly remunerated for his services, and this must be considered with the fact that the demand for engineering service is very fluctuating and uncertain. Being an expensive service to corporations, it is the first to feel the shock when retrenchment becomes necessary. It is affected by every financial panic and even by the seasons and local conditions of the crops. The young graduate is also put in unjust competition with the so-called practical man, who has been taught to carry a chain and has learned by observation which is the eye end of the telescope, as he has learned, by a long felt experience, which is the business end of a vicious mule, and who thinks the sine is determined by the phases of the moon and that the focusing of an instrument is the removing of a covering that concealed the cross-hairs. But this should not discourage the young engineer who has, by hard study and at great expense, prepared himself for the practice of his profession. There is a limit beyond which the uneducated cannot pass, and there are responsibilities that they dare not assume and duties that they cannot discharge.

But, even if this hindrance to his progress were wholly eliminated, the graduate should not expect to take an advanced position in an engineering party. As in his college course he began with the elementary studies, so in his practice he must again take a place near the lower end of the ladder. The solution of his problems will now have a more important significance than merely obtaining the correct answer. His calculations now have a time and money value. If he errs in the measurement of an earth embankment or of an irregular rock excavation, some one is defrauded. A mistake in judgment of the classification of materials has the same result and often leads to expensive litigation. The loss of property and life are also involved in his higher calculations. Whatever confidence he may have in his ability he will feel the pressing of this additional responsibility. Even the adjustment of an instrument in the field will appear different from what it was in class practice, and there will be many occasions when he will be much embarrassed in the presence of his chief, and under the merciless gaze of an old time party. Experience alone will give the required confidence and put him at his ease.

The chief of the party is held responsible by the management for the work done under his direction, whether it be a stake wrongly marked or carelessly driven, an error in the reading of an angle, or a blunder in the location. Hence, he will select his assistants from those who have had experience and who have been proven competent in their work. He will also have a kind consideration for the deserving, and will take pleasure in advancing them whenever he has opportunity. Careful attention to details is an element of success worthy of cultivation. It will require a long time to restore confidence after a blunder or an act of carelessness. The opportunities for error are as numerous as the increments of his practice. We cannot enumerate them or point them out. The only safe rule is, know for yourself that you are right.

The first step in the location of a railroad is the reconnoissance. The reconnoissance is not always made by the person who is expected to make the surveys. All engineers are not adapted to reconnoissance work, and there is an advantage in having the survey made by another person, for by so doing the management has the benefit of the judgment of two engineers.

A careful map study of the country over which the line is to be run should first be made. Sectional maps which show the drainage systems fairly well can now be had of all subdivided countries. The maps of the mountain districts are deficient in detail, but general information only, in such cases, is required. A very careful study of the drainage systems, water divides and other physical features should be made. The map study should be supplemented with such information as can be obtained from persons who are acquainted with the country. Note upon the map all points to be touched by the survey and join the consecutive points by a light pencil line. It should be a straight line unless the topography clearly determines its course. This guide line will be of value in the determination of a choice between two or more possible routes, as the line which deflects least from the guide line will be preferred, other conditions, such as curvature and bridging, being the same.

The location of a line is more difficult and the cost of its construction more expensive, when its direction is across the drainage of the country, instead of following the course of some large stream. Especially is this the case when the streams to be crossed are of considerable size, for in such cases the divides are usually high and the country much broken. The roughest country may be expected on the side of the divide toward the larger stream. The most favorable crossing of a high divide is likely to be found where small tributaries to the principal streams head at the same point on the ridge.

In mountainous countries where long distances of heavy grade are required, advantage must be taken of that route which affords the best opportunity to develop a line. The saving of distance is not a consideration when extreme elevations are to be overcome. In mountainous countries where much snow and ice may be expected, preference should be given to the slope most exposed to the sun, but generally the drainage will be deeper cut upon the sun side of the slope and the cost of bridging will be greater.

The engineer, having made a careful map study and supplemented it with such other information as he has been able to obtain, can now indicate upon the map the various routes which he wishes to examine upon his reconnoissance. He should procure township atlases, or make tracings from them, for use in the field, upon which he should show the topography of special places and trace the proposed location more definitely than can be done on the sectional state map. In a pocket memorandum book he should enter full explanatory notes of all matters pertaining to the location, construction and maintenance of the road. The height and length of bridges; the length and depth of summit cuttings with classification of material; the supply, cost and quality of local building material; the mineral, manufacturing and agricultural products; the value of real-estate and the sentiment of the settlers toward the proposed undertaking, are all matters of importance which should receive close attention. The difficulties of making a reconnoissance are often very much increased when the engineer is enjoined not to make his business known.

The instruments usually taken upon a reconnoissance are, a tape line, pocket compass, a pocket level and an aneroid barometer. No suggestions are required upon their use, except the last named. The aneroid is a very useful instrument but exceedingly treacherous. It should be looked upon with suspicion. It may be highly recommended by its maker, and the "compensated" upon its face may give it a very honest appearance, yet it should be closely watched. The writer once made a reconnoissance unassisted by any means of instrumental measurement and he reported that the proposed route would require a grade of seventy-five feet per mile. As the line was to be located upon a ruling grade of forty-two feet per mile, this was unfavorable to the parties who had a pecuniary interest in the adoption of that route. They requested that a more careful examination be made. Assisted by a "compensated" aneroid from one of our best manufacturers, I went over the ground again. The readings taken showed that the country could be crossed on the ruling grade. Subsequently, an instrumental survey was made, which proved that the eye was very much more accurate than the aneroid and the route was abandoned. Many instances could be given where the unreliability of the aneroid barometer has been proven by instrumental measurements. Readings taken at different times at the same point show a great variation with no perceptible change in the meteorological condition, except, perhaps, a few degrees in temperature.

The reconnoissance should be made with great care. An error in judgment may cause many miles of the reconnoissance, and even many miles of the surveyed line, to be abandoned. If the engineer assumes that a summit can be reached at a certain place and he continues his examination of the country beyond with reference to that point, but the subsequent instrumental survey proves that he was so much in error that the additional distance of maximum grade required to gain the summit, has thrown him so far from the line of reconnoissance that he can not return to it, he will then have to make a new reconnoissance of the country ahead, or in case the selected summit crossing is a governing point on the survey, he may have to back up, perhaps five or ten miles, and change his surveyed line so as to arrive at the point designated.

The reconnoissance being completed, the engineer makes his report to the projectors of the undertaking. If the report is satisfactory to the management, a preliminary survey is ordered. A field party is then organized, which, under ordinary circumstances, consists of a locating engineer, who is chief of the party, a transitman, levelman, topographer, rodman, two chainmen, flagman, marker or stake artist, axemen, as many as may be required, and usually two teamsters and a cook. The topographer is sometimes allowed a tapeman and the cook an assistant. When the work is being crowded, extra men and teams are required to move the camp and to furnish supplies. Formerly, on frontier work, a squad of soldiers were added for protection, but it is a question if they ever demonstrated their usefulness, except to consume supplies and occasionally furnish sport for some gang of horse thieves who surprised them, robbed them of their outer clothing, arms and mules and sent them to camp *en dishabille*.

Too great care can not be taken in selecting men for the party. There is no position in the party that "any man" can fill. An engineer corps is not a hospital for invalids who want to rough it for their health. It is not a tourists' expedition to offer one an opportunity to see the country. It should not be made the dumping ground where your friends can unload some worthless ward. It is not a reformatory to cure men of the drink habit by taking them out of reach of intoxicants. Whoever associates himself with an engineering corps, in any capacity, must expect to render hard service and to discharge every duty with conscientious faithfulness if he expects to retain his position.

The transitman, who is first assistant, must be a person of good judgment, quick and accurate with the use of his instrument, and reliable in his mathematical calculations. He should have good command of men, for in the absence of the chief he will have charge of the party. His notes must be so plain and complete that they will require no explanation or filling out in order to be understood in the office. He must give close attention to the details of the work on the line. The chainmen and axemen are under his immediate direction, and he is expected to observe the work of the topographer and level party as he has opportunity and to advise and assist them whenever it may be necessary. He should give careful attention to the chopping and clearing and see that no more be done than is necessary. Unnecessary work is useless labor and much loss of time is caused by inattention to this matter. But whatever is required to be done should not be neglected or slighted.

The value of a preliminary survey depends very much upon the work of the topographer. The position of buildings, the course of streams, ledges of rock and other obstacles within the limits of a possible location should be carefully noted. On hillsides the contours should be accurately drawn for each five or ten feet of difference in levels. If he is not an accurate pacer he should use a tape line. In specially important places he must have a rodman. He should have a pocket level and a small compass with a Jacob staff, and he should work one day behind the level party, that he may note on his book the crossing of the contour lines taken from the profile. He is also expected to plat the survey and show upon the map the contours and other notation made in the field.

Accuracy and quickness are the necessary qualifications of a levelman. He must have good judgment, so that on irregular ground he will not have to set his instrument a second time in order to get a rod reading. On hillsides his back-sights should come within the last foot of the rod, and if going down the slope, an expert will scarcely ever read above the 0.5 mark on back-sights. The adjustments of the instrument should be tested each morning and noon, and more frequently if he has reason to believe that the adjustments have been affected by the weather or by handling. His notes must be neatly kept and his figures must be so plain that they can not be mistaken. He must keep his calculations up with his work by recording the elevation of the point immediately after the rod reading has been entered, and must not keep the rodman waiting, though he ran between stations. He should verify his calculations before platting the profile, which must be done at the close of each day's work. His notes should give accurate contours of the ground, and at the crossing of streams the high water mark, the water surface at time of the survey, and if possible the cross-section of the channel should be given. The elevations of ledges of rock projecting from hillsides should be taken, as it may be a matter of importance in adjusting the grade line.

The rodman, also, must have good judgment and an accurate eye, to quickly determine where readings should be taken in order to give the information required. He must be active in his movements and should be able to follow the line and find the stakes, even when concealed by grass. He should be an accurate pacer, so as to locate his plus distances quite closely without the use of a tape line. He must keep a peg book in which he notes the position and elevation of all turning points and benches. The levelman and rodman must compare elevations at each setting of the instrument and for all benches. They should have a system of signals by which to communicate numbers when they can not do so with the voice. When plus readings are taken between stations, the rodman can note the distances on a piece of paper and hand them to the levelman when passing instead of taking time to communicate by signals. A Philadelphia self-reading, thirteen-foot rod is the best for general purposes. In rough countries where the hollows are not very deep and the ridges not too far apart, much time may be saved if the rodman will carry an extension eight or ten feet long made of window stop, which can be quickly attached by means of a socket secured to the end of the rod. As all readings on benches and turning points must be taken from the target, this extension can not be used for such purposes. For special readings the rod must be held vertical. To do this, the rodman must stand directly behind the rod and wave it in the vertical plane of the instrument while the levelman notes the shortest reading. Rod levels are of no advantage, except in rough rock work where the rodman can not take his correct position. There are many time saving methods practiced by expert levelmen which we can not mention here. It is the duty of the rodman to assist the levelman in platting the profile by calling out the elevations.

The importance of having a good head chainman is not always recognized. The progress of the survey depends very much upon his ability to efficiently perform his work. On tangents across open country, by selecting a fore-sight, he should keep his direction so closely that when he arrives at the chain's length he is well in line for setting his flag, and as soon as he receives the signal of "all right" from the transitman, he should at once move rapidly forward to the next station. Knowing the degree of the curve and the last two stations being in view, he should so closely determine the position of the stake that no movement of the body will be necessary. In timbered countries he must direct the axemen in their work, that they may not delay the progress of the party by doing unnecessary chopping. This he can do by holding his flag pole horizontally in the direction of the line and sighting along its top side, or better, by having the transitman set the flag in line as far in advance of the instrument as the clearing will permit; then by taking a position ahead of the axeman he will be able to discover all obstructions to the sight. He must exercise good judgment in selecting transit points, that the transitman may have a good view of his back-sight and of the country ahead. He must be accurate in setting off fractional distances on the chain, and every precaution against error should be taken in this matter, as well as in the numbering of the stakes. The fractional number upon the stake set should be called aloud by the rear chainman, and the fractional distance to be set off for the next station will be called off by the head chainman, which should be verified and repeated by the rear chainman. If the rear chainman makes the division upon the chain, he must verify his position by counting from both ends of the chain. If the transitman is within hearing and seeing distance, he should give close attention to the whole matter. At every station the rear chainman must call out the number upon that stake, which will be answered by the marker calling out the number upon the stake about to be driven. The head chainman must observe that the numbers called are consecutive. These precautions may seem unnecessary to the novice, but he who will not observe them is an unsafe man and not qualified for the position. The stake must be marked and ready to set the instant its position is determined by the head chainman.

The cook is by no means the least important member of the party. Men will always render better service when the stomach is well filled with properly cooked food. Hence, the cook must be a baker and not merely a mixer. He should know that cooking is something more than boiling, that flour starch is neither pastry nor gravy. He should know enough about fruits so as not to spoil a good sauce to make a very poor pie. He must be prompt with his meals, cleanly in person, and obliging in manners. He should understand his rights and privileges as well as know his duties. He should have the courage to insist upon having the former and the disposition to willingly and cheerfully perform the latter.

In all well conducted parties, each member will have some special duty assigned him, for the performance of which he will personally be held responsible. But it is expected that each will assist the others as may be necessary in order to advance the work. Even the chief of the party will not lower his dignity by assisting his axemen through a brush tangle, or by bringing them a cup of fresh water.

The camp and field equipment should receive close attention. Experience alone will qualify one to properly outfit a party. Even the veteran engineer who has been assigned to frontier work, will not load his outfit until his camp has been set up entire and it has been examined in every detail of its equipment. Many useful suggestions could be given, but we will only say that nothing essential must be omitted, and that which is not necessary must be discarded, even to surplus clothing.

Though great care has been exercised in the organization of the party, yet discipline in camp and field is necessary. At the first call of the cook all must arise and be ready for breakfast at the second call, twenty minutes later. No laggard who requires a second call, or who is habitually late at breakfast, should be retained, whether he be axeman or transitman. All should sit down at the table together and should not forget that they are gentlemen. Boorishness at the table will rob the best prepared meal of its power to satisfy or to please. We do not feed swine from a silver platter, neither will the most tasty and competent cook prepare a gentleman's table for a company of unbred boors. The chief should occupy the head of the table and his four assistants should have seats upon his right and left, and the others should have regular places at the table.

No one should have an oppportunity to get drunk twice while he is a member of the party. Intoxicants, as a beverage, should not be permitted in camp. Card playing and smoking are so generally associated with camp life as to be regarded a part of it. But gambling must not be allowed in camp, and the office tent should be kept free from the fumes of tobacco. It is an offensive act to send notes to the general office which are saturated with the smell of tobacco.

It is a sad reflection upon the engineering profession when public opinion is such that the people expect to meet a set of hoodlums when they learn of the approach of an engineering corps. This being the case, the first persons to meet a party upon entering a new place are, generally, the vagrants and bums, who expect the boys to "set 'em up," while the respectable citizens will keep at a distance and, except for matters of business, they would not seek to make your acquaintance.

The writer, in his practice, has endeavored to correct public opinion, and many times he has been highly gratified when taken by the hand by good citizens and warmly congratulated upon the gentlemanly conduct of the members of his party, and for having demonstrated that engineering parties can be respectable. Some very amusing incidents could be given of the slinking away of disappointed bums, upon their discovery of having met the wrong men.

Courtesy, like charity, must begin at home; hence, the members of the party must be courteous to each other if they expect that recognition among strangers. Courtesy among fellows is necessary to a pleasant companionship, and a lack of it is certain to engender strife. An insufficiency of well cooked food and the habit of keeping a party out late at night, as is the practice of some, are causes of discontent. Give the men no just reason to grumble at the table, and listen to no complaints about hard work. By making good use of the regular working hours of the day, more will be accomplished, and more pleasantly too, than by loitering along for twelve or fourteen hours. A party will not work up to its full efficiency under unfavorable circumstances, no more than an engine will develop its rated horse power with poor fuel and an adjustment of parts that will cause excessive friction in every bearing.

There is a difference of opinion among engineers concerning the proper scale of wages to be adopted. It is the practice of some to have an equal rating for all below the levelman. Others make the wages commensurate with the qualifications required and the responsibility assumed. The latter plan is certainly more just and satisfactory. Upon a basis of $100 per month, a fair rating is as follows: Transitman, $100; topographer, $85; levelman, $85; rodman, $50; head chainman and cook, $45; all others, $35. Many companies, however, adopt $90 as the maximum and $30 as the minimum. This is in addition to boarding and traveling expenses, and some companies furnish blankets also.

One of two general methods may be followed in making the surveys for a line of railroad. First, the preliminary survey of the entire line, or a considerable section of it, may be completed before the location survey is commenced. Second, the preliminary and location surveys are sometimes so combined as to be made by the same party and at the same time, but in an alternating manner.

Likewise, a railroad company may have either one of two general purposes in view when they put a party in the field to make a survey. It may be the bona fide intention of the company to build a line of road. But it frequently occurs that the purpose is to obtain more favorabe terms with a connecting road by making a show of building a competing line; or, perhaps its object may be to discourage and intimidate some independent enterprise which might be fostered by a competing company.

It would not be advisable to keep the location up closely with the preliminary survey on mountainous work, or where a long distance of maximum grade is required. It frequently occurs that in such cases some obstacle is encountered, which it was not possible to foresee and which will require such a change in the surveyed line as to involve considerable expense in case the location had been made. If the purpose of the survey is to bluff, a location is not required unless it becomes necessary to play the game very intensely.

When a considerable extension of a line is proposed, it sometimes becomes necessary to establish a priority of right to a mountain pass or a narrow canon far in advance of the regular work. A preliminary survey will hold the right of way, although the location may not be required for some years afterward. When two great companies are contending for the same advantage, then we have the diversion of a railroad war. The contention between the Santa Fe' and the Denver and Rio Grande companies for priority in the Grand Canon of the Arkansas, is probably the most notable instance upon record.

When the conditions and circumstances will permit, there is a a great advantage in making the preliminary and location surveys jointly. The party is handled to much better advantage with a consequent saving of time and expense. The camp should be pitched five to ten miles in advance of the terminus of the location and the preliminary should be run to a distance of five to ten miles beyond the camp, or to some governing point from which it can be extended. When the preliminary has been run as far as necessity and convenience may require, the party, without moving camp, can resume the location. The preliminary line having been platted as before directed, the chief can now plat in the line as he wishes to locate it and instruct his assistants how to proceed with the survey. This will give him an opportunity to attend to a multitude of other duties, which is not within our limits to define, while the work on the line can proceed without his personal supervision.

If the engineer who is conducting the survey has also made the reconnoissance, he will be able to project the line with the knowledge he has already obtained. But if he did not make the reconnoissance, it will be necessary that he look up the country well in advance of his party. Neither must he confine himself to the route mapped out by his predecessor, but must examine the country upon both sides of this line within the limits of a possible economic location. He knows that as the unaccounted-for possession of stolen property is an evidence of guilt, so he who is last upon the ground will be held responsible for the condition of the work. Sometimes two or more routes covering a distance of five, ten, or even forty miles will be discovered, the choice of which can be determined only by a preliminary survey over each route.

On preliminary work, it is necessary to run an angle line only. Along bluffs and rock cliffs the line should be so run as to form a base from which the topography may be accurately taken. In canon work, triangulation can sometimes be used to advantage. But if the inaccessible gorge is of considerable length it may be necessary to take advantage of the winter season and run the base line upon the ice. In mountain regions where a great amount of preliminary work is sometimes required in order to find the most feasible way of crossing the range, the stadia can be used to very great advantage. This will furnish accurate information of distances, but the elevations of stadia stations only will be given. This, however, will be sufficient to determine where transit and level lines should be run. In mountainous work the grade line must be run from the summit. In all cases the angle line should approximate as closely as possible to the line of location, but I have not much confidence in the location made by an engineer who claims to have run his preliminary so exact as to require only the curves to be put in, to complete the location. When an obstacle is encountered on preliminary work, it should be passed as speedily and as easily as possible. It may be a tree, a house, a haystack or a bend in a stream that is difficult to cross. And it is sometimes prudent to make a flank movement on a colony of belligerent hornets. Deflecting by an angle is the preferred practice on preliminary work. If the obstactle is discovered in time, the deflection should be made at the distance of a full sight of the instrument. In timbered countries, an angle of five or ten minutes may save much time in chopping. On location work, it is better to make two square offsets on each side of the obstacle. They should be two hundred feet apart, and farther if possible. Deflecting by acute angles and measuring distances, to get around an obstacle, can not be recommended on a located tangent.

A record should be kept of all side lines run, whether they were found favorable or not. Unless this is done, the locating engineer is apt to lose much time with his party in finding out for himself that what seems to be a probable improvement is not at all practicable. The same route has probably been examined by his predecessor and rejected. Much time has been wasted on preliminary work by running lines that ordinary judgment should have condemned after a careful reconnoissance. The engineer is expected to obtain the very best route possible and he should take sufficient time to discover it. But he is also held responsible for any wanton waste of time and of money that is not his own. He must be a conscientious agent of the parties who have intrusted to him this great responsibility. It has been stated that God has prepared a way, but it is the province of the engineer to discover it.

All the information reported by the engineer on reconnoissance should be verified and added to as far as possible. On the profile he must note the classification of material in every excavation. The examination and other excavations in the vicinity will assist him in this matter. Definite information must be given about bridges and drainage. The amount of drift in a stream in time of flood has much to do with determining the length of the spans and consequently the cost of the structure. The cost of diverting a stream from its natural channel must be compared with the cost of two crossings. The expense of protecting an embankment with rip-rap must be figured against that of excavating a road-bed in the bluffs. His information must be complete, so that a close approximation of the cost of construction can be made.

The preliminary line is the base from which the location survey is to be made. Its value is measured by its efficiency to serve this purpose. If the locating engineer is not the person who conducted the preliminary survey, he must make a careful and thorough examination of the ground in connection with the information furnished by the maps, profiles and other notes of the preliminary survey, before projecting his location. This examination must not be confined to the route of the preliminary, but it must include all possible routes suggested by the topography of the country which has not been examined and reported upon by his predecessor.

As before stated, in mountainous countries the principal object to be attained is an elevation. The elevation to be overcome is a fixed quantity for which the engineer is not responsible. He can modify it only by a summit or tunnel crossing of the range. Upon any ruling grade a definite distance will be required to overcome this elevation. But this distance will be affected by the curvature. Each degree of curvature will necessitate an increase in the length of the line equal to the rate of compensation divided by the rate of grade per one hundred feet. Hence, curvature has a two-fold effect upon the operating expenses of the road. But curves are necessary to decrease the cost of construction. The problem of the engineer, then, is to determine how much curvature he will be justified in using, to cheapen the construction at the increased cost of operating the road.

There is also another important factor to be considered in mountain districts. Any increase in the length of the line above that required to overcome the elevation, adds to the distance requiring heavy engine tonnage. Again, the further the heavy grade is continued down the slope, the shorter will be the aggregate length of the whole line. While no rule can be given by which to locate the junction of the heavy and lighter grades, it is generally best to continue the heavy grade as far as the slope of the country will permit. Other conditions, such as water and station grounds, may justify the use of several miles of an intermediate gradient beyond the point where the country requires a maximun. If there is a great difference between the two rates, the use of this intermediate grade is further justified by the distance saved in not requiring the line to be developed upon the lighter grade in order to reach the elevation required.

When the survey crosses an undulating country, where direct and adverse grades are used alternately as the topography of the ground requires, the principles of economic location are the same, but somewhat modified. The compensation for curvature will not operate to increase the length of the line in the manner above noted, unless it should occur upon a considerable stretch of maximum grade. With a light gradient and high equating values for curvature and distance, it is better to take excessively heavy work across a valley, rather than deflect and develop the line along the bluffs.

To properly lay a grade line requires good judgment, which is attained only by experience. Where the maximum grade is used continuously, the ground line must be adjusted to the grade line. But where a continuous use of the maximum grade is not required, or where the ground is undulating, the grade line is to be adjusted to the ground line in a manner to give the most economic construction consistent with good drainage. The grade line should not have the appearance of scooping out a cut, or of putting a hump on an embankment.

Using the preliminary line as a base does not mean that any considerable portion of it will be adopted on location. The roughest country is often so densely covered with young timber and brush that it is impossible to determine on a course more than a few hundred feet in length. In such cases the preliminary line becomes so angular as to resemble upon the map the plan of a worm fence with rails of various lengths. But with accurate topography and with the assistance of a string and a few pins, the proper line of location can be readily determined. At each adjustment of the string the new ground levels should be lightly dotted upon the profile and examined with reference to the adjustment of the grade line. When the line has been traced upon the map it must be run upon the ground. It will require very great care to do this. If the preliminary and location lines have points in common which can be accurately determined upon the map, the angle of intersection may be calculated and the course of the tangent will be determined. If one point selected is not upon a tangent already located upon the ground, it will be necessary to produce the line backward to an intersection with the located line. It is generally more satisfactory to determine the position of two points upon the proposed location by latitudes and departures, assuming any course of the preliminary as a base, and from this data calculate the angle of deflection. But for long distances it is better to determine the course of the tangent by offsets from the base line rather than by angular deflection. It is the experience of the writer that a line can be projected in this manner between points distant five or six miles with an error not to exceed three-tenths of a foot, even when three or four angles are turned on the preliminary line. In one instance he projected a line sixteen miles and came within fifteen inches of the point sought. There were not less than six angles turned on the preliminary line. Hence the necessity of accurate work on the preliminary survey if you expect to use it with any confidence on location.

No part of any survey should be done in an indifferent manner. No transit point must be taken without reversing the instrument, and the transitman should be able to see the point of the flag pole. When it is impossible to do this the plumb bob must be used in setting points. Every angle upon transit points must be twice measured. The deflection angle of two tangents must be measured from their point of intersection, unless it is inaccessible. The beginning and ending of a curve must be set before the curve is run in. On a curve of two thousand feet in length, over hills and hollows, the chaining should agree within one foot with the points set off on the tangents, and the angular measurement within one minute of the angle of intersection. The magnetic bearing of every course on the preliminary, and of every tangent on the location, must be read and recorded. The calculated bearing of each course, determined from the magnetic bearing of the first course, must also be entered and compared with its magnetic bearing, as a check against an error which might otherwise occur by making a wrong record of the direction in which the line was deflected. Every mathematical calculation affecting the work must be verified. All copies of notes from the office record, for use in field, must be carefully compared with the original. The levels on location must be compared with the preliminary levels at every bench mark. A variation of more than .03 in a distance of two thousand feet must be verified before extending the levels.

He who thinks these precautions too exacting will learn by experience their value. It is no recommendation to a man to claim that he never makes a mistake. The true estimate of such a person is, that he is very conceited and has not intelligence enough to discover a mistake when he has made one, nor the courage and honesty to acknowledge and correct it. The man to be trusted is he who knows that he sometimes makes blunders, but is ever on the lookout to discover and correct them.

There are many opportunities and inducements for an engineer to be dishonest. Land speculators will try to influence him in the location of the line. Contractors will ask for favors in the classification and measurement of material on construction. Others will offer a commission on the amount obtained for them as damages for trespass and right of way. Merchants will wish to bestow gifts and favors, to secure influence that would benefit their trade.

Honesty is not always rewarded. But the consciousness that you have been faithful and true to the trust confided to you, and honest in all your motives and transactions, will be of greater satisfaction to you than any success of renown, or accumulation of wealth, that you might have otherwise achieved.

TEST OF A HEATING SYSTEM.

By L. P. Breckenridge, Professor of Mechanical Engineering.

Report of a test, made on December 28th and 29th, 1895, of the heating system in Engineering Hall of the University of Illinois.

To the Committee on Buildings and Grounds,
University of Illinois.

Gentlemen:—I take pleasure in submitting to you the following report concerning an examination and test of the heating system recently installed in Engineering Hall by the Maltby & Wallace Company of Champaign, Ill.

The heating system of Engineering Hall was first put in my charge December 19, 1894. A careful inspection of the entire plant, including the 6-inch main leading from Natural History Hall, was made by J. Morrow and myself, and a list of unimportant defects was sent to the contractors. These defects have all been made good, or measures taken for so doing.

There are some points concerning the system that it seems to me should be changed. The most important one is that of providing some means of shutting out the cold air from the indirect stacks. Considerable trouble has been experienced with these stacks from the freezing up of the air valve connections, and this would be avoided if provision were made as suggested. It was a mistake to connect the trap discharge to the drain pipe from the down spouts, as steam fogs up these spouts might cause trouble by melting snow at the top and causing it to freeze and to stop up the down spouts. Besides the two points mentioned there does not seem to be anything about the system that could be changed for the better. These may easily be remedied.

You have in this building an excellent heating system. The materials of construction are all first-class. The work done by the contractors is very satisfactory, and the whole system works well; it is noiseless and circulates on a pressure of two pounds with perfect freedom. It will heat the entire building to 70 degrees in zero weather, and most of the rooms can be heated to 75 degrees with an outside temperature of 15 degrees below zero.

Test of the System.

Arrangements were made on December 27th for a test of two days duration to begin on Friday, December 28th. Thirty thermometers were hung side by side and a series of readings taken from them for comparison with a standard thermometer. Twenty-four thermometers were then hung in as many of the leading rooms in the building, six on each floor, and six were kept for moving from room to room. Everything seemed to conspire to make the conditions for a test favorable. On the morning of the 28th the thermometer stood at 3 degrees below zero and only averaged 11.1 degrees for the day. Steam was kept on the building over night on a part of the radiation, and early Friday morning all the radiators in the building were turned on, and the test started.

Observations were taken every thirty minutes throughout the day, of the temperature of the twenty-four rooms having thermometers in them, and of the external air temperature; the steam pressure on the building, and on the 6-inch main in sub-basement.

Readings were also taken of the temperature of every room in the building not included in the twenty-four rooms mentioned above at some time during the day.

The results of this test are recorded in the tables on pages 164 and 165, each floor being reported in a separate table. The pressure on the building and on the main is only reported with the table of the fourth floor. It may be seen by inspection of these tables that the average temperature of the four floors is by floors as follows:

Fourth floor,	84.1
Third floor,	79.3
Second floor,	73.6
First floor,	64.5

Average for building, 301.5÷4=75.4 degrees approximately. All the radiation was turned on. Average external air temperature, 11.1 degrees. Date, December 28, 1894.

On the following day, December 29th, a further test was made as follows: An attempt was made to hold the temperature of all the rooms at 70 degrees by shutting off radiators. This proved to be an interesting and valuable test. The outside temperature was not low, only varying from 19 degrees to 40 degrees during the day, so that the average was 31 degrees, or nearly at the freezing point. The results of this test are shown on pages 166 and 167, each floor being in a separate table.

At 8 a. m. every room on the fourth floor was above 80 degrees, and between 8:30 and 9 every radiator on this floor was shut off and remained so during the day. On the third floor nearly all the indirect and at least one half the direct radiators were shut off. On the second floor most of the radiators were running; in three rooms only was any radiation shut off. On the first floor all the radiators except three were running.

Under these conditions the results were as follows:

Fourth floor, ...	82.3
Third floor, ...	77.2
Second floor, ...	74.4
First floor, ...	69.3

Average for building 303.2÷4=75.8 degrees.

It is evident from the results of these two trials that there was much more radiation on the top floor than was needed, while the amount on the first floor was not enough. In accordance with suggestions made to the contractors, they moved some 400 feet of direct radiation from the top to the first floor.

Since these changes were made we have had two mornings when the temperature was below zero, and the rooms where changes were made are much improved, and satisfactory. There are three rooms, however, that need more radiation and the contractors are now arranging for this.

FIRST FLOOR.

Temperature December 28, 1894.

Time	Corridor	105	109	112	121	External Air
	Number of Room.					
8:20	67° F	61°	67°	61°	58°	1°
8:45	66	60	66	62	56	1
9:15	66	61	67	61	56	1
9:40	67	62	66	61	56	3
10:00	67	63	66	62	56	4
10:30	68	64	67	62	56	5
11:00	68	66	68	62	57	9
11:30	70	68	68	62	58	9
12:00	70	69	68	62	59	10
12:30	70	70	68	62	60	11
1:00	70	71	68	62	60	13
1:30	70	70	68	64	60	14
2:00	70	70	68	64	61	14
2:30	70	70	64	64	62	15
3:00	71	66	63	64	63	16
3:30	71	66	61	65	63	16
4:00	71	65	61	64	63	16
4:30	72	64	60	64	63	15
5:00	72	64	60	64	63	16
Average	69.25	65.8	65	63	59.5	11.1

Average temperature for the floor 64.5. All radiators on this floor were turned on.

SECOND FLOOR.

Temperature December 28, 1894.

Time.	208	209	Corridor	212	221	External Air.
	Number of Room.					
8:20	74° F	72°	68°	64°	61°	1°
8:45	76	74	74	62	60	1
9:15	79	73	78	64	61	1
9:40	84	75	68	64	62	3
10:00	—	74	68	65	62	4
10:30	88	74	69	65	63	5
11:00	88	74	70	66	64	9
11:30	96	74	68	67	64	9
12:00	102	74	70	68	65	10
12:30	103	74	71	69	66	11
1:00	93	76	71	69	67	13
1:30	93	75	71	70	67	14
2:00	94	75	71	72	68	14
2:30	100	75	72	73	69	15
3:00	92	75	72	76	69	16
3:30	90	75	72	81	70	16
4:00	87	75	72	72	70	16
4:30	84	75	72	71	70	15
5:00	82	70	71	71	70	16
Average	89	74	71	68.75	65.5	11.1

Average temperature for the floor 73.6. All radiators on this floor were turned on.

THIRD FLOOR.

TEMPERATURE DECEMBER 28, 1894.

Time.	Number of Room. 305	300	309	319	Corridor	312a	External Air.
8:20	80°F	77°	84°	74°	74	61°	1
8:45	81	78	80	74	78	66	1
9:15	82	78	81	74	70	64	1
9:40	91	80	81	76	70	65	3
10:00	86	80	82	76	74	66	4
10:30	87	82	84	77	73	65	5
11:00	88	90	82	78	74	67	9
11:30	92	96	83	79	74	68	9
12:00	98	99	83	80	74	69	10
12:30	97	98	83	84	75	70	11
1:00	91	87	83	81	75	70	13
1:30	90	87	84	82	75	74	14
2:00	92	85	84	83	75	72	11
2:30	99	85	84	83	76	73	15
3:00	91	84	84	83	76	74	16
3:30	87	84	83	83	76	75	16
4:00	84	84	83	84	76	74	16
4:30	79	79	81	85	76	72	15
5:00	77	78	82	80	76	70	16
Average	88	84.5	82.5	79.5	74.5	69	11.1

Average temperature for the floor 79.3. All radiators on this floor were turned on.

FOURTH FLOOR.

TEMPERATURE DECEMBER 28, 1894.

Time.	Number of Room. 400	423	424	407	408	Corridor	External Air.	Pressure on Building (lbs.)	Pressure on Main (lbs.)
8:20	—°F	81°	80°	81°	80°	76	1°	—	—
8:45	82	82	80	84	80	78	1	3.9	42
9:15	82	84	80	82	84	78	1	4.0	45
9:40	84	81	81	82	82	77	3	3.8	*42
10:00	86	85	85	83	81	79	4	3.7	40
10:30	88	85	82	83	82	80	5	3.8	45
11:00	89	85	82	83	82	78	9	3.9	50
11:30	90	88	83	84	84	78	9	4.0	56
Noon	91	87	84	84	84	80	10	4.2	55
12:30	92	87	84	85	84	80	11	4.0	62
1:00	92	87	84	85	84	80	13	4.1	41
1:30	93	88	85	85	86	80	14	4.0	42
2:00	90	88	85	85	84	84	11	4.0	42
2:30	88	88	86	85	85	81	15	4.2	44
3:00	88	89	86	85	85	80	16	4.2	52
3:30	84	89	87	85	85	80	16	4.3	55
4:00	84	89	87	86	84	84	16	4.2	58
4:30	86	89	87	85	85	82	15	4.5	58
5:00	86	90	87	85	85	82	16	4.7	54
Average	87.5	86.5	84.0	83.9	83.3	79.5	11.1	4.1	49

Average temperature for the floor 84.1. All radiators on this floor were turned on.

FIRST FLOOR.

Temperature December 29, 1894.

Time.	Corridor	124	105	112	109	External Air.
	Number of Room.					
8:00	74°F	—°	63°	—°	58°	19°
8:30	74	66	64	68	59	20
9:00	74	69	66	66	60	22
9:30	75	68	65	67	60	23
10:00	74	69	67	68	63	26
10:30	74	69	68	66	65	26
11:00	74	70	68	66	66	28
11:30	74	70	70	66	65	30
12:00	74	71	70	67	68	32
12:30	74	72	71	67	69	34
1:00	74	72	69	66	69	34
1:30	75	72	69	67	69	36
2:00	75	72	69	68	70	38
2:30	75	73	71	69	70	39
3:00	76	74	70	69	70	39
3:30	75	74	70	69	70	40
4:00	76	74	69	69	70	40
Average	74.5	71	68.2	66.75	66	31

Average temperature for the floor 69.3. All radiators on this floor were turned on except one in corridor.

SECOND FLOOR.

Temperature December 29, 1894.

Time.	208	221	209	Corridor	112	External Air.
	Number of Room.					
8:00	74°F	72°	83°	72°	70°	19°
8:30	75	72	75	73	71	20
9:00	78	73	76	72	71	22
9:30	79	73	77	73	72	23
10:00	82	73	75	73	72	26
10:30	83	74	74	73	72	26
11:00	82	73	74	73	73	28
11:30	86	74	73	73	73	30
12:00	82	74	73	74	73	32
12:30	82	75	73	74	74	34
1:00	78	75	73	73	74	34
1:30	76	75	73	73	74	36
2:00	76	75	73	74	74	38
2:30	77	75	73	74	73	39
3:00	75	75	73	74	74	39
3:30	74	75	72	74	75	40
4:00	74	76	73	74	74	40
Average	78.4	74	73.8	73.3	72.8	31

Average temperature for the floor 74.4. All radiators on this floor were turned on except three.

THIRD FLOOR.

Temperature December 29, 1894.

Time.	Number of Rooms — 305	309	Corridor	300	312a	319	External Air.
8:00	88°F	87°	77°	77	72°	79°	19°
8:30	79	84	78	75	71	78	20
9:00	81	83	77	75	71	78	22
9:30	81	84	77	73	72	77	23
10:00	82	84	77	71	70	77	26
10:30	84	84	76	75	69	76	26
11:00	81	80	77	76	70	77	28
11:30	84	80	76	83	72	77	30
12:00	86	80	78	80	73	77	72
12:20	84	80	78	78	71	77	34
1:00	80	80	77	74	74	77	34
1:30	79	80	77	73	75	77	36
2:00	78	80	77	72	71	77	38
2:30	80	80	77	76	71	77	39
3:00	78	79	77	72	71	76	39
3:30	77	80	78	72	76	76	40
4:00	80	79	78	72	77	75	40
Average	81.1	80.9	77.2	75.1	72	77	31

Average temperature for the floor 77.2. All indirect radiators and about one-half of the direct radiators on this floor were turned off.

FOURTH FLOOR.

Temperature December 29, 1894.

Time.	Number of Room. — 423	407	424	400	Corridor	408	External Air.	Pressure on Building (lbs.)	Pressure on Main (lbs.)
8:00	95°F	84°	91°	—°	82	85	19	1.7	20
8:30	94	85	94	89	82	85	20	5.4	35
9:00	95	87	94	89	81	81	22	5.5	50
9:30	94	86	88	86	80	82	23	5.5	50
10:00	94	86	85	85	80	80	26	3.8	50
10:30	90	86	83	80	80	79	26	3.7	46
11:00	89	87	81	79	80	78	28	3.6	47
11:30	88	86	81	77	80	77	30	3.6	40
Noon	87	85	80	75	80	76	32	3.8	50
12:30	86	84	79	80	80	76	34	3.7	40
1:00	85	85	78	80	80	75	34	3.8	50
1:30	85	84	77	89	80	75	36	3.8	40
2:00	84	83	77	79	81	75	38	2.1	50
2:30	84	83	77	80	84	73	39	2.0	43
3:00	84	84	77	80	80	75	39	2.2	43
3:30	82	84	77	80	80	75	40	2.2	44
4:00	80	83	76	80	80	74	40	2.0	40
Average	88	84.8	81.7	81	80.4	77.9	31	3.5	42

Average temperature for the floor 82.3. All radiators on this floor were turned off.

In addition to the results of the test here recorded, every room in the building has been examined and the radiation now in the room has been checked up and compared with the space and wall and glass surface. This data has been properly recorded for future reference and will be of considerable value to the heating department. It did not seem desirable to add all of this matter to this report, but below are given the totals for the several items for the entire building.

Data from heating system of Engineering Hall:

Space heated (cu. ft.)	747 207
Outside wall area (sq. ft.)	43 558
Glass area (sq. ft.)	7 286
Direct radiation from radiators (sq. ft.)	5 908
Direct radiation from pipes (sq. ft.)	1 650
Total direct radiation (sq. ft.)	7 557
Total indirect radiation (sq. ft.)	3 157
Total radiation (sq. ft.)	10 642
Total area of direct and $\frac{3}{4}$ indirect (sq. ft.)	9 699
Heating surface required by Mills' rule (sq. ft.)	9 966
Ratio of heating surface to space heated	1 to 77

The above items have been worked out for each room in the building.

ACTUAL SURFACE IN RADIATORS.

The actual surface in the direct radiators was measured and found to agree with the surface as given in the catalogue of the makers, The American Radiator Co. The actual surface in the indirect radiators is not as given in the catalogue, being something like 20% short. Each section of these indirects contains 2.58 square feet of surface; the amount in the catalogue ratings is 3.22 square feet per section.

REGISTERS.

The registers admitting warm air into the rooms from the indirect radiators are of the Tuttle & Bailey make, most of them being 16x20 inches. The proportion of air openings in each register is 58.7% of the nominal size. The "Ideal" pattern of direct radiators is used, and the Western Tube Co.'s pipe radiator for indirect radiators. Each radiator is four sections wide by different lengths, all 24 inches high. The radiators are not painted. The Marsh No. 6 automatic air valves are used on all radiators.

The length of the 6-inch main connecting this building with the 8-inch main at Natural History Hall is about 750 feet. In this main are two expansion joints and six elbows, an angle valve at Natural History Hall and a gate valve in Engineering Hall. The loss of pressure between these buildings is about two pounds for a pressure of forty pounds on the main. The loss from the boiler house to Engineering Hall is about 3.5 pounds. This loss of pressure should be made the subject of a more careful test and comparison of gauges. It seemes small, but is not far from correct.

Hoping that this report may meet with your approval, I remain,

Yours respectfully,

L. P. Breckenridge,

Superintendent of Heating Department.

Additional Notes.

The system of heating used in Engineering Hall is what is known as the Mills overhead system. The steam, which is delivered into the sub-basement of the building at about 40 pounds pressure, is passed through an 8-inch Davis reducing pressure valve and the pressure reduced to 1, 2, 3, 4, or 5 pounds, as the external temperature demands. For three weeks of this winter, 1894-5, the temperature was down to zero nearly every night, and on this occasion was 22 degrees below. During this severe weather the building was easily warmed with 5 pounds of steam. With the temperature between 10 degrees and 32 degrees above, 3 pounds is sufficient to warm the building, while for warmer weather 1 to 1.5 pounds is all that is required.

The steam, after passing the reducing valve, is carried through an 8-inch main to the attic of the building, where it divides into three equal branches 4.5 inches in diameter, and is thus distributed to the three wings of the building. The overhead mains in the attic are covered with asbestos fire proof covering. From the mains run the smaller mains to the sides of the building and then drop to the sub-basement in one straight run. From these drop pipes connections are taken one to each radiator. Liberal provision is made for expansion of all pipes and connections.

Nearly all the direct radiators are connected to the drop pipes by a tee in the pipe near the ceiling of the room below; while the indirects are connected mostly by tees in the pipe at the floor line of the room in which the radiators are placed.

The indirect radiators are in all cases placed under the windows and in a recess left for them in the brickwork. The air supply comes through openings in a cast iron plate which forms the lintel of the window below, passing up to the radiator through a space left for it in the wall. Provision has now been made for shutting off the air from the outside by means of a slide damper operated from the room in which the indirect is placed. Air is induced to flow through those radiators by ventilating shafts distributed throughout the building. These shafts are of two kinds; one is heated by pipe coils entending from the top to the bottom floor, and the other is arranged to be connected to an exhaust fan placed in the basement of the building.

On February 20, 1895, all the steam used to heat the building from 10 a. m. to 4:30 p. m. was weighed as discharged from the traps, being mixed with a known amount of cold water for convenience in weighing. The following results were obtained:

Average temperature of external air (deg.) .	37.000
Steam condensed in building per hour (lbs.) .	3 020.000
Water discharged by trap at end of 6-inch main per hour (lbs.)	87.000
Average pressure on building (lbs.)	3.000
Average pressure on main (lbs.)	45.000
Heating surface in use (sq. ft.)	7 200.000
Condensation per square foot of heating surface	0.402

External conditions: moderate wind, sun shining about one-half of the time.

Arrangements have now been made so that further tests of the different radiators may be made and the condensation per square foot of surface determined with the radiators in position. It is believed that this arrangement of the indirect radiators is new and credit should be given to the architect, Mr. G. W. Bullard, for introducing into the plans for the heating and ventilating of the building.

THE COLLEGE OF ENGINEERING.

BY W. R. MORRISON '95 AND P. JUNKERSFELD '95.

In 1870 instruction in engineering branches was first offered at the University of Illinois. Since that time much attention has been given to this part of the work of the University. From the first this department gradually increased and later was recognized as one of the four distinct colleges of the University. During the last few years the growth of the College of Engineering has been remarkable and it now stands among the leading technical colleges of the country.

It has been the aim to teach such branches and to give such training in the mechanic arts as will promote liberal and practical education and fit young men for the special duties of the engineering profession.

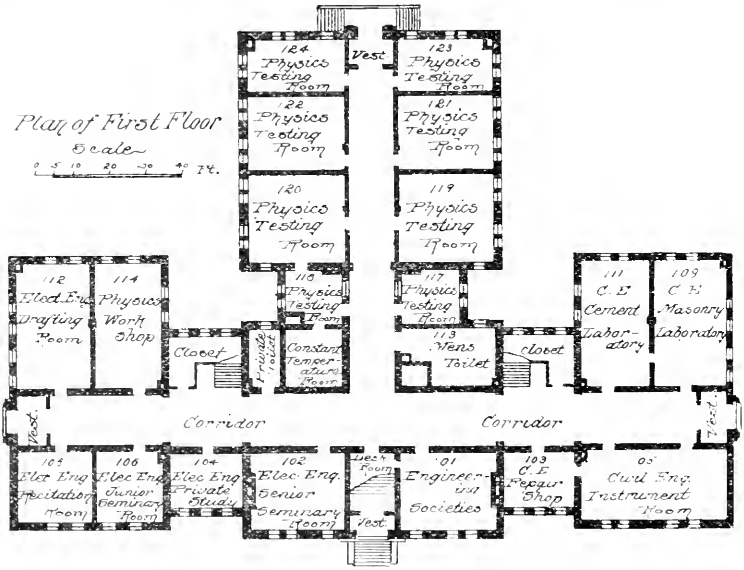
Under the organization of the College of Engineering there are five departments, each of which offers courses leading to degrees. The departments are architecture, architectural engineering, civil engineering, electrical engineering, mechanical engineering, and municipal and sanitary engineering.

The rapid development of these departments and the large number of students attending made a demand for better and increased facilities. In 1893 the legislature passed a bill appropriating $160-000 for a building and equipment to be used exclusively by the College of Engineering. Competitive designs for such a building were asked for by the trustees, and prizes offered. G. W. Bullard of the class of '82 was the successful competitor and was made architect of the building. December 13, 1893, the corner stone was laid, and November 15, 1894, the building was formally dedicated.

Engineering Hall is located on the north side of Green street, midway between the north and south groups of buildings, and facing University Hall. It has a frontage of 200 feet, a depth of 76 feet at the wings and 138 feet at the center. The building is four stories in height and contains 60 000 square feet of floor space. The arrangement and numbering of rooms and the purpose to which each is devoted are shown by the accompanying floor plans. The building is heated by a system of direct and direct-indirect steam radiators.

The direct-indirect radiators are placed in the walls and directly under the windows. Much care has been exercised in the lighting of the building. In every room, provision has been made for an abundance of natural light and also for gas and electric light. The sanitary requirements have been looked after with great care, both as to utility and convenience. A large collection of drawings, photographs and engravings serve to enrich the interior of the building.

Rooms for the use of the engineering faculty are located on the third floor and include a parlor in which the faculty holds its meetings, a business office for the dean and a reading room. In the reading room the computing instruments and similar apparatus are kept. A Thomas 10-place arithmometer, Amslers integrator, Corar-

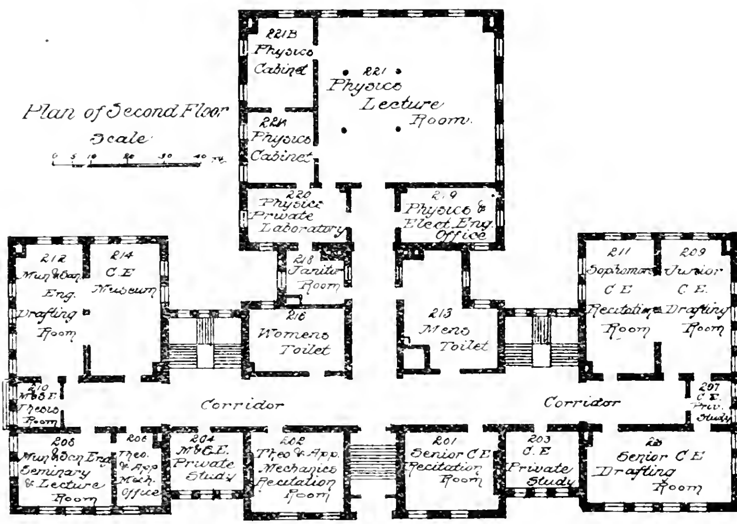


dis rolling and radial planimeters, a large pantagraph, numerous tables and other aids in computation may be mentioned.

A room has been provided for the use of engineering societies. The room is funished with a business desk, book cases, pamphlet cases, tables and chairs. It is fitted up as a reading room and is provided with the leading technical journals. It is also used as a general office by those in charge of the publication which is issued by the societies.

In the assignment of rooms, each department was provided with an office, private studies for instructors, a seminary room, class and drafting rooms and a cabinet room. The offices are equipped with curtain top desks, Shannon filing cabinets, letter presses, card indexes and cabinets designed especially to meet the wants of each department.

The methods of instruction in use in the College of Engineering may be classified as lecture and recitation, drafting and designing, shop and laboratory, and seminary work. The lecture and recitation work is arranged not only with a view to acquiring facts but for the disciplining of the mind and the training of the ability to secure and use the information needed in engineering work. The drafting work is made to conform as nearly as possible to the best practice. The shop and laboratory work is adapted to the requirements of the different courses and receives considerable attention. The seminary



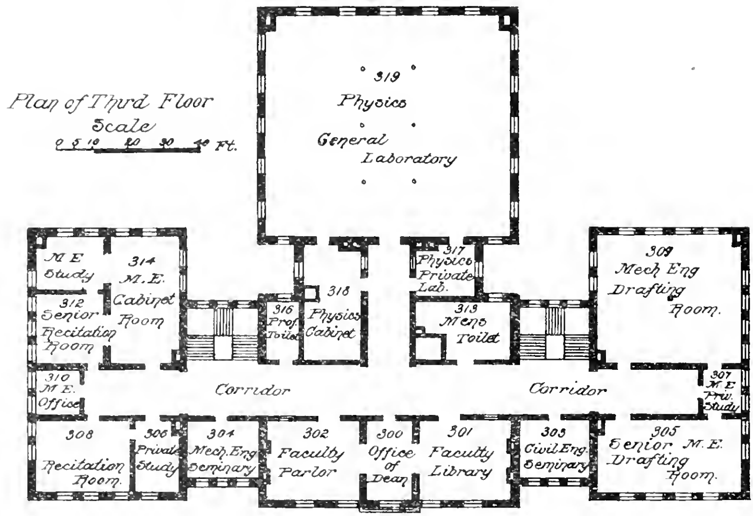
system of instruction has been used to some extent since 1878 and at present is in use in all the departments. References are given to standard engineering publications and from them the student is required to gather information on some particular subject. In some departments weekly meetings are held in the seminary rooms for the discussion of technical literature. In each of the seminary rooms are kept on file all the leading American and foreign technical journals pertaining to the work of the department.

Architecture and Architectural Engineering.

The department of architecture was organized in 1873, under the direction of Professor N. Clifford Ricker, at present dean of the

College of Engineering. Since that time he has been at its head, and it is chiefly through his labors that this department has attained its present high standing. In 1873 there were but two institutions in the country giving instruction in architecture but at present there are eight. The number of students receiving instruction in this department exceeds the number attending any other school of architecture in this country.

The fundamental aim is that the architect should be first a safe and economical builder, second a man of business capacity, and third an artistic designer. The object is to give the young architect a thorough preparation for the whole round of his professional

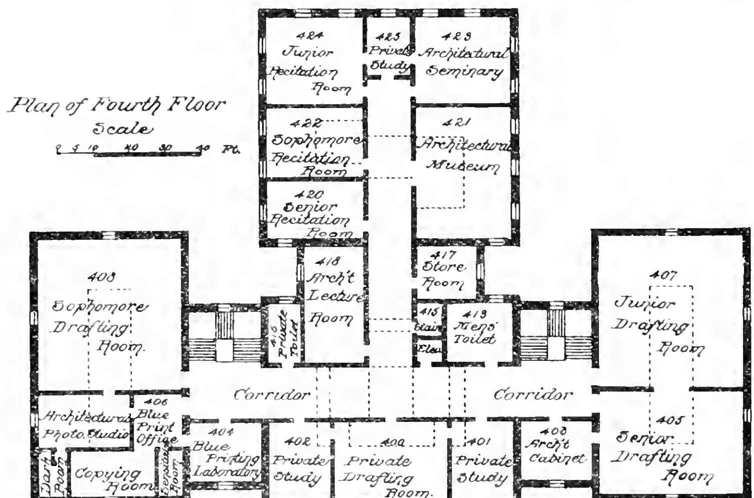


duties. Among the graduates of this department may be found many of the most successful architects of the country.

The department occupies the entire fourth floor of Engineering Hall, comprising about 15 000 square feet of floor space. This is divided into drafting rooms, class rooms, private studies for instructors, a blue print laboratory, a photo studio, a seminary room and a lecture room.

The drafting rooms are lighted from above, thus giving an excellent distribution of light. The adjustable drafting table shown in the cut was designed especially for use in this department by Professor Ricker. The drafting rooms are equipped with these tables and with small lockers for boards and drafting materials. The senior and junior drafting rooms are each provided with a portfolio case. The former is supplied with 7 000 and the latter with 8 000 mounted plates. In the sophomore drafting room full sized details are used instead of mounted plates.

The lecture room is fitted up with a stepped floor and has a seating capacity of seventy-five. The cabinet contains 1 200 lantern slides. By means of a card index the use of these slides is greatly facilitated. The electric arc lantern is of the latest and most approved pattern. The photo studio is equipped with a number of cameras and a dark room. The blue print laboratory consists of an office, a sensitizing room and a printing room. The last mentioned room is equipped with a printing frame, developing sinks and drying frame. The museum contains many valuable ex-



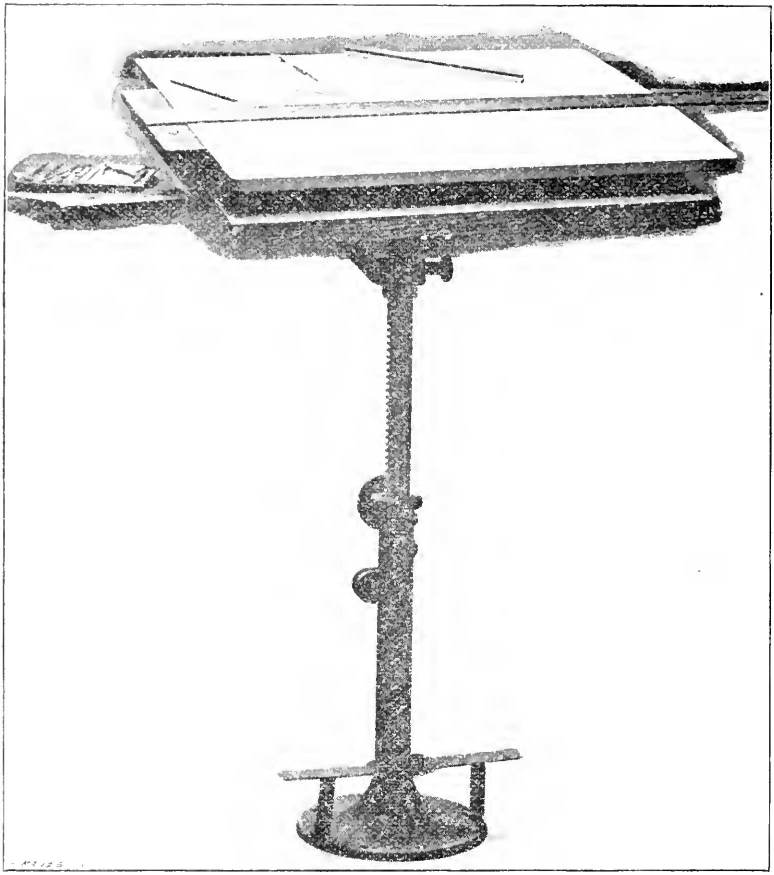
hibits of raw and finished materials. Among these are a fine series of moulded press bricks, and panels of mosaic floor and pressed brick work which were donated to the department.

The architectural shops occupy about one-half of the first floor of Machinery Hall. They are equipped with thirty benches each supplied with a full set of tools, ten power lathes having the necessary turning tools, a large planer and a number of power saws.

The Russian system of shop practice was first introduced in this country by Professor Ricker, and is still in use in the shops.

CIVIL ENGINEERING.

Instruction in civil engineering was first given at the University of Illinois in the fall of 1871 under the direction of Professor J. Burkitt Webb. The present incumbent of the chair, Professor I. O. Baker, was placed in charge in 1878. He has done much toward bringing the department to its present standing and especially to-



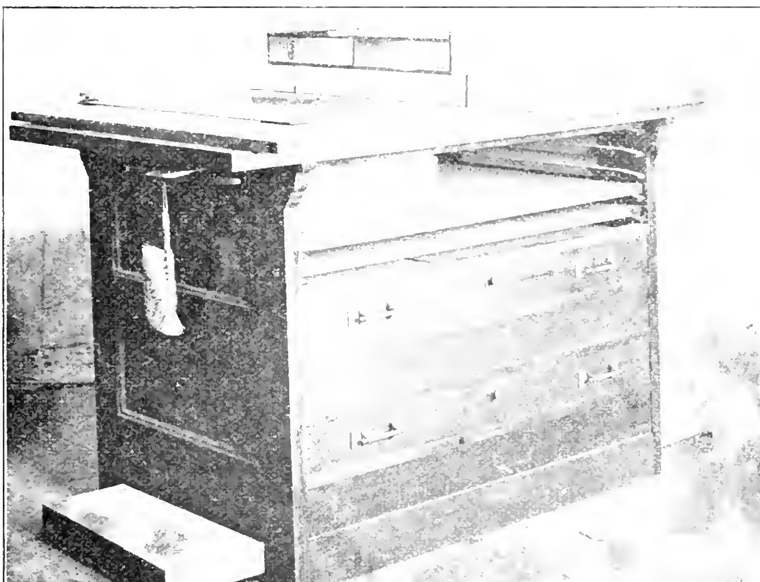
ARCHITECTURAL DRAFTING TABLE.

ward establishing the very cordial relations that exist between it and the engineering profession of the state.

An aim of the instruction is the training of the mental powers to greater activity and of the power of the student to apply the knowledge already acquired. Instruction is given by lectures, text book work and assigned reading, to which are added numerous problems and exercises. Many practical problems in field work requiring the use of the different instruments are also given.

The department occupies the first and second floors of the east wing, a seminary room on the third floor of the east wing and a museum on the second floor of the west wing.

On the first floor two large well lighted rooms are devoted to the masonry laboratory. The equipment consists of cement testing and briquette moulding machines, a number of slate tables, briquette moulds, scales, sieves, a rattler and a stone grinder, the two last mentioned being driven by electrical power. The laboratory also contains samples of cement, sand, brick, stone and several piers of masonry that have been tested. Great care has been taken in selecting the equipment for this laboratory. It is said to rank second to none in the United States.



Double Drawing Desk.

The instrument room contains a large number of wall lockers where the field instruments are kept. In this room may also be found the tables used in the computations, and the drawings pertaining to field work. The equipment consists of five engineer's transits, two solar transits and two mining transits, five compasses, five ordinary levels, two levels of precision, three common and two fine plane tables, stadia boards, lining rods, chains, tapes and other necessary apparatus. Each instrument is placed in a separate locker and only the person using it has access. Adjoining this room is the workshop which is equipped with tools and supplies for repairing instruments.

The drafting rooms are equipped with double drawing desks. The museum contains a large number of models of bridges, elevated railroads, full sized iron joints of bridges, and samples of all kinds of merchant iron. The cases contain drawings and details of many actual works now in use.

The engineering observatory is located in a separate building. Here are mounted, on brick piers, an astronomical transit, an altazimuth instrument reading to seconds, two polar chronometers, one sideral chronometer, two sextants and several barometers.

Physics and Electrical Engineering.

The department of Physics and Electrical Engineering was created six years ago. Prof. S. W. Stratton, now of the University of Chicago, was placed in charge. Previous to 1888 physics had been taught by professors in other departments, and some instruction in electrical engineering had been given incidentally in the mechanical engineering course. For the past two years Dr. D. W. Shea has been at the head of this department. The growth of the department has been very rapid and it is now one of the largest in the University. The work in physics presented for all students in the College of Engineering is intended to give such a knowledge of the more important laws and phenomena of physical science as to enable the student to profitably pursue his subsequent technical studies. More extended courses for scientific research are also offered. The work in electrical engineering is given with special reference to the needs of those who are preparing for work in the practical applications of electricity.

In Engineering Hall the department occupies the first floor of the west wing and the first, second and third floors of the north wing. The rooms include an office, private studies, a lecture room, a large laboratory, cabinet rooms, preparation room, testing rooms, a constant temperature room, class room, drafting room, seminary rooms and a work room.

The lecture room is in form of an amphitheatre and has a seating capacity of 200. The lecture desk is composed partly of thin masonry pieces, thus permitting the use of apparatus in demonstration which could otherwise be used only in the testing rooms. The facilities for experimental demonstration and illustration are very complete, gas, water, steam and electricity being available. Many phenomena may also be shown by the use of an electric lantern. The curtains of the room are controlled by means of an electric motor so that the room can be easily and quickly darkened.

The general laboratory occupies the third floor of the north wing. The equipment consists of apparatus carefully selected with special reference to quantitative laboratory work. Most of the apparatus used by students is kept in the adjoining store room. By means of a small freight elevator, this room is in direct communication with the cabinet room on the second floor and the testing rooms on the first floor. In advanced work the apparatus for special investigations is set up permanently or kept in specially provided cases. The testing rooms are all provided with masonry piers and dark curtains.

The dynamo laboratory is located in the basement of University Hall. The rooms are: a direct current dynamo room, an alternating current dynamo room, two general testing rooms, a battery room, a photometry room, a store room and a work room. The laboratory is supplied with power from a 50-horse power steam engine. The equipment in direct current machinery includes a Brush 10-arc light plant, a Thomson-Houston 3-arc light plant, two Edison and a Thomson-Houston incandescent dynamo, and a Jenny 500-volt power plant. The alternating current machinery comprises a Thomson-Houston 300-light plant, two small single phase Westinghouse machines and a number of transformers. The measuring instruments are of late design and from the best makers. There are very complete sets of Weston and Whitney ammeters and of Weston voltmeters and voltmeters for direct and alternating currents, electrostatic voltmeters, condensers, electro-dynamometers, Thomson balances, portable testing sets and galvanometers of all kinds. The laboratory is also supplied with much accessory apparatus, such as cradle dynamometers, prony brakes, contact makers, non-inductive resistances, arc and incandescent lamps and an electric light photometer. A number of lathes and a large variety of tools constitute the equipment of the work room.

Mechanical Engineering.

The department of Mechanical Engineering was established in January, 1870. Professor S. W. Robinson, now of Ohio State University, was placed in charge. He immediately set to work and with an appropriation of only $2 000 secured a small boiler and engine, a lathe and other necessary tools and began instruction. This was the first distinctively technical school shop instruction given in this country. From time to time many valuable additions in buildings and equipment have been made. Since September, 1893, Professor L. P. Breckenridge has been at the head of the department.

The instruction is intended to give the student a thorough training in the fundamental principles underlying the science of machines and mechanics and thus enable him to become familiar with some of the numerous applications.

The department occupies the third floor of the east and west wings of the building. The space consists of an office, private studies, drafting rooms, class rooms, a cabinet room and a seminary room.

The drafting rooms are equipped with desks designed especially for this purpose by Professor Breckenridge. The desk, as may be seen from the cut, contains the necessary drawers, drawing boards and places for T-squares to accommodate four students and may be used by two students at any one time. It has been adopted by all of the departments of the college except that of architecture.

In the cabinet room may be found sets of the kinematic models of Reulaux and Schroeder, machine models, specimens of defective boiler plate and sectioned steam specialties, many of the last mentioned having been donated by the manufacturers.

The mechanical engineering laboratory is located in the basement of the Chemical building. It contains engines, boilers, pumps, surface condensers and a large assortment of indicators, gauges, scales, thermometers, dynamometers, calorimeters, reducing motions, planimeters, measuring tanks and apparatus for the calibration of instruments. The engines may be run with or without condenser, with plain slide or expansion valves and with automatic cut-off or throttling governors. The heating and power plant of the University contains eight boilers, two Root, one Sterling, three horizontal tubular and two Babcock & Wilcox, aggregating 800 horse power. These, together with the power plants, pumping station and factories of the two cities, furnish additional opportunity for tests and investigations.

The mechanical engineering shops occupy the entire second floor and the west half of the first floor of Machinery Hall. They comprise four distinct shops: machine shops, wood shops, forge shop, and foundry, each of which is in charge of an instructor. The equipment of the machine shop consists of fourteen lathes ranging from 14 to 27 inches swing, two planers (one being 30x30 inches by 8 feet,) two shapers, one universal and one plain milling machine, a universal grinding machine, three drill presses, numerous small machine tools and a supply of small hand tools. In the wood shop are fourteen new wood benches, a universal trimmer, a 34-inch band saw, a 20-inch wood planer and a full line of hand tools. The forge shop is equipped with sixteen forges, a blower, an exhaust fan, and tools for general light work. A small traveling crane and a cupola with the necessary sand, flasks and ladles comprise the foundry equipment. The boiler room adjoining Machinery Hall contains two 40-horse power horizontal tubular boilers which furnish steam for a 25-horse power Ball automatic engine and for the heating of this building and of Military Hall.

Municipal and Sanitary Engineering.

The department of Municipal and Sanitary Engineering, the last to be established, was organized three years ago with Professor Arthur N. Talbot in charge. It was established in response to a demand for the training of young men who intend to make a specialty of city engineering work. The course as now offered is a modification of the civil engineering course, but includes also the study of chemistry, botany, and bacteriology with special reference to their application to water supply engineering and sewage disposal. The subject of road and street engineering, water supply engineering, and sewerage are given special consideration. The head of this department also has charge of the department of Theoretical and Applied Mechanics.

The department occupies the west wing of the second floor of Engineering Hall. This includes a private study, a drafting room, a thesis room, and a seminary and lecture room. There is also a recitation room and an office and computing room for the work in theoretical and applied mechanics. The drafting room is equipped with double drawing desks similar to the one shown in the cut, but modified slightly to meet the special requirements of the work of this department. A large collection of plans, prints, specifications, reports, and photographs covering municipal and sanitary engineering subjects belongs to this department.

The laboratory of applied mechanics is at present located on the first floor of Machinery Hall. It includes the materials testing laboratory, and the hydraulic laboratory. An Olsen testing machine of 200 000 pounds capacity is arranged for tension, compression and flexure tests. This machine will allow the testing of beams up to a length of 20 feet. At present a series of tests are in progress on wooden timbers, 10 inches in depth. A Riehle testing machine of 100 000 pounds capacity, a Riehle wire tester, and a machine for testing small beams are among the equipment. A large collection of extensometers, deflectometers, scales, micrometers, calipers, and other measuring devices are in use. The hydraulic laboratory has an elevated tank and stand pipe connected with the water-works and with a steam pump. A pit containing tank, scales, together with weir boxes and other necessary appliances, allows experiments on orifices, tubes, weirs, pipes, etc. A collection of meters, weighing scales, tanks, weirs, and gauges are among the equipment. The quarters for this laboratory are very crowded, and allow little room for the equipment. The trustees of the University are asking for an appropriation for enlarged quarters, and it is hoped that more room may be obtained in the near future. The work is now required of all students in the Engineering College.

BOOKS REVIEWED.

Electricity, One Hundred Years Ago and To-Day. By Edwin J. Houston. The W. J. Johnston Co., Limited, New York.

The author traces in an interesting manner the progress of electrical science from the time of Thales to the present day. Epoch-making discoveries and inventions are treated at some length and numerous interesting abstracts from original papers are given. The outlines of investigations are concise and clear, and the discussion concerning the effects and relations of discoveries and inventions show careful study and sound thinking. The author is perhaps too sanguine concerning the future of electrical science.

BOOKS RECEIVED.

Dynamo and Motor Building for Amateurs. By C. D. Parkhurst. The W. J. Johnston Co., Limited, New York.

EDWARD M BENSON.

Edward M. Benson was born near Carlock, McLean county, Ill., March 25, 1865. He was reared on a farm with only such educational advantages as were offered by a district school. In 1886 he entered the University of Illinois, took a course in civil engineering, and graduated in 1890. After his graduation he spent two years with the Northern Pacific Railway in Idaho and Washington, and one year with the Spokane Falls & Northern in British Columbia. In the fall of 1893 he again attended the University, taking some special work in the municipal and sanitary and in the electrical engineering courses. Last autumn, while sojourning in central Iowa, he was stricken with typhoid fever and died after a brief illness, on October 8, 1894.

Mr. Benson was an industrious and thorough student and an energetic and trustworthy engineer. The years after graduation had developed his powers even beyond the promise of his student work. While in charge of railroad construction, his executive and constructive faculties became apparent, and with his high character, his success as an engineer was assured, if only his life had been spared.

THE TECHNOGRAPH

NO. 10

UNIVERSITY OF ILLINOIS.

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THE TECHNOGRAPH

. . OF THE . .

ASSOCIATION OF ENGINEERING SOCIETIES.

THE TECHNOGRAPH is a scientific publication issued annually by the Association of Engineering Societies of the College of Engineering of the University of Illinois. It is essentially technical in its scope, and contains articles of permanent value in the various departments of scientific investigations carried on at the University or by its graduates.

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UNIVERSITY OF ILLINOIS.

ANDREW SLOAN DRAPER, LL.D., PRESIDENT.

COLLEGE OF ENGINEERING.

FACULTY AND CORPS OF INSTRUCTION.

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OF THE

UNIVERSITY OF ILLINOIS.

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Organized Jan. 8, 1883.

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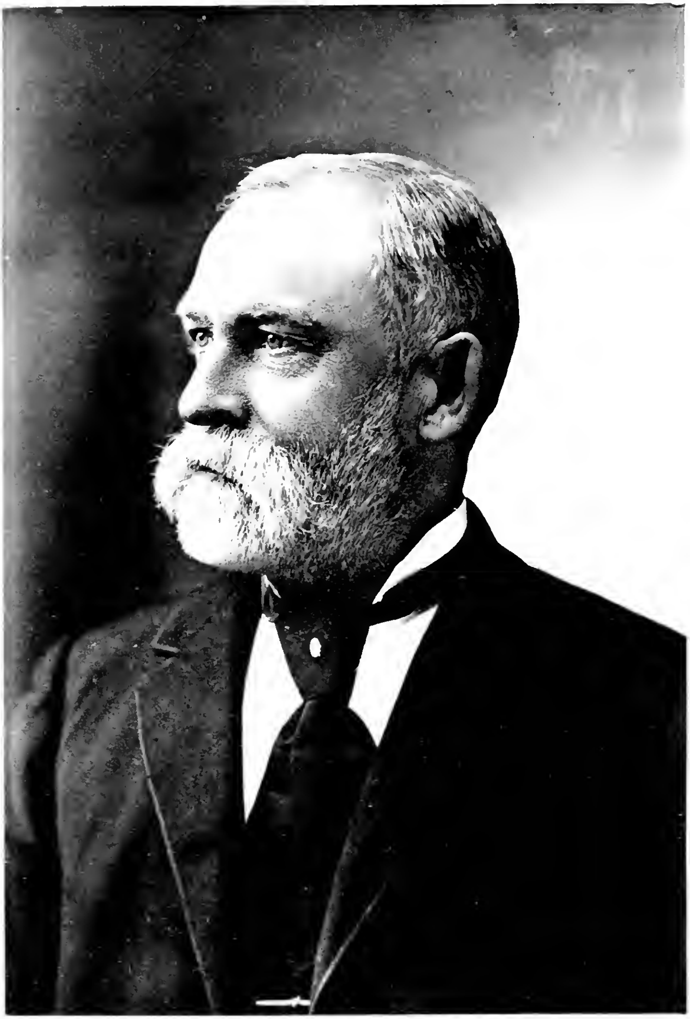
PREFACE.

ALTHOUGH the Association of Engineering Societies of the University of Illinois has only just completed the first year of its existence, it has quite conclusively shown that it fills a long-felt want in the University, in furnishing an opportunity for the different societies to co-operate in their efforts, and thus further advance the interests of the engineering student. But the field of usefulness of the Association does not end here. If the Association existed solely for the mutual advantage of its members, it would only half fulfill the object of its establishment, which, according to its constitution, is the promotion of the sciences and art. In order to accomplish this, it is necessary to place before the public a publication; and in so doing it furnishes a medium, so to speak, through which the student and professor studying upon some special line of technical work, can communicate directly with those who are actively engaged in the engineering profession, and who are consequently placed in a position to best utilize the results of this study.

It is with no little satisfaction that, in consequence of the active interest in the Association manifested by its members, and the hearty co-operation of the professors, the Association is enabled to make this Technograph, No. 10, a book which not only maintains but distinctively elevates the standard,—a book which we hope will be of value to the student, the physicist, and the engineer.

J. E. PFEFFER.



Yours truly.
N. Clifford Ricker.

THE TECHNOGRAPH

No. 10. UNIVERSITY OF ILLINOIS. 1895-96.

NATHAN CLIFFORD RICKER.

By Cyrus Daniel McLane, '92, Instructor in Architecture.

The subject of this sketch, Nathan Clifford Ricker, was born on a farm near Acton, York county, Maine, in 1843. He is of Scotch-English descent, though his father's ancestors came to this country about 1660, settling near Dover, New Hampshire.

The early years of his life he spent much as other boys, wandering among the hills surrounding his rugged New England home. At the age of thirteen he began work in a mill owned by his father, and here, for the eight years following, he spent the greater part of his time laying the foundation of the strength which was afterward to carry him through his college course. The winters of the first five years he was employed in the mill, he spent in the district school, but the winter in which he was eighteen he made his first attempt in the profession to which he has since done such credit, and for the two following winters conducted a country school. At the age of twenty-one he felt the necessity of a better education and left home to begin work for himself. In order that he might obtain the means of accomplishing his purpose, he learned the trade of piano case-making, at which he worked for two and one-half years. The evenings of this time he devoted to the task of preparing himself for college—a task which, after years of hard study, he accomplished by his own courage, energy and perserverance.

In 1867 he came to Illinois, spending three years in the western part of the state working at carpentry and wagon-making. His desire for an education was in no way lessened by his change of location, and his studying was continued with unflagging zeal. The ability to do hard, steady work, which so characterizes his life, was early shown in these efforts to prepare himself for college. His untiring energy and the faithful way in which he performed the mental tasks which he had allotted to himself reveal something of his true character. The manner in which he studied French was, to say the least, unique and might with profit be adopted by students to-day, having perhaps, better advantages. He set about his task in a thorough and systematic manner, lessons were assigned to himself and prepared as regularly and as faithfully as though they were to be recited to the most exacting task master rather than to himself. Two evenings were given to each lesson, one to the preparation, and the other to the recitation or review, and a lesson was not considered learned if it could not be satisfactorily recited to himself the evening following its preparation. Latin was studied also in a similar way, so that when he entered the University in 1870 he was able to obtain advanced standing in these two subjects.

In the early history of the University each student was required to do manual labor a certain number of hours a day, the chief mitigating circumstance being that he was slightly remunerated for his services. Mr. Ricker's skill in wood-working thus proved helpful, both to himself and to the University, and it was early in his course as a student that his first architectural work was designed and executed. In the annual report of the Board of Trustees for 1870 is found the following, which explains itself:

"A proposition of students Ricker and Cantrell to make a spring wagon for the use of the Horticultural Department was referred to the Regent and the Professor of Horticulture (Dr. Burrill)."

The action of the Regent and the Professor of Horticulture must have been prompt, for in the Business Agent's report for the same year is found after a date four days later than the above, the following:

"For material for wagon. $70.00." The wagon was completed sometime that year at a cost of $140.00, Mr. Ricker doing the wood-work and Mr. Cantrell the iron-work. For the next ten years this product of the embryo architectural department withstood the vicissitudes of University life and proved itself worthy of its creators. Only in very recent years has it been retired from active service.

During the year 1871 Mr. Ricker was foreman of the architectural shops. The first six months of 1872 were spent in the office of J. W. Roberts, architect, Chicago. He returned to the University the next year, and was graduated at the end of the second term, having finished a full course in a little over three years. During his last two terms at the University he had temporary charge of the Architectural Department. Immediately after graduation he started for Europe, where he spent six months in study and travel. While there he attended the Vienna Exposition, and visited Paris, London and other cities for the purpose of studying their architectural monuments. The greater part of his time, however, was spent as a student in the Bauakademie in Berlin. He returned home in September, 1873, to take the position of Instructor of Architecture in the University. It was at this time that he introduced the Russian system of shop practice, so that to him must be given the credit of first introducing in American Universities this system, which has now become almost universal. Two years later he was made Assistant Professor of Architecture. It was in the same year that he was married to Miss Mary C. Steele, who had just graduated from the College of Literature.

In 1877 he received the title of Professor of Architecture, and the next year was made Dean of the College of Engineering.

Every year since he took charge the Architectural Department has witnessed improvement in the character of the work done, as well as in the method of doing it. The whole energy of his life has been directed toward the advancement of his department. For seventeen years he was unaided in his work of instruction, having personal charge of all the strictly architectural work in the University. In 1890 an assistant was appointed, so that in recent years he has had more time to devote to the upper classmen.

In addition to the regular work of the Department he has designed and built the Chemical Laboratory, Military Hall, and Natural Science Hall. In all of this work he has given his personal supervision to the preparation of the working drawings, as well as to the erection of the buildings. The roof of Military Hall, which is a monument to his skill, covers a floor space one hundred by one hundred and fifty feet, and is carried entirely on the walls by means of graceful trusses, which are silent but expressive witnesses of the quiet yet sufficient power of their designer. At this writing he is engaged as one of the architects of the New Library Hall to be erected this year on the campus of the University at a cost of one hundred and fifty thousand dollars. The structural part of this building is being designed either by himself or under his personal supervision.

Professor Ricker has been too busy a man to give much of his time to writing for publication. He has, however, published a text book on "Trussed Roofs," which has received flattering recognition among prominent architects, and is largely used in architectural offices. He has also written a series of lectures on Architectural Construction, which are published in blue print form and are used by students as text-books in construction. In addition to this he has found time to translate for the use of his own classes the following works: LUBKE'S *Geschichte der Architektur;* REDTENBACHER'S *Architektonik;* PLANAT'S *Chauffuge et Ventilition;* THIERSCH'S *Proportion in Architektur*, and the following articles from VIOLLET-LA-DUC'S *Dictionnaire de l'Architecture: Mennserie, Serrurerie, Peinture, Flore and Construction.* He has made partial translations of numerous other German and French works.

It is the untiring devotion of such men as he that has made the University of Illinois what it is to-day. At one time when remonstrated with for working so hard he replied: "It is better to wear out than to rust out." The spirit that prompted this reply is what sustained him during his boyhood and early manhood while struggling alone to fit himself for college. It was this same spirit that carried him through his college course and gave him that hungering for knowledge which caused him to forget all other feelings, so that he would often do without a meal rather than take the time necessary to go for it. It is the same spirit that has characterized all his life in the University since his connection with it, and has enabled him to accomplish the work that he has in his department.

Professor Ricker is a thoroughly broad-minded man—broad in his culture and in his sympathies. With history, literature and art he is as thoroughly conversant as with the more technical studies of his own department. So generally is this recognized that it is often said that if one wants to know the latest information in these subjects he has but to ask Professor Ricker.

No instructor in the University is more highly respected or more warmly loved than he. The student who has ever been in his classes is forever afterward his ardent admirer and his friend. No matter how busy he may be, he can always find time for the student who needs advice or help or encouragement. It is that kindly unselfish nature that has so endeared him to all with whom he has come in contact.

Few—very few men are so thorougly unconscious of themselves as is he. Modest and unassuming, forgetful of himself and his attainments he is devoting his unselfish life to the progress of the University and to the greatest good of the students who are under him.

THE CONSTRUCTION OF A RAILWAY TUNNEL AT HAMILTON, ONTARIO.

By Peter Mogensen, '94, School of Civil Engineering.

The Toronto, Hamilton and Buffalo R. R. extends from Waterford, through Hamilton, to Welland in the province of Ontario, Canada, a distance of 81 miles, and connects with the Michigan Central R. R. at both ends. The principal offices are at Hamilton, 43 miles from Waterford and 38 miles from Welland. A branch, about 40 miles long, joining the Canadian Pacific R. R. at Toronto, Ont., has been surveyed and will probably be constructed in the near future. When the system is completed the Michigan Central R. R. will be given track privileges over these lines to Toronto, and the Canadian Pacific R. R. will, by a similar arrangement, perhaps obtain access to Buffalo, N. Y.

In the fall of 1894 the city of Hamilton passed a by-law granting a bonus of $225 000 to the railway company, provided, among other things, that the road should be open to the public by December 31, 1895. The contract for the tunnel contemplated the completion of the work not later than that date.

The work is mostly of a light nature except at Hamilton, where the tunnel was constructed, and for some distance east and west of that city where the line ascends and descends the "Mountain," a continuation of the Niagara bluffs.

The railway follows the street grades from the southeastern limits of the city to Hamilton Station, and runs west on Hunter Street on a nearly level grade for a distance of 550 ft. It then descends on a 0.75 per cent grade and at Park Street, about 1 000 ft. from the station, it enters the tunnel. The tunnel extends to Queen Street, approximately 2 900 ft. from the station. West of Queen Street is a large open cut spanned by substantial wooden bridges at the street intersections.

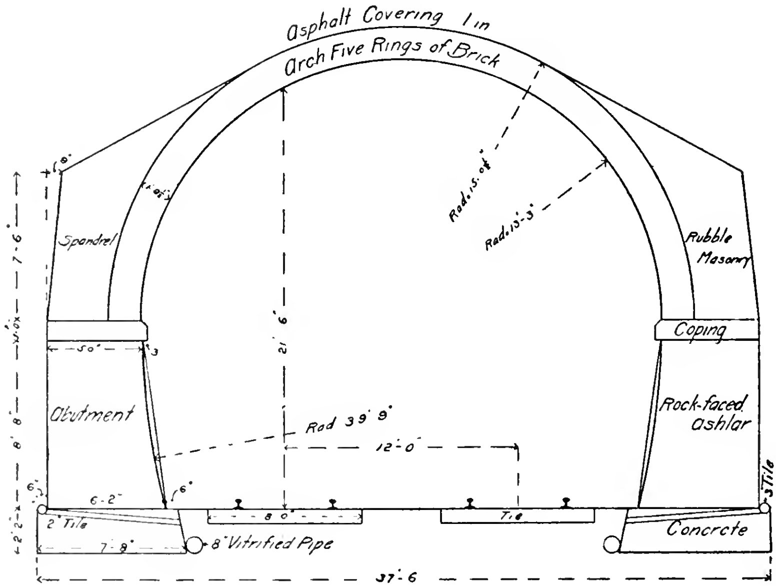


FIG. 1. CROSS SECTION OF TUNNEL.

The tunnel carries two tracks of standard gauge, spaced 12 ft. between centers. The cross section, with all dimensions, is shown in Fig. 1. This section was employed the entire length except at the east portal, where for a distance of nearly 80 ft. the arch consists of steel deck beams and buckle plates. The latter construction was adopted to reduce the height, and thus make lighter grades for a street which crosses at that point.

Hunter Street, on which the tunnel is located, is 66 ft. wide and lined with private residences on both sides nearly the whole distance. It was intended to keep the sidewalks open as much as possible, requiring a width of from 6 to 8 ft. on either side for this purpose. As the extreme width of the tunnel is 37.5 ft., it will be seen that an open cutting of sufficient width would require nearly vertical banks. The tunnel is 1 905 ft. long and the excavation varied in depth from 13 ft. at the east end to 46 ft. near the middle, averaging 44 ft. for about 400 ft., and then decreased to 24 ft. at the west end. The height of the tunnel is 25.79 ft. It thus rises above the street surfaces at the ends and has a covering of 20 ft. near the middle.

Excavation. The excavation was commenced at the east end in June, 1895. The material at the surface was earth and sand, but at depths varying from 8 to 15 ft. cemented gravel was encountered. This material required blasting, and, being in the heart of the city and surrounded by dwelling houses, much care had to be exercised to avoid damaging adjoining property. The refractory nature of this material retarded the work, but the slow progress was compensated for to some extent by the strength of the banks, which made shoring unnecessary. The excavated material was removed by teams hauling through the end of the cutting. A stratum of blue clay of unknown thickness follows the grade of the tunnel in a general way, rising from 5 to 9 ft. above sub-grade, except at the east end, where it falls rapidly below the foundations. On the top of this clay is a layer of water-bearing sand. To remove this water direct-acting steam pumps were employed, the steam being supplied from the boilers of hoisting engines attached to the various derricks on the work.

In July a steam shovel was put to work at the west end. The material here was mostly gravel and sand, well suited to be excavated by this means. Fig. 2 shows the machine loading a train of flat-cars under the first line of shoring. The steam shovel did not excavate to sub-grade, a considerable amount of material being left to be taken out by other means and used for back-filling. The work of excavating was carried on day and night with few interruptions.

In Fig. 3 is shown a steam derrick, erected in August, and used for excavating at the point where the teams and the steam shovel met. The buckets used held 25 to 26 cu. ft. After being raised they were swung over a hopper and there unloaded into wagons. In the background are seen the abutment walls and the arch of the tunnel in course of construction. The excavation was here in cemented gravel, and it will be noticed that the banks stand without shoring. The top of the clay stratum is seen in the bottom of the cut. The pump located to the left was supplied with steam from one of the boilers of the traveling derrick at the end of the masonry.

The excavating derrick was of the common stiff-legged type, with 30-ft. mast and 45-ft. boom, operated by a double-cylinder two-drum hoisting engine rated at 18 H. P., with 80 lbs. boiler pressure. Under the most favorable conditions, when the buckets were loaded within easy reach of the derrick, the out-put was from 275 to 300 loads of 25 to 26 cu. ft., in ten hours during the day, and 200 to 225 loads in the same number of hours at night. But when the buckets had to be brought a considerable distance on cars, and when limited space above ground required the location of the hopper in such a position as to necessitate the raising and lowering of the boom for each load, the capacity was often reduced by one half of the above quantities. Several similar derricks were used in various places along the cutting, after the steam shovel stopped working.

When the construction of the tunnel had proceeded into the deeper portions of the cutting where considerable back-filling was required, a traveling cableway was erected by the Lidgerwood Manufacturing Co. Fig. 4 shows the tail tower, carriage, and bucket of this cableway. The buckets were similar to those used at the derricks, but somewhat larger, containing from 1 to 1¼ cu. yds. The excavation was carried on under the shoring in the back-ground. The method of working can be readily understood from the picture.

The span of the cableway was 450 ft., with a sag of 20 ft. when loaded. The head and tail towers were 50 and 70 ft. high respectively, and were built of pine timber with posts 12 x 12 in., trussed with ¾-in. iron rods. The horizontal bracing was 3 x 12 in., and the diagonals 2 x 12 in. The cables were all of steel wire with the following dimensions:—Main cable 1½ in., fall rope ⅝ in., carriage rope ⅝ in., button

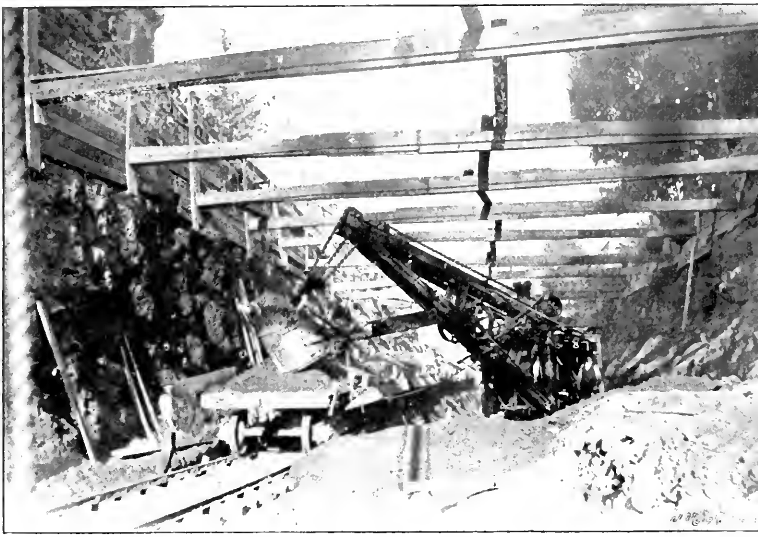


FIG. 2. STEAM SHOVEL LOADING FLAT CARS.

FIG. 5. EAST PORTAL.

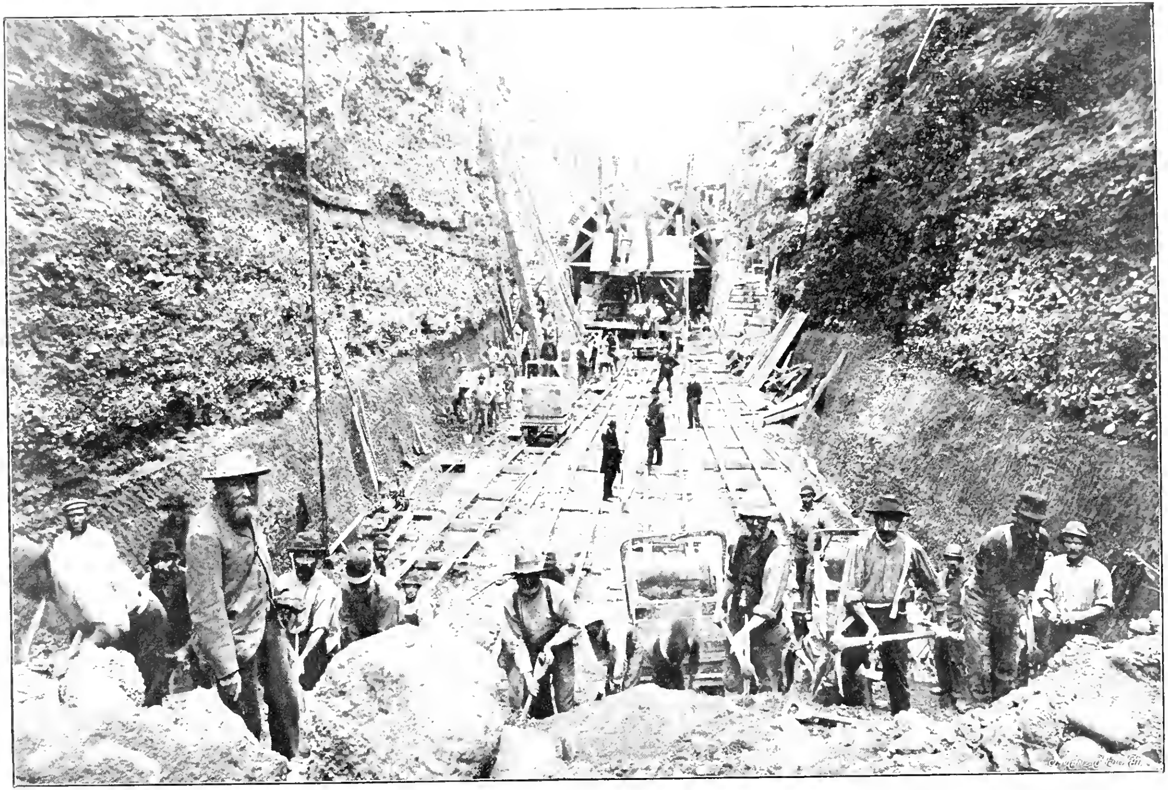


Fig. 3. Excavation in Cemented Gravel.

FIG. 4. TRAVELING CABLEWAY. TAIL TOWER, CARRIAGE AND BUCKET.

rope ½ in. The power was furnished by a double-cylinder, two-drum hoisting engine of 20 H. P. with 80 lbs. boiler pressure.

The engine-man was guided by a system of electric-bell signals given by a man conveniently stationed so as to watch the motion of the buckets among the shoring.

The capacity of this cableway varied from 150 to 175 loads in ten hours during the day, and from 125 to 150 loads at night. This output was considerably less than anticipated. The cableway was therefore discarded when the excavation had proceeded to the tail tower and derricks were employed for the remainder of the work.

The system of shoring first adopted is seen in Fig. 4. This gave fairly satisfactory results during the summer and in dry weather, but proved entirely inadequate in the deeper parts of the cutting during the fall and winter when the rain and frost made the ground unstable. The banks caved in in numerous places, causing much delay and the loss of many thousands of dollars.

A very serious cave-in occurred at the point where the tail tower of the cableway is shown in Fig. 4. The shoring farther ahead gave way shortly after and the foundation walls of the buildings on the right were exposed. Later the banks caved in on both sides nearly 150 ft. farther; a part of the foundations of the houses then fell in, causing the end of the building to settle badly. It was rebuilt after the tunnel was finished. In January, 1896, another cave-in occurred whereby a part of a brick building fell in on the arch which was then under construction at that place. Similar accidents, though not as serious, took place in other parts of the excavation.

Much time was lost in removing the earth which thus caved in. Nevertheless, by strenuous efforts new and substantial shoring was erected, and the excavation cleared sufficiently to allow of the tracks being laid on December 28, the official inspection taking place on the same day; two days later the government license was obtained, and the road was opened to the public. There still remained several hundred feet of the tunnel to build, but as the traffic was established within the time specified by the Hamilton by-law, the principal condition for earning the bonus had been complied with.

CONCRETE FOUNDATIONS. It was intended to make the foundations of concrete throughout, but when the excavation could not be completed sufficiently in advance of the abutment walls, the foundations were made of large flat stones laid in cement mortar. By this means the time required for the concrete to set was gained. However, the greater portion of the tunnel rests on concrete, consisting of limestone broken to the usual dimensions, cemented by mortar made of one part Portland cement to two parts clean sharp sand. The amount of mortar was such as would, in the judgment of the engineer, properly fill all voids in the stone. The resulting mixture usually consisted of one part cement, two parts sand and four parts stone. It was placed in layers 8 to 9 in. thick and thoroughly rammed. The qualities of the cements used will be discussed later.

ABUTMENT WALLS. The straight and the curved batter lines of the abutments shown in the section are those of the tunnel and the portals respectively. The transition from curved to straight batter was made in a distance of 15 to 20 ft., and, the walls being rock-faced, this change was almost imperceptible. The masonry was broken range ashlar work of superior quality. It was built of a hard flinty limestone quarried at Longford Mills, Ont., with mortar made of one part natural cement and two parts sand. At least one third of the stones in the face work were headers evenly distributed throughout the walls. No stones were permitted in the face having a length less than 3 ft., a width less than 1½ ft., or a thickness less than 9 in. The least bond permitted was 8 in. No mortar joints were allowed to exceed ¾ in. in thickness within 8 in. of the face of the wall. The backing was made of large stones well bonded. The coping was one foot thick extending unbroken across the wall.

Niches or manholes, 100 ft. apart and alternating on the two sides, were made to give shelter to workmen from passing trains.

Two traveling double derricks, operated by steam, were used for building this masonry for a considerable distance at both ends of the tunnel. Near the middle, derricks similar to those used for excavating were employed as the presence of shoring near the bottom made the use of the former machines impracticable. In the background of Fig. 3 is a rear view of a traveling derrick whose principal features were as follows: Car platform, 20 ft. long by 15 ft. wide; four wheels 18 in. diameter; gauge, 13 ft. 9 in.; masts, 12x12 in., 14 ft. long; booms, 10x10 in., 24 ft. long; legs, 8x10 in., 17 ft. long; two double-cylinder, two-drum hoisting engines rated at 14 H. P. with 80 lbs. boiler pressure;. fall and boom ropes ⅞-in. steel wire cables.

Under favorable conditions two gangs of masons could build, by means of this derrick, 20 to 25 ft. of wall on both sides in a day of ten hours.

ARCH. The arch was built of carefully selected bricks with mortar of one part Portland cement and two parts sand. The bricks were well soaked in water before being laid, except in freezing weather. The inner and outer rings were carefully laid with pushed joints, and the intermediate rings were grouted.

In Fig. 5 is shown one of the centers used under the arch. They were made of three thicknesses of 1-in. pine boards, and were placed 3 ft. 8 in. apart. The centers rested on posts standing on the concrete foundations. The lagging was of pine 2x4 in., 14 ft. long.

SPANDRELS. These consisted of ordinary rubble masonry with stones laid by hand in natural cement mortar, the latter containing one part cement to two parts coarse sharp sand.

ASPHALT COVERING. For the purpose of preventing water from percolating through the arch the latter, and the upper surfaces of the spandrels, were covered with a layer of asphalt one in. thick, made as follows:—A thin coat of hot coal tar was first applied; a layer of asphalt ¾ to ⅞ in. thick, containing 16 per cent asphaltic cement and 84 per cent sand was then put on and rolled; and, finally, this layer was covered with a coat of pure asphaltic cement ⅛ to ¼ in. thick. In several places the layer of asphalt mixture was omitted and two coats of asphaltic cement were used. The Trinidad asphaltic cement was employed, and this was mixed with a sufficient amount of heavy oils to make it of the proper consistency.

PORTALS. Fig. 5 is from a photograph of the east portal and adjoining retaining walls. The west entrance is similar in construction, though the retaining walls are there somewhat different. These structures are of strictly first-class material and workmanship. The stone is from Beamsville Quarries, Ont., and was furnished, cut ready for building, by Mr. William Gibson, M. P. The mortar used was made of one part Portland cement and two parts fine sharp sand, and all joints were ¼ in. thick.

In the background of the picture will be seen a stone ring which terminates the brick arch, and between this ring and the portal the steel arch was placed.

STEEL ARCH. As previously noted nearly 80 ft. of the tunnel at the east end is covered by a steel arch. This consists of ribs made of deck beams 7 x 5⅛ in., weighing about 25 lbs. per ft., spaced 3 ft. ½ in. between centers, and buckle plates 3x3 ft., ¼ in. thick, riveted to the flanges of the deck beams. The longitudinal edges of the plates are covered by a T section 3 x 3 in., weighing about 7 lbs. per ft., and are riveted to form butt joints. The arch is supported on the sides by spandrel walls similar to those on the brick arch, and is covered on the top with Portland cement concrete extending one inch above the deck beams. The ribs were bent to a radius of 3 in. larger than that of the brick arch, and were placed in pockets 2 ft. deep in the abutment walls.

CEMENTS. The Portland cement was supplied by the Owen Sound Portland Cement Company. A series of tests made of this cement at the School of Practical Sciences, Toronto, Ont., gave the following average results: Specific gravity 3.10; fresh pats kept in air at 150° F. remained sound; retained on a No. 100 sieve 21.40 per cent, and on a No. 50 sieve 3.30 per cent; tensile strength of neat cement 190 lbs., 346 lbs., and 474 lbs. per sq. in. when 2, 7, and 30 days old respectively. As might have been expected, the coarser samples gave a higher tensile strength than the finer ones. The weight of a barrel of 4 cu. ft. was approximately 350 lbs.

This is an excellent cement for mortar of one part cement to two parts sand, but for mortar mixed with a larger proportion of sand it could, in the writer's opinion, be considerably improved by finer grinding.

The natural cement was of the class known as Queenston cement, and was furnished by Messrs. Usher & Son, Queenston, Ont. With the exception of a few laboratory tests made when the masonry was commenced, no tests of the cement were available, but from rough experiments made on the works, and from the opinions of persons who have used large quantities of this cement, it was deemed to be of a fairly good quality, and, though rather slow setting it will attain considerable strength at an age of from 6 to 12 months. The weight was 240 lbs. per barrel. The inability of the writer to have proper tests made of all the cement is much regretted.

PROVISIONS FOR BUILDING MASONRY IN FREEZING WEATHER. The paramount importance of completing the work with as little delay as possible made it necessary to build a large portion of the masonry in freezing weather. To do this especial precautions had to be taken to insure a high grade of work.

The requirement that the bricks should be thoroughly wetted before using was discarded, and none but dry bricks, perfectly free from ice and snow, were accepted. The mortar for all classes of work was made with hot sand and water, and when the temperature fell below 10° F. about 3 ounces of salt were added to each gallon of water. With each gang of bricklayers was a man constantly tempering the mortar on the boards with hot water, and hot water was used for grouting the intermediate rings in the arch. All unfinished brickwork was covered with tarpaulins at night, and all surfaces of frozen uncompleted masonry were thoroughly thawed and cleaned with hot brine before fresh work was added. Ice and mud frozen on stones were removed by thawing over a fire, or by steam from the boiler of the nearest derrick, or by sprinkling with salt and then cleaning with hot water.

It is needless to say that work under such conditions required an efficient corps of inspectors, and close and constant supervision.

DRAINAGE. Referring to Fig. 1, it will be seen that at the back of each abutment wall is placed a 3-in. tile; this is covered with 6 in. of broken stone, not shown in the drawing. The water collected by this tile is carried to the inside of the tunnel by weep-holes made of 2-in. tile, placed 100 ft. apart. All water inside the tunnel is drained off by 8-in. vitrified pipes laid with open joints at the bottom of the foundations and on the same grade as the tunnel.

VENTILATION. It was not thought necessary to make any special provision for the ventilation of the tunnel. The smoke and gases from the engines of passenger trains do not ordinarily cause any annoyance to passengers, but at the passage of slowly moving freight trains the tunnel is often completely filled with dense smoke, which, however, usually clears away in 20 to 40 minutes.

BACK FILLING. In the spaces between the banks and the abutment walls and spandrels the material was placed in suitable layers and rammed, but above the arch the earth was not compacted except partially by the movements of teams, wagons and men. The street was provisionally covered with cinders, it being intended to make a macadamized surface after settlement had taken place.

COST. In the following table is given the cost of labor for building, and the amount of cement used per cu. yd., in the various classes of masonry. These elements of cost remain nearly constant in similar work. The prices of the materials, freight charges, etc., which vary considerably with the location and attendant conditions, and which for this work are of little or no interest to the reader, are not given.

LABOR AND MATERIAL REQUIRED FOR DIFFERENT CLASSES OF MASONRY.

CLASS OF WORK.	LABOR.	CEMENT.
CONCRETE	$ 0.93	1.25 to 1.40 bbl.
ABUTMENT WALLS	1.32	0.55 "
BRICK ARCH	1.95	0.95 "
SPANDRELS	1.90	0.80 "

The above cost of labor was for work under ordinary conditions. When the progress was impeded by shoring, passing trains, etc., these values were often increased nearly 50 per cent. Masons received 33½ cts. and laborers 15 cts. per hour. The amount of cement used in freezing weather was somewhat greater than as given in the table.

The stone for the portals was delivered f. o. b. cars at railway station nearest the quarries for $12.00 per cu. yd.

The cost per lin. ft. of the tunnel of regular section, including the drains but not including portals and excavation, was $87.00. The total average cost was about $120.00 per lin. ft.

The contract price for the steel arch with spandrels and concrete covering was 33 per cent more per lin. ft. than for the brick arch and spandrels as shown in Fig. 1, but on the basis of actual cost the former would, perhaps, be 55 to 60 per cent more expensive than the latter.

QUANTITIES. The total quantities of the various classes of work were as follows :—

Excavation, approaches, etc.	163 000 cu. yds.
Excavation, tunnel	98 000 " "
Portland cement	2 952 " "
Stone masonry, in portals	317 " "
Stone masonry, in abutment walls	7 329 " "
Stone masonry, in retaining walls	1 383 " "
Stone masonry, in spandrels	4 893 " "
Brick masonry, in arch	5 366 " "
Asphalt covering	72 000 sq. ft.
Steel arch	66 100 lbs.
Back filling	42 000 cu. yds.

As before stated, the tracks were laid on December 28, 1895, when but little excavation remained to be done, and after that date trains passed daily through the tunnel. The masonry was finished early in February, 1896, and the back filling was completed later in the same month.

The structure thus briefly described is owned by the Toronto, Hamilton and Buffalo Railway Company. Mr. E. B. Wingate was chief engineer, the writer was engineer in charge, and Mr. John Chalmers assistant engineer. The contractor for the work was Mr. Andrew Onderdonk, who was represented by Mr. William Doheney as general superintendent and Mr. W. R. Northway as consulting engineer.

THE DESIGN OF TOP WORK FOR COAL MINES.

F. W. Richart, '91, School of Mechanical Engineering

The design of a modern mining equipment requires technical knowledge belonging to the professions of mechanical, electrical, civil, and mining engineering. It is the purpose here to discuss matters pertaining to top work only, and not to consider underground systems of mining, or ventilation, the subjects to be considered in this paper pertain more particularly to the province of the mechanical engineer.

Location. We will suppose the existence of a good vein of merchantable coal, and the necessary shipping facilities.

The first questions to be settled are the depth and the pitch of the vein. A considerable number of bore holes are made, and a set of levels run to determine the elevation from some datum level, of the coal at these points. By this means the pitch or inclination of the vein are determined. These holes are usually made with a diamond drill, which takes out a core showing the formation of the various strata passed through, the quality and thickness of the coal, and the character of the overlying roof.

If all other features are favorable, the shaft would ordinarily be located about the center of the field to be mined, so that the length of underground haul would be as short as possible. But if there is any probability that much water will be encountered, the shaft should be so located that the drainage of the coal stratum will be toward shaft. If other conditions do not permit such a location for the main shaft, an auxiliary shaft should be sunk. It is very easy to provide for pumping water directly up a shaft, but the placing and operating of the necessary fixtures for moving water a long distance underground are difficult and expensive. Water collecting at the face of the workings is decidedly disagreeable to the miners, besides wet coal is difficult to screen, especially the smaller sizes, and presents a dirty appearance on the cars. When the workings slope toward the hoisting shaft, a down grade is available for hauling loaded cars.

Deep mines are not as likely to be troubled with water as

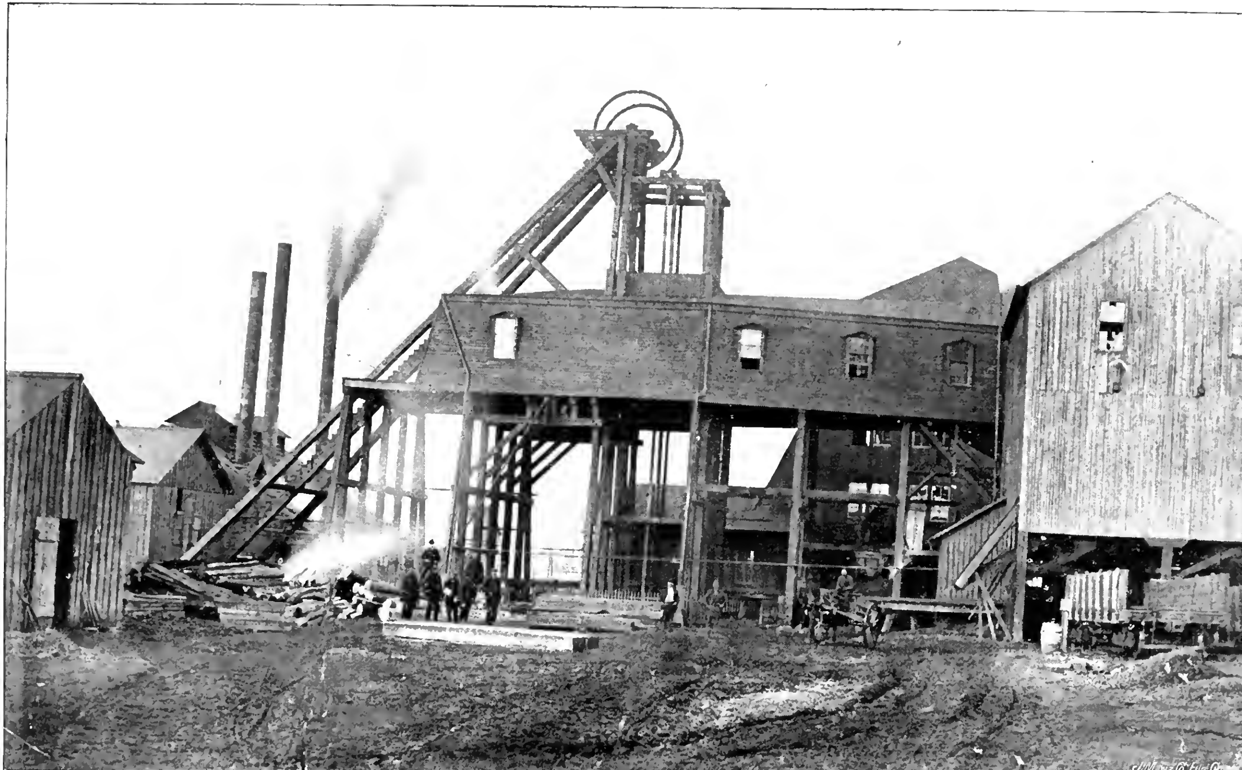


Fig. 1. Top of Coal Mine. Modern Equipment.

shallow ones. Sometimes workings are so dry that it is necessary to sprinkle the roads to keep the air free from dust for the workmen, and also to reduce the danger from dust explosions where open lights are used.

OUTPUT. The quantity of coal to be handled is one of the chief factors in determining the size of the plant, and the cost of operation. The greater the output the less the relative cost of production, and hence greater profit per ton. There is, of course, a limit to the number of cars that can be hoisted and dumped from a given depth, with a given hoisting outfit. From shallow mines, say 150 ft. or less in depth, with "first motion" engines, a rate of two cars per minute can probably be kept up for the day, if the top and bottom are properly arranged and no delays occur. For a short length of time cars can be handled faster than this. A mine in southern Illinois (shown in the half tone) 112 ft. deep, with a 150-ft. hoist, and 3-ton pit cars claims to have hoisted and dumped four cars per minute for a short length of time.

The capacity of pit cars varies from one to three tons each, two tons being an average size for shafts having an output ranging from 1 000 to 2 000 tons per day, and one to one and one-fourth tons for shafts of 500 tons capacity. The greatest difficulty to overcome in handling a large output is the manipulation of the cars at the bottom. Four or five hundred tons per day is a small enough amount to figure on for a commercial mine, and 3 000 tons per day is about the safe limit in the other direction.

The coal should be graded so as to realize the most for it. Sometimes but one grade is made, and occasionally as many as seven or eight grades are made. When all of the coal is dumped together it is called "mine run." Usually at least three grades are made, lump, nut and slack. A very nice run of sizes is lump, egg, nut, pea and culm. Slack fires reasonably well, as it contains not only the very fine but some of the coarser coal. Culm can be fired very well where the boilers are equipped with mechanical stokers, but it is very hard to fire by hand if boilers are steamed to their rated capacity. The slack is frequently thrown away, but it is a cheap fuel for those near the mines who are properly equipped to use it. Lump is not so salable for a steam coal as the egg and nut, as it is harder to handle in firing and the large lumps must be broken up. Lump coal is sometimes crushed into smaller sizes, and in fact this is the general practice in the anthracite regions.

METHODS OF GRADING COAL. The three ordinary forms of screens for grading coal are bar, revolving and shaking The bar or fixed screens are made of iron bars, rolled to a shape suitable for the purpose and set edgewise and parallel at a fixed distance apart. The distance between the bars is fixed by the size of the coal that is expected to pass between them. The slope of screens of this kind depend slightly upon the momentum the coal receives before striking the screen. A slope of one to two, or an angle of about 26½°, will usually be about right for screens 20 to 30 feet long, including aprons; but when the screen is longer the lower part of the screen may be made flatter, i. e. it may be about 20°. If the slope is not flattened in long screens, the coal attains such a high velocity that the large lumps are often smashed into fine coal when they strike the car. On the other hand, should short screens be flat, or long ones flat at the upper end, the fine coal would check, or even choke, the flow of coal entirely. Fine coal will not slide down as flat a slope as large coal, and especially is this so when any of the coal is wet. In this connection it may be well to say that chutes from bins containing nut and the smaller sizes, should have a slope of 40° or more. Culm, if damp, will of itself hardly slide at all, and always cakes if binned. All coal slides more readily on bars than on plates.

Since coal nearly always slides in a body when dumped, the bar screen is sometimes stepped, that is at each 10 to 14 ft. of length, there is a fall of 8 to 12 in. to compel a break up of the mass so that the fine coal may not be carried beyond its part of the screen. This is a good plan with the fine sizes of coal, but is hardly necessary with the larger ones, and may even cause an undue amount of breaking of large lumps, and a consequent increase in the smaller sizes.

Revolving screens are built in two forms, one turning upon an axle, and the other rolling on friction wheels. Both woven wire cloth and perforated plates are used in these screens. In the first form the screen is bolted to the outside of wheels having thin wrought-iron rims, keyed to a shaft. As the load to be carried is not very heavy, the axle is often made by welding a short piece of shafting to either end of a gas pipe. In the second form, the screen cloth is bolted to the inside of cast or heavy wrought iron rings, which roll in two sets of grooved wheels, and by which the screen is driven. Only the finer grades of coal are run through the revolving screen, the lump having passed off over a bar screen.

These screens do excellent work with dry coal, but when the coal is wet the fine particles stick to the screen and clog up the smaller meshes. To overcome this difficulty, steel wire brushes are used, but they are of little advantage except in the second form of screen, where they can be placed both inside and outside if necessary. Possibly a better way of keeping revolving screens clean lies in a different form of construction, that is, making the cross section square or hexagonal instead of round. This gives a more sudden fall to the coal, and jars the wet coal loose. A principle to be observed in revolving screen construction, especially with round screens, is that the wetter the coal to be handled the greater the diameter the screen required to keep the meshes open. With dry coal a small diameter screen, four ft. for instance, works admirably.

The screening capacity will depend upon the size of the meshes, size and speed of screen, and dryness of coal. A screen making three grades of coal, having a diameter of four ft., length 12 ft., meshes ½ and ⅞ in., and making about 12 to 15 turns per minute has a capacity of about 200 tons per 10 hours. A slope of 1 ft. in 12 or 14 is about the right inclination for the axis of the screen.

A revolving screen is usually set above a row of bins, each holding a car or more of a particular grade. In this way one track, or at most two, can accommodate all the grades made. Some form of elevator must be used and usually also a conveyor. Ordinarily the link belt with steel buckets is employed as the elevator, and the conveyor is of either the screw, rope or traveling trough type. Probably the rope conveyor will be most satisfactory under ordinary circumstances.

Shaking screens are usually made of flat steel perforated plates, bolted to an iron or wooden frame suspended by iron rods. The plates are $\frac{3}{16}$ to ¼ in. thick and the width usually from 6 to 8 ft. There should be a drop of 6 or 8 in., near the center of the finest screen, to break up the mass of coal and cause a thorough separation of the fine coal. Still another method of separating the fine coal without having an excessive length of screen, is to place a short bar screen in the shaker and 4 or 5 in. above the perforated plate at the upper end. This will keep the large coal off the perforated plate till the small sizes are pretty well worked out. The shaking screen has an advantage over other forms, in that the coal is spread out and moves slowly so that slate may be picked out.

The slope of shaking screens is usually 1 to 3 or 1 to 4. An angle of 17° is good. The experience of at least one coal company has been that the upper end of the screen should be flatter than the lower end, as the coal flowed along too rapidly at first to completely separate the fine sizes. The stroke may be from 4 to 6 in. and the speed 90 to 125 revolutions per minute.

As the weight of the screen is considerable and the weight of the coal sometimes much more, the question of a suitable supporting frame is a serious one, as is also the consideration of methods for reducing the vibration due to the rapid shaking of such a heavy weights. In the first place, the supporting frame should be entirely free from the tipple, so that vibrations will not be transmitted to it. The framing should be such that there shall be no tendency to a separation of joints. Mortice and tenon work should be entirely avoided. The structure should be built-up of smaller timbers, and thoroughly bolted together, using large washers to prevent the bolt-heads and nuts from sinking into the wood. Mortice and tenor work is comparatively weak and has the further objection that it offers a place for the collection of water which rots joints, and also when built of unseasoned timber will shrink, leaving loose and unsightly joints that cannot be tightened up. Judgment should, however, be used in this as in other parts of the work, for sometimes a solid timber of the required size can be used to advantage when it can be obtained at a reasonable cost.

Where heavy and long screens are used, it will be found decidedly advantageous to cut the screen in two, and drive the two parts in opposite directions, thus greatly reducing the vibrations. Both screens should be driven from the same shaft, and that the connecting rods driving the two parts ought to be as nearly parallel as possible.

TIPPLE. The tipple, or headgear, as it is sometimes called, is worthy of close attention and study, because it must be strong to resist its everyday use and high wind pressures, for it is not infrequently a structure of considerable height. The material ordinarily used is wood on account of its cheapness. Of recent years some tipples of steel have been erected. They have less surface to catch wind, and if properly constructed may be easily taken down and removed to new shafts. Great care must be exercised to protect the steel from the corrosive action of the mineral water that is usually present in coal mines.

The half-tone illustration (opposite page 22) shows the side view of a modern equipment, and a few remarks about its peculiarities may be of interest. The winding drums are 6 ft. in diameter, the sheave wheels are 12 ft., and the rope used is 1½ in. in diameter. At first thought it would seem useless to have sheave wheels so much larger than the drum, but a glance at the construction of the tower will show that in order to keep the weight directly over the post timbers and for the rope to reach the center of the shaft, the wheel must be large. This tipple is made on the built up plan. The height is 68 ft. to the center of the sheaves. The braces running back to the engine house and also the posts, spread out at the ground to nearly three times the distance they are apart at the top, thus obviating the necessity of side-bracing. A peculiarity of the posts is that they are built of four timbers, separated by several inches, so other framing timbers may be bolted between them in either direction, as may be seen in the view. Each of the four timbers consist of two timbers 5x8 in. bolted flat together.

In designing a tipple 10 to 15 ft. of headroom should be allowed when the cage is at its highest dumping point. This allows a margin in case of accident, and is sometimes convenient when adjusting the hoisting ropes. The method of dumping the cars will have considerable effect on the general design, and will be mentioned later. The diagonal bracing may be of iron rods or timbers. The timbers should be painted before the tipple is erected. It is well to dip all bolts in a mixture of linseed oil and plumbago. This will preserve the bolts, and the shrinkage of the wood may be easily followed up with the nuts. The cage guides are made of various sizes from 4x4 to 6x6 in., of hard wood to prevent wear, and are fastened every 6 to 10 ft. to the other timbers, either with bolts or lag screws. The heads of the bolt must be counter sunk to prevent the cage catching.

THE HOISTING OUTFIT. The hoisting outfit consists of steam plant, engines, cages, ropes and sheaves.

Mine water is usually abundant, and sometimes it may be found necessary to use it temporarily for boiler purposes. As it usually contains large quantities of mineral salts, especially lime sulphate, some form of live steam purifier should be used. Cylinder or flue boilers are most frequently used, they being more easily cleaned from scale and sediment than other forms. Notwithstanding the fact of comparatively cheap fuel, the use of inefficient boilers, and then allowing much scale to accumulate, makes the ordinary mine steam plant a considerable running expense. There is no doubt but that well designed boiler plants, with water tube or tubular boilers and facilities for purifying the feed water, would be a profitable investment in many places.

Hoisting engines for shallow mines have heretofore usually been geared, but of late the tendency has been to use "first motion" engines for shallow as well as deep mines. Single engines have been used, but are giving way to double engines, as they are more prompt in starting, more easily handled, and requiring no fly wheel. A hoisting engine is sometimes subjected to very severe strains by reason of large lumps of coal falling from the pit cars and wedging between the shaft timbers and cage. It is necessary to select an engine heavy enough to withstand such shocks. The proper size of cylinder depends on the weight of cars to be hoisted, height of hoist, size of drum, and output per day. One prominent manufacturing concern figure a double engine so that one cylinder is large enough to do the work. This gives an abundant power to make the engine prompt acting. The valves should be balanced so that the reversing gear may be easily handled.

The size and kind of winding drum is of considerable importance. The ordinary straight drum, consisting of two spiders keyed to the shaft and lagged with wood, is very commonly used. This drum is usually 6 to 8 ft. in diameter, except in deep mines, and long enough to hold one rope; if both ropes are wound on one drum, it must be long enough to hold all of one rope and part of the other, for as one rope unwinds the other winds, and they may overlap each other on the central part of the drum. Cast iron drums, with a spiral groove cast in the face, are also frequently nsed. In deep mines where the unbalanced part of the rope makes a considerable difference in the starting load, tapering cast iron drums with a spiral groove cast in the face are used. The ropes are so attached that the loaded cage at the bottom begins to wind on the small end of its drum and the empty cage at the top begins to unwind from the large end of its drum. There is but one disadvantage to this drum, the cage is moving fastest (relatively to the engine) at the top of the lift, thus making it more difficult to handle. This objection is most serious when self-dumping cages are used. The "camel back" drum overcomes this difficulty. A continuous rope is used for both cages. Beginning at one end, two or three wraps are made around the drum, then as one rope winds on the drum the other side winds off, the wraps crossing from one end of the drum to the other. This drum is cast iron, with grooves in the face, and is considerably larger in the center than at either end, so that as the cage starts from either top or bottom it moves slowly, runs rapidly at the middle of the lift and slow again as the cages approach "landing" and "bottom." Thus the engine has great starting power at the beginning of the hoist and also permits the cage to be easily handled at the top. Its only disadvantage is that a break anywhere in the rope compels the whole to be discarded while if two ropes are used only one may be damaged. This disadvantage is offset, however, by the fact that a much shorter length of rope is required with the "camel back" drum than where two separate ropes are used.

Steel wire rope having 6 strands of 19 wires each on a hemp core is generally used, the diameter varying with the weight to be lifted. Some of the sizes used in Southern Illinois are, for 3 ton cars 1½ in. rope, for 2 ton cars 1¼ in. rope, and for 1¼ to 1½ ton cars 1⅛ in. rope. The breaking strength of these sizes are 154 000, 104 000, and 84 000 pounds respectively. If the cage and car weigh as much as the coal the factor of safety is in each case about 13 or 14, neglecting the weight of the rope. This large margin of safety is necessary on account of the sudden strains to which it is so often subjected.

Sheave wheels should have a diameter great enough to prevent too short bending of the rope. Good practice is to have the sheave diameter and also that of the drum, 60 times that of the rope. It is not uncommon to see but 40 diameters used, and occasionally almost as great as 100. Sheave wheels are sometimes lined with wood or leather to prevent too great wear of the rope, but it is questionable whether this adds materially to the life of hoisting ropes, as the cast iron drums of the engine are rarely, if ever, lined with either of these materials.

The modern mine cage is built in a great variety of forms, but may be divided into two general classes. First those used for hoisting only, and second, those used for dumping as well. It is a requirement of the mining law that at least one cage shall be equipped with a hood that will protect men from any object that may fall down the shaft while they are being hoisted or lowered, and also that the same cage shall be provided with safety catches that will hold the cage from falling in case the rope should break.

Some form of "keeper" is used to prevent the car from rolling off the cage while being hoisted, and when self-dumping cages are used, it must hold the car to the cage bottom while being dumped. Some keepers automatically stop and hold the car when it comes to the right place, while others must be operated by hand. The former admits of more rapid "caging" of cars, and for that reason are preferable.

There are two general methods of dumping coal. By the usual method the car is pulled off the cage and run to the dumping place, usually 10 to 30 ft. away. Here the car is stopped on a pivoted platform, which is tilted far enough to cause the coal to slide out of the car, the end of the car being automatically opened at the same time. This method is used at the mine shown in the illustration (opposite page 22). But the most interesting feature at that place is that the empty cars are not pushed directly back to the empty cage, but take another track back to the shaft, and are elevated by a movable platform on an inclined track to the cage level, and pushed on from behind by a steam pusher, which shoves off the full car at the same time. Thus no time is lost in waiting for the car to be dumped. Cars are sometimes run into a frame that turns completely upside down, either on a pivot or by rolling along a track. The novelty of this arrangement is in the fact that the center of gravity of the car and frame is above the turning point, both when the full car has run into the frame, and when the car has been emptied, so that the car automatically dumps and then rights itself.

The second general method of dumping is that in which the car remains on the cage, but the cage bottom is automatically inclined and the car door opened, so that the engineer does the dumping. This method saves some cost in labor, and also requires less material in the tipple. The most important consideration in selecting a self-dumping cage, is to be sure that no loose coal can fall down the shaft from the car while it is being dumped, for it must be remembered that the men below are likely to be exposed while putting on a loaded car.

THE STRAIN SHEET AND ESTIMATE OF COST FOR A PRATT TRUSS HIGHWAY BRIDGE.

BY A. B. LOOMIS, '93, SCHOOL OF CIVIL ENGINEERING.

We shall assume that our data include the span or distance center to center of end pins, width of clear roadway, and width and number of sidewalks. The panel length of the trusses will depend upon the kind of joists used—steel or wood. Steel joists permit of longer panels than do wood joists, and long panels are more economical than short ones. Given the number of panels and the span, the economical height of truss may be obtained from Prof. DuBois's table.* The economical height of truss has been found to be such that the weight of the web system about equals the weight of the chords.

The capacity of the floor system varies with the nature of the traffic on the bridge. If not specified, it is usually taken at one hundred pounds per square foot. For a city bridge a road roller should be provided for. Road rollers will usually govern in the design of floor joists, and with short panels will also determine the floor beams.

The live load per lineal foot equals the capacity per square foot multiplied by the width of roadway and sidewalks. It may be somewhat less than this if the bridge be of considerable span, as such a bridge is less likely to receive its full load.

DATA.

The following data will be used for the case under consideration:

Length of span..................	160.2 ft.
Width of roadway	16 "
Live load........................	80 lbs. per sq. ft.

*THE STRAINS IN FRAMED STRUCTURES, BY A. J. DUBOIS. Table V, p. 457.

The span will be divided into 9 panels. The depth, determined from DuBois's table, is 24 ft. From these data the following deductions are made:

Panel length	17.8 ft.
Length of posts	24.0 "
Length of ties	29.88 "
Live load per lin. ft.	1 280 lbs.
Live load per panel per truss	11 392 "
Sec θ	1.2449
Sin θ	0.5957

DETERMINATION OF WEIGHT OR DEAD LOAD.

Before we can calculate the stresses in the truss it is necessary to determine approximately the weight of the bridge. The weight of the flooring, joists, and hub guards may be arrived at directly, and will be calculated per lineal foot of bridge. The details of the weight are as follows:

Lumber:		
flooring, 3 in.×16 ft	48 ft.	
wheel guards, 2 ps. 5×6 in	4 "	
spiking pieces, 7 ps. 3×5 in	9 "	
	61 " @ 4 lbs. =	244 lbs.
Joists, five 7″ I beams @ 15 lbs		75 lbs.
" , two 7″ channels @ 9½ lbs		19 "
Hub guard		16 "
		354 "
Weight of trusses, floor beams, and lateral bracing (roughly estimated)		376 "
Total		730 "

Where a record of former estimates is kept, the weight of iron in a new bridge can easily be approximated if a bridge with about the same span and with the same number of panels can be found. The loading need not be the same. The method assumes that the weights per lineal foot of the trusses for like spans are proportional to their respective total loads per lineal foot. Suppose for our case we find a similar bridge whose truss weight is 374 lbs. and whose total load is 3 130 lbs. per lineal foot. We have for the total load of the given bridge:

Live load per lin. ft.	1 280 lbs.
Weight of joists, guards and lumber	354 "
Assumed weight of trusses, etc.	376 "
Total	2 010 "

By proportion, truss weight : 374 :: 2 010 : 3 130, from which the weight of the proposed truss equals 240 lbs. per lin. ft. To this add 25 per cent for weight of details and the equivalent weight, per lin. ft. of bridge, of the cross beams and lateral bracing. These latter are estimated to be 42 and 34 lbs. respectively. The result is 376 lbs. As this total weight of iron agrees with our original assumption, we can proceed. If it did not agree with the assumed weight, we should modify the assumed weight and repeat the process.

CALCULATION OF STRESSES.

Chords. For the chords the maximum stresses occur with the bridge fully loaded. The center moment equals $\frac{W\,l^2}{8}$, in which l equals the length and W the load per foot. The live and dead loads per panel per truss are 11 392 and 6 497 lbs. respectively. Calling these quantities L and D, the expression for our center moment becomes $\frac{9\,(L+D)\,l}{8}$. The moment at any point varies as the square of its distance from the center. As the chord stress in any panel equals the bending moment at the adjacent panel point nearer the center divided by the height of truss, we can say that the chord stresses vary as the squares of the distances from the center.

The value of the center moment divided by the height is

$$\frac{9(11\,392+6\,497)\,160.2}{8\times24}=134\,335.$$

The stress in $E\,F$ (Fig. 1, next page) equals the stress in $D\,E$,

$$=\frac{\text{moment about } e}{24}.$$

e is distant $\frac{1}{9}$ from the center to the end of the span. So we subtract $(\frac{1}{9})^2\times134\,335$ from 134 335 to get the stress in $D\,E$. For the stress in $C\ D$ we subtract $(\frac{3}{9})^2 \times 134\ 335$ from 134 335, or $(\frac{8}{81})134\ 335$ from stress in $D\ E$. In like manner the stresses in $B\ C$ and $a\ b$ are found.

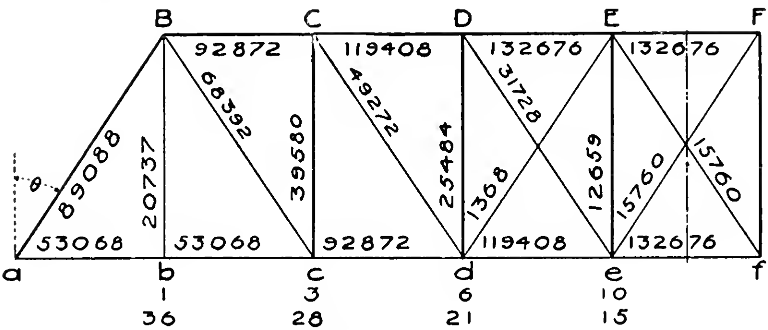


Fig. 1

Tabulating, we have: Center Moment ÷ 24 = 134 335.0

$\frac{1}{81} \times 134\ 335$ = 1 658.5

Stress in $D\ E$ .... = 132 676.5

$\frac{8}{81} \times 134\ 335$ = 13 268.0

Stress in $C\ D$ .... = 119 408.5

$\frac{16}{81} \times 134\ 335$ = 26 536.0

Stress in $B\ C$ .... = 92 872.5

$\frac{24}{81} \times 134\ 335$ = 39 804.0

Stress in $a\ b$ .... = 53 068.5

It will be seen that the above fractions are such that all the quantities may be obtained from the first one.

WEBS. The stress in a diagonal member equals the shear in the panel multiplied by sec θ. The stress in a post equals the shear in the adjacent panel which is nearer the center. The live load shear in panel $a\ b$ is greatest with all panels from b to the right end of truss fully loaded. This shear equals 4 panel loads, equals $\frac{36}{9}$ panel loads. In the same manner the maximum live load shear in panel $b\ c$ equals $\frac{28}{9}$ panel loads, etc. The numerators of these coefficients are written just below the diagram (page 35). The lower row is for maximum live load shears and the upper for minimum live load shears. The former are used to determine the stresses in the main diagonals and the latter the stresses in the counters.

The shear due to the dead load is zero at the center of the truss and increases by D at each panel as we move from the center. If the above truss were of an even number of panels, the dead load shear in the first panel from the center would equal $\frac{D}{2}$ and increase as before.

COUNTERS. The stress in the counter of any panel is found by subtracting the dead load shear from the minimum live load shear and multiplying the difference by sec θ. Thus:

$$\text{Stress in } e\,F = \frac{10\,L \sec\theta}{9} = 15\,760.$$

$$\text{Stress in } d\,E = (\tfrac{6}{9}\,L - D)\sec\theta = 1\,368.$$

MAIN DIAGONALS. The stress in the main diagonal of any panel is found by adding the dead load shear to the maximum live load shear and multiplying the sum by sec θ. Thus:

$$\text{Stress in } D\,e = (\tfrac{15}{9}\,L + D)\sec\theta = 31\,728.$$
$$\text{" " } C\,d = (\tfrac{21}{9}\,L + 2D)\sec\theta = 49\,272.$$
$$\text{" " } B\,c = (\tfrac{28}{9}\,L + 3D)\sec\theta = 68\,392.$$
$$\text{" " } a\,B = (\tfrac{36}{9}\,L + 4D)\sec\theta = 89\,088.$$

As the maximum stress in $a\,B$ and the maximum stress in the chords both occur with the full loading on the truss, we have by resolution of forces:

$a\,B \times \sin\theta = a\,b$, or $89\,088 \times 0.5957 = 53\,069.7$. As our stress for $a\,b$ was 53 068.5 this is sufficiently accurate.

POSTS. For the stresses in the posts the simplest method is to divide the stress in the diagonal intersecting the post at the top, by sec θ. This is easily done with a slide rule. Otherwise the stresses may be obtained in the same manner as the diagonals, using $\frac{L}{9}$ instead of $\frac{L \sec\theta}{9}$ and D instead of D sec θ.

LATERAL RODS. The stresses in the upper bracing are calculated for a wind pressure of 150 lbs. per ft. of truss, and in the lower bracing 250 lbs. per ft. of truss. The stresses and the method of obtaining them will not be given.

ESTIMATE OF MATERIAL.

We shall not go into the method of proportioning material, but will show how having done this the estimate is completed. The distribution of the metal and the resulting weights are shown in the bill of material on page 38.

The unit stresses used are:

Tension....12 500 or 10 000 lbs. per sq. in.
Compression.........10 000 " " "
Bending.............16 000 " " "

TRUSS MEMBERS. For the lengths of tension members we add enough to the center to center lengths to cover the extra material in the eyebar heads. In this case 3.5 ft. were added. This much was also added to the length of the end post to cover the material in the shoe. The length of the intermediate posts will depend on the manner of detailing the connection with the top chord. If the post extends only to the under side of the top chord, its length center to center pins will be sufficient.

PINS, BATTEN, ETC. Having the weight of the trusses it is necessary to add something to cover weight of pins, pin plates, rivets, lacing on compression members, splice plates, batten plates, etc. The weight of these details will vary with the specifications, but 25 per cent for panel lengths up to 20 ft., and 20 per cent for longer panel lengths may be taken as a fair basis for estimating.

BEAMS. The weight of one floor beam with connections as it will be shipped is figured; and this, multiplied by the number of times it occurs, is inserted with the other material.

LATERAL RODS. The lateral rods may be tabulated as is most convenient. Their length will vary with the detail of their attachment. In the present case we have used the diagonal length of a right triangle, one side being the panel length of the truss and the other side the clear distance between trusses. To this was added 2.5 ft. for nuts, upsetting, etc.

TOP LATERAL STRUTS. The upper struts are all made alike, as it is usually not practicable to proportion them for the small stresses they receive. Where standard struts are used it is well to have their total weights calculated for different weights of angles.

PORTALS. Certain standard portals may be used, the weight of which will depend on the span and on the width of roadway. This weight may be roughly estimated without designating the portal.

JOISTS. If steel joists are used their weight should be kept separate from that of the other material, as the shop cost on them is different.

HUB GUARDS. Certain standard hub guards may be used, and the weight may be assumed without designating the details of the design.

LUMBER. For this item we have only to multiply the amount per lineal foot, previously estimated, by the full length of the bridge.

BILL OF MATERIAL.

Member.	Material.	Area	Wt. per ft	Length.	No.	Total Wt
		sq. in	*lbs.*	*ft.*		*lbs.*
LOWER CHORD.						
a—c	2—2½ × ⅞	4.38	14.6	21.3	8	2 488
c—d	2—4 × 15/16	7.50	25.0	21.3	4	4 942
d—e	2—4 × 1¼	10.00	33.0	21.3	4	
e—f	2—5 × 1 1/16	10.63	35.4	21.3	2	1 508
UPPER CHORD.						
B—C	2—9″ Channels @ 14 ℔, 14 × ¼ Pl.	11.90	39.9	17.8	4	
C—D	2—9″ " @ 14.5℔, 14 × 5/16 "	13.07	43.9	17.8	4	9 448
D—E	2—9″ " @ 15.5℔, 14 × ⅜ "	14.55	48.9	17.8	4	
E—F	2—9″ " @ 15.5℔, 14 × ⅜ "	14.55	48.9	17.8	2	1 741
WEBS.						
a—B	2—9″ Channels @ 14 ℔, 14 × 5/16 Pl.	12.77	42 9	33 4	4	5 731
B—c	2—3 × 15/16	5.63	18.7	33.4	4	
C—d	2—2½ × 13/16	4.06	13.5	33 4	4	
D—e	2—2 × ⅝	2.50	8.3	33.4	4	6 306
E—f	1—1¼ square	1.56	5.2	33.4	4	
E—d	1—¾ round	.44	1 5	33 4	4	
B	2—1¾ × ⅝	2.19	7.3	27.5	4	803
C	2—8″ Channels @ 11 ℔	6.60	22.0	24.0	4	
D	2—7″ " @ 9.5℔	5.70	19 0	24.0	4	5 472
E	2—6″ " @ 8 ℔	4.80	16.0	24.0	4	
						38 439
DETAILS.	25 per cent of above					9 610
FLOOR BEAMS.	I beams @ 850℔				8	6 800
LATERAL RODS.						
a — b	1½″ round		6.0	28.4	4	
b — c	1⅜″ "		5.0	28.4	4	
c — d	1⅛″ "		3.4	28.4	4	
d — e	⅞″ "		2.0	28.4	4	
e — f	¾″ "		1.5	28.4	4	2 692
A—B	1″ "		2.7	28.4	4	
B—C	⅞″ "		2.0	28.4	4	
C—D	¾″ "		1.5	28 4	4	
D—E	¾″ "		1.5	28.4	2	
TOP STRUTS.	4— ∟s, 2½ × 2 × 2.8℔				6	1 404
PORTALS.	....	....	....	....	2	1 255
						60 200
JOISTS	....	....	94.0	162.0	.....	15 228
HUB GUARDS	....	....	....	....	2	2 560
LUMBER	9 880 ft. B. M.					

ESTIMATE OF COST.

COST OF TRUSS. Having the amount of the material, it remains to estimate the cost. To find the cost of the material, determine the percentages of I beams, channels, bars, plates, and angles in the structure.

These percentages are:

I beams	11%
Channels	28%
Bars	31%
Plates and angles	30%

From these data and the market price, the average price per pound may be computed as follows:

I beams and channels,	39% @ 1.68 cts.	per lb.	f.o.b.	shop			.6552
Bars,	31% @ 1.35	"	"	"	"		.4185
Plates and angles,	30% @ 1.88	"	"	"	"		.5640
Average price		"	"	"	"		1.6377

The cost per lb. of the truss is then found thus:

Cost of steel, f. o. b, shop, per lb.	1.64 cts.
Shop cost per lb	0.55 "
General expenses per lb	0.50 "
Freight to destination per lb	0.16 "
Total cost of truss per lb	2.85 "

Cost of Beams.

Cost of steel f. o. b. mill, per lb.	1.68 cts.
Shop cost per lb.	0.10 "
General expense per lb	0.51 "
Freight to destination per lb	0.16 "
Total cost of beams per lb	2.45 "

Total Cost of Bridge.

Trusses,	60 200 lbs. @ 2.85 cts.	$1 715.70
Beam,	15 230 " @ 2.45 "	373.14
Hub Guard,	2 560 " @ 3.10 "	79.36
Lumber,	9 880 ft. B. M. @ $20.00 per M.	197.60
Erection		250.20
Total cost of bridge		$2 616.00

CHEMICAL SURVEY OF THE WATER SUPPLIES OF ILLINOIS.

By Arthur W. Palmer, '83, Professor of Chemistry, University of Illinois.

Since the middle of September, 1895, there has been under way at the University a series of examinations of the water supplies of the state. With funds appropriated by the last legislature for this purpose, special quarters have been fitted up in the Chemical Laboratory and the work is now fairly under way. The original plan contemplates making a complete chemical survey of the waters of the wells, streams, and lakes of the state. That this undertaking is of considerable importance and magnitude is obvious, and although the investigation is now as far advanced as practicable, yet it is much too soon to make any but very general statements concerning it.

Since September we have been making analyses of water from various streams, and particularly the Illinois river and its tributaries. Each week we have samples taken from the Illinois river at Morris, LaSalle, and Havana; from the Spoon river at Havana; from the Kankakee river at Wilmington; from the Des Plaines and also from the Illinois and Michigan Canal at Lockport; from the Big Vermilion at LaSalle. Also we frequently have samples from the Fox river at Ottawa and from the Illinois at Peoria; and occasionally samples from the Illinois and Michigan Canal at LaSalle and at Ottawa.

Our purpose in the investigation of these waters is to determine the sanitary condition throughout the seasons of the year with a view of acquiring additional data concerning the effects of freshets, local contamination, etc., and especially for the purpose of studying the influence of Chicago sewage upon the waters of the Illinois river before and after the opening of the new drainage canal.

One of the most important objects of our survey is the determination of standards of purity for well waters. In most sections of the state the only available source of general supply consists of wells of greater or less depth. The water taken from the lower strata, as is well known, is quite different in character from that coming from near the surface. In many cases the water from wells ranging in depth from 60 to 200 ft. has an unpleasant taste and is otherwise objectionable on account of odor, color, or turbidity. Nevertheless these waters frequently are to be preferred from a sanitary standpoint to the more palatable, clear and apparently pure waters of shallow wells, which, although general appearances are strongly in their favor, yet frequently are unquestionably unfit for use because of contamination with surface water or sewage. It is undoubtedly true that in nearly all thickly populated towns shallow wells are as a rule contaminated with refuse matters of animal origin. Wherever we have had to make examinations of well waters from towns or villages, we have found it necessary to condemn many of these sources because of the evidences of contamination and pollution.

The standard of purity for both shallow and deep wells must depend on the character of the soil in the localities whence the waters proceed. Standards usually accepted have been originally determined for localities where the conditions have been quite unlike those which prevail in Illinois and generally throughout the Mississippi Valley. For the purpose of acquiring data whereby we may rationally judge of the purity of water supplies from wells we are making periodic examinations of water taken from certain shallow wells and also of water taken from certain deep wells, the wells being selected because of their being representative of general conditions and above all suspicion of contamination.

A feature of our work which may appeal more immediately and directly to the individual citizens of the state, consists in the examination for private parties of any well waters which are suspected of inducing or favoring disease. Whenever such cases are brought to our notice we send clean bottles and directions for collecting samples, and analyses are made at once and reports sent to the interested parties. We prefer that requests for this sort of work should come through the local health officer, but such analyses are made for any citizen of the state who applies either through the health officer or directly to the chemical department of the University.

Since beginning the work we have made about 650 analyses, a large proportion of which have been for private citizens as above indicated. The work upon the Illinois river and tributaries may be considered as supplementary to that conducted by the State Board of Health in 1888 upon the same waters.

The problem concerning the ground waters of the state as indicated by analyses of the waters of wells of greater or less depth, is a problem which has not hitherto received such attention as the importance of the subject deserves, and while the progress must necessarily be slow, yet the outcome will undoubtedly be of benefit as furnishing a more certain basis for judgment concerning the condition and suitability of waters from these sources.

INSPECTION OF WATER-PIPE LAYING.

By Ralph P. Brower '97, School of Civil Engineering.

Most of the water works plants which are being constructed are comparatively small ones. The inspection of such work is often placed in the hands of inexperienced men who are also frequently required to do much of the engineering work. It will be the purpose of this paper to offer suggestions to those who may be so placed.

It is not expected that the methods here given will apply to all cases. Nearly every contract will present conditions for which special methods and devices will be required. To become proficient in this, as in any other line of work, close observation of details is necessary.

In staking out the work, the method of procedure will vary with the local conditions. Water mains are usually located a fixed distance from the center lines or from the curb lines of the streets. If the street intersections or block corners are marked by monuments, the transit will not be needed in giving lines; if curb lines are marked or curbs set, the work can be laid off from them; but if street intersections, block corners, or curb lines are not marked, a survey will be necessary. Stakes should be set about one hundred feet apart, and one or two feet from the edge of the proposed trench. In order that they may be accessible for checking the alinement of the trench, stakes should be placed on the side opposite to that on which the dirt will be thrown.

Water mains are not usually laid with regular gradients. When the streets have no established grades, it is customary to lay the pipes four and one-half or five feet below the surface, varying the depth at critical points in order to avoid air pockets and abrupt changes in gradient. Where street grades are established the pipes are usually laid at a constant depth below street grade, except where the surface of the ground is below such grade, when they are placed this same depth below the surface.

In giving depths for trenches, the method of using a level and computing the grade elevation and corresponding rod reading for each station would be a waste of time. Such accuracy is not necessary. The gradienter comes into use here very nicely, the method of procedure being as follows: The transit is set up at a street intersection or at a break in grade and the height of intrument determined by a level reading on a bench mark. The target is set for grade at the instrument and the gradienter adjusted to correspond to the rate of grade. The rod is then held on the ground on the line of the trench, the target being left clamped. If the line of sight is below the target the rodman adjusts his finger to it, and notes the difference between this reading and that of the target. This difference is added to the depth of trench below grade and the cut marked on the stake. If the line of sight is above the target, the surface of the ground is below grade and no correction is necessary. In this case the man at the instrument gives the "all right" signal without waiting to find the difference between ground and grade elevations.

If levels have been taken on the streets and the notes are available, they can be used for this work. Grade and ground elevations at each station are compared, and the cuts thus determined.

Stakes locating valves, hydrants, and specials should be set at the time of laying out the trench. Such stakes should have witness stakes telling what they locate.

As soon as the work is staked out, all cuts should be recorded and all stakes locating valves, hydrants and specials should be carefully referenced from trees, light-poles, fence or curb corners. All of the delay and work caused by the loss of stakes is thus avoided.

Water pipe is often purchased without any test or inspection at the factory. It must be admitted that this is very poor practice; especially so in the case of large contracts. As foundry inspection is usually done by one of the companies which make a business of such work, it will not be dealt with here. This inspection however, does not insure perfect pipe. Cracks due to rough handling during transportation are not uncommon.

If the contract for pipe is a separate one, the weights should be checked and a careful inspection made at the car while unloading. If the contractor for the work furnishes material also, the inspector takes care that no defective pipes, or pipes that are under weight, get into the trench. After pipes are delivered on the ground they should be carefully inspected for cracks and sand holes. Each piece should be sounded with a heavy hammer. The spigot end should be examined with great care, for it is here that cracks are most likely to be found.

The special castings should all be delivered before the work begins or as soon thereafter as possible, each piece being checked off on the map when delivered. Missing castings may then be ordered at once and much trouble and costly delay avoided. If the contract is a large one, the work of checking off pipe and specials will take quite all of one man's time.

It is the work of construction that requires the most attention. Each pipe should be swabbed and all dirt cleaned from the bell before it is laid. Small boys take delight in hearing stones rattle through iron pipe. These and many other things not intended for use in a water main, are often brought out by the swab. If the end of pipe already laid is not securely plugged at night, small stones are almost sure to find their way in; and they cause no end of trouble in the operation of valves and hydrants. An ordinary cast-iron plug, yarned in, will prevent this trouble.

The depth of the trench and the bedding of the pipe should receive special attention. The latter requires more care when, as is nearly always the case on large contracts, three or four lengths are calked together on the bank and lowered into the trench by means of derricks. If left to follow his own inclinations, the average foreman will have bell holes dug only where joints are made in the trench, leaving the other bells resting on the bottom and carrying the whole weight of the pipes. The settling of some of these bells and springing of joints is the inevitable result of this practice.

Some engineers insist that every joint should be made in the trench, giving as a reason that the joints are sometimes sprung in lowering two or more pieces which are calked together. This objection, however, is more than counterbalanced by the better opportunity for getting a well-calked joint than can be obtained in the ditch. If the lowering into the trench is properly and carefully done, very few joints will be sprung, and such joints can be readily detected and the opening easily calked.

The work of the yarners and calkers will at all times bear close watching. The condition of their tools should receive especial attention. The yarning irons should not be allowed to become sharp, or to have sharp edges that will cut the yarn. The calking tools, on the other hand, should have sharp corners, and the faces should be beveled slightly, but not too much. A little bevel on the face allows a straighter tool, and consequently less elasticity and a greater blow. The bevel should be such that the face of the tool, during use, will be perpendicular to the axis of the pipe.

The yarner should not be allowed to use a hammer on his tool until he has nearly the required amount of yarn in the joint; but he should get each strand well home as he puts it in. Then the hammer is used and the yarn driven back until it is solid. If it is not solidly packed it will permit the lead to be driven back further than is compatible with good work. When finished the yarn should be at a constant depth below the face of the bell around the entire circumference. No lumps or kinks should be tolerated. The depth to be left for lead is usually fixed by the specifications, but should in any case be a quarter of an inch deeper than the back of the lead ring, or groove in the bell.

Before running the lead the joint should be clean and dry. The hot metal will convert any water in its way into steam which will blow off the roll and ruin the joint. The temperature of the lead should be noted occasionally. This is determined by its color, a knowledge of which can be gained only by observation. Suffice to say that when it has a dull color the lead is too cold to run joints properly. If only enough lead is carried to fill the joint the last that is poured from the ladle will have cooled beyond the proper limit. The joint should, therefore, be run from a full ladle and at a single pouring.

The coldest lead is of course at the top of the joint, or the "gate," hence the density of the lead is least at this point. In order to equalize the density the calking should be commenced at the bottom and done toward the place of the gate. The lead is first loosened from the pipe with a chisel; then the calking tools are used in order, beginning with the smallest and finishing with one that completely fills the joint.

When setting a hydrant, much care should be exercised in getting the barrel plumb. One who has seen a hydrant which is not vertical will testify that it is a very unsightly object. There are to be found any number of men who can sight in a hydrant perfectly "by eye." When the piles of loose dirt are removed from the vicinity the hydrant is usually found to be out of plumb. An ordinary carpenter's level is easily adjusted to fit the side of the barrel, and should always be used. The working of the valve and of the drip should be tested before the hydrant is put in the ground.

Sewers and house drains are an endless source of trouble. No small part of the inspector's work is caused by the difficulty of properly replacing them. It is always best, when possible, to leave them undisturbed; but should it be necessary to remove them, they should be replaced with great care. This work should not be left for any common laborer to perform. A man skilled in this class of work is required in order to have it properly done. To replace a broken sewer and to do it well is a much more difficult task than laying a new one.

The prevalent method of testing water mains after the trench has been filled is not to be recommended. It is generally admitted that a large amount of invisible leakage accompanies most systems of water supply, the cause of the difficulty being the impossibility of securing perfect workmanship in the joints. Absolutely tight water conduits can be obtained only after testing in the open trenches. In nearly all cases this can be done with no great inconvenience or cost. If the pumping plant is not completed at the time of laying the mains, the pressure can usually be obtained from some factory pump, or fire engine, and transmitted to the mains through small pipe or fire hose connected with a hydrant nozzle. The leaks, large and small, can all be readily detected and repaired before the pipe is covered, and a perfectly tight conduit is secured.

If rock excavation is encountered in the trenches and it is desired to plat the surface of rock on the city's profiles, a convenient method of measuring it is as follows: Use three columns in the note book. Record in the first, the station numbers, in the second the depth of surface of rock below the ground, and ip the third the difference betwsen this depth and the total cut, or the depth of rock excavation. The first and second columns are used in platting rock on the profiles, and the first and third in computing quantities.

The relations between the contractor and inspector should be frank and pleasant. The inspector should be considerate of the interests of the contractor in so far as is consistent with the proper conduct of the work. Small concessions, when they are not detrimental and save money for the contractor, work no harm and lead to pleasanter relations. They should be made with considerable discretion, for if carried to extremes, they will prove the foundation for larger askings which will be hard to refuse.

Much confusion and annoyance always results from dealing with sub-contractors, mechanics, or laborers. Of course there are many exceptions, but it is generally best to hold one man responsible for the work. If the contractor so desires, orders may be given to sub-contractors or laborers, but in this case it should be clearly understood that the orders will be considered as having been given to him.

All questions should be carefully weighed before being decided. When a decision is once given it should be firmly upheld, unless it is proved to be wrong, in which case the mistake should be frankly acknowledged. Nothing is gained by arrogance. Tact and good judgment will lessen friction and thus aid in securing superior construction.

FLOW OF WATER THROUGH SIPHONS.

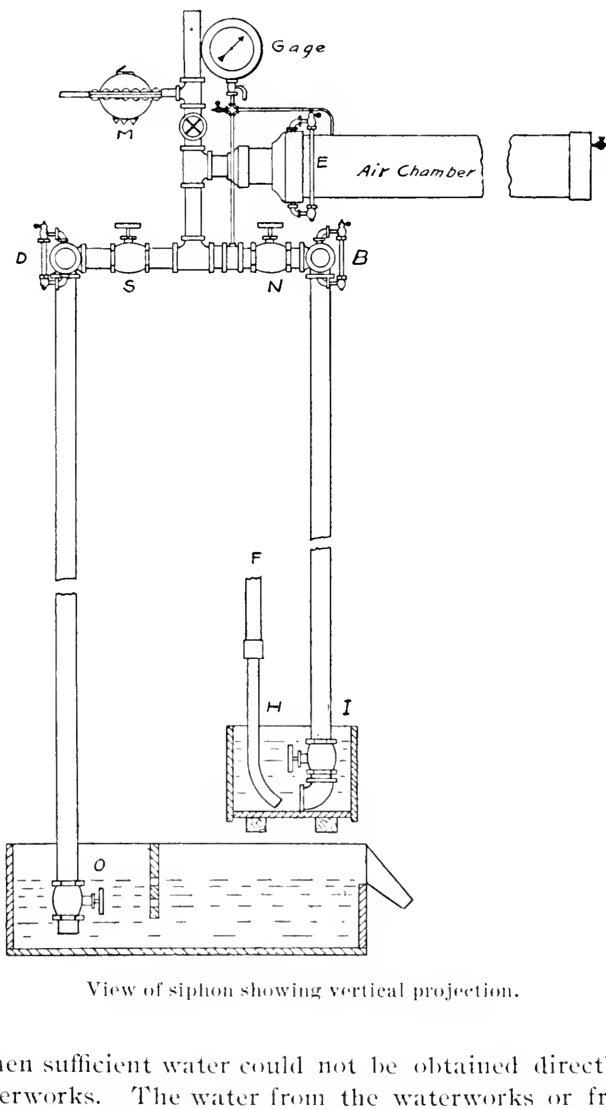
By Milo S. Ketchum, '95, Assistant in Civil Engineering.

In waterworks and irrigation systems it is often found necessary or desirable to conduct water over a divide or summit by means of some simple, reliable, inexpensive method. Where the height of the summit, or rise, is not large, and the difference between the level of the water at the inlet and outlet, or head, is sufficient to give a fair velocity, the siphon has been found to satisfy all the above requirements. Considerable difficulty has been encountered, however, in obtaining satisfactory results in a siphon having a head sufficient to give a velocity of only 2 or 3 feet per second, where the rise was more than 15 or 16 feet. The partial vacuum at the summit causes the air in the water, due to leaky joints or carried in suspension from the inlet, to expand and check the flow, thus making it necessary in many cases to recharge the siphon at intervals. The best example known to the author of a large siphon working under severe conditions is that at New Rochelle, New York, described in The Technograph No. 6 by J. N. Chester, '91.

In view of the small amount of data available on the subject, the experiments, which form the basis of this article, were made in the Laboratory of Applied Mechanics under the direction of Prof. A. N. Talbot, by C. V. Seastone, '95, and the writer, in connection with the preparation of their graduating thesis for the degree of B. S. in Civil Engineering.

Apparatus. The siphon was made of 2-in. wrought-iron pipe. The inlet and outlet legs rose vertically to the top, where 162 ft. of horizontal pipe connected them at *B* and *D* (see Fig. page 49). The air chamber was made by capping one end of a 6-in. pipe 10 ft. long, and reducing it to a 2-in. pipe at the other. It was placed 8 in. above the horizontal pipe. The outlet and inlet valves, *O* and *I*, were gate valves; all the others were globe valves. Water-gage glasses and pet-cocks were placed as shown. All joints and connections were thoroughly coated with white lead before beginning the experiments, and no trouble was experienced from leaky valves or joints.

Water was obtained from the city waterworks. A 5×7×10-in. duplex pump was used to pump the water back to the inlet



View of siphon showing vertical projection.

tank when sufficient water could not be obtained directly from the waterworks. The water from the waterworks or from the pump flowed into a supply tank, holding 1 400 gallons, placed four feet above the air-chamber. The tank was connected by a 4-in. pipe with a 12-in. standpipe. From this standpipe the water ran through a 2-in. feed pipe into the inlet tank. The water in the inlet tank was kept at a constant head by gaging the feed water with a globe valve placed near the end of the feed pipe, and by means of the overflow pipe in the inlet tank.

CHARGING AND STARTING. The outlet and inlet valves being closed and all pet-cocks opened, water was metered into the air-chamber from the supply tank. When the water spurted freely from all the pet-cocks, the valves and cocks were closed and the siphon was ready for action.

This method did not remove all the air from the pipes and considerable difficulty was encountered at first in starting the siphon. With a rise of 21.5 ft. and a head of 8.43 ft. a flow was obtained by turning on the feed water suddenly at the instant of opening the outlet valve. With the same rise and a head of 4 ft., and also with more extreme conditions of rise and head, in order to start the siphon it was found necessary to force water through the apparatus at a considerable velocity by connecting the rubber hose H with the inlet pipe. When the water had run long enough to drive out all air bubbles, the hose was removed and siphoning began.

EXPERIMENTS. Twelve experiments were made. Experiment 9, the longest one, is given in full, as it shows all of the most interesting facts developed during the series. (See p. 51.)

DISCUSSION OF EXPERIMENTS. The experiments will be briefly discussed under 4 heads: 1. Vacuum; 2. Flow; 3. Amount of Air; and 4. Stoppage.

1. Vacuum. The vacuum was measured in inches of mercury by means of a Crosby vacuum gage, and for purposes of comparison was reduced to feet of water.

The head should, of course, be equal to the sum of the various resistances: viz., the loss or head due to entrance, the loss of head due to friction, and the loss of head due to velocity.

The rise, plus the velocity head, plus the friction head in the inlet leg, plus the loss of head due to entrance, should be equal to the vacuum at the top of the inlet pipe. The rise plus the head, minus the friction head in the outlet leg, should be equal to the vacuum at the top of the outlet leg.

EXPERIMENT IX.

Time.	Vacuum in Inches of Mercury.	Amount of Water in Air Chamber.	Head on Weir in Feet.	Discharge in Gallons per Minute.	Theoretical Discharge in Gallons per Minute.	Velocity in the Siphon in Feet per Second.	REMARKS.
8—50	25.5	Full.	0.150	30 0			
9—00	26.5		0 126	24 0	26 0	2.25	Rise=27.5 Ft.
9—15	26.6	Empty.	0.124	24.0		2 25	
9—30	"		0 123				Head=4.33 Ft.
10—00	"		0.125				
10—30	"		0.122				Both of the air-chamber valves N and S in Fig. were open at the beginning of the experiment; at 8:55 the valve N was closed and remained so during the remainder of the experiment.
11—10	"		0.125				
11—50	"		0.124				
12—30	"		0.123				
1—00	"		0 123				
1—20	"		0 122				
2—30	"		0.121	23.5		2.22	
3—00	"		0 121				
3—30	"		0.122				The siphon started at 8:45 A. M., April 11, 1895, and ran until 12:30 P. M., April 12.
4—40	"		0.122				
6—15	"		0 122				
8—00	"		0.122				
9—30	"		0.120				
10—30	"		0.120				Amount of air in air-chamber at the end of the experiment was 1.0 cubic foot, 7.5 gallons.
12—35	"		0.119				
2—30	"		0.119				
4—30	"		0 116	22.5		2.14	
6—30	"		0.116				
9—00	"		0.116				
10—30	"		0 116				
12—20	"		0.117				
12—30	The Siphon stopped suddenly.						

The difference between the vacuum at the top of the outlet pipe and the corrected rise plus the head, as shown by the following table, was probably caused by the abrupt turn in the pipe at the top of the outlet leg after the water had run through the horizontal pipe at the summit. The abrupt bend would tend to cause an increased velocity and a decreased cross-section at and

TABLE SHOWING DIFFERENCE BETWEEN THE THEORETICAL AND OBSERVED VACUUM.

No. of Exp.	Rise in Feet.	Correction for Friction Velocity, and Entrance.	Corrected Rise.	Vacuum at the top of Inlet Pipe in Feet.	Difference.	Rise plus Head	Correction for Friction in Outlet Pipe.	Corrected Rise plus Head.	Vacuum at the top of Outlet Pipe.	Difference.
3*	21.5					29.92	1.05	28.87	28 14	0.73
7	21.5					24.25	0 36	23.89	23 73	0.16
8	27.5	0.30	27 8	27.8	0.00					
9	27.5					31.83	0.54	31.29	30.06	1.23
10	27.5					29.32	0.24	29.08	28 60	0.48
11	27.5	0.45	27.95	27.91	0.04	30.43	0.36	30.06	29.38	0 68
12	27.5	0.33	27.83	27.65	0.18	29.33	0.23	29.10	29.10	0 00

*Experiments 3, 4, 5, and 6 gave the same results.

just below the bend. The water in this contracted section would not fill the pipe, but would leave an air space. The reading of a gage placed above this point would be in error an amount equal to the difference between the weight of a column of water and a column of air having a height equal to the height of the air space. The variation is practically equal to the height of the air space, since the weight of the air may be neglected at the vacuum considered.

2. Flow. The flow was gaged by means of a 4-in. Cippoletti weir. The flow for short intervals was also determined by weighing. In computing the theoretical discharge the resistance of elbows, return bends, valves, and the velocity head was reduced to that for an equivalent length of straight pipe, using coefficient for an average velocity of 2 ft. per second.

The tables for flow of water through pipes given in the report of the City Engineer of Providence, R. I., for 1890, gave values which were uniformly 6 per cent. in excess of the measured flow. The formula *$Q^{1\frac{1}{6}} = \frac{I}{C'}$, in which Q equals the discharge in cu. ft. per second, I equals the friction head in feet per foot, and C' equals a coefficient varying with the size and roughness of the pipe, gave results uniformly 15 per cent too small. These comparisons show that the flow of water through siphons may be computed by means of the ordinary formulas for flow of water through pipes.

3. Amount of Air. The rate of accumulation of air was quite uniform as long as observations could be made, which was as long as water remained in the air-chamber. After the air-chamber became filled with air, nothing further could be determined in that direction. The siphon appeared to run as well and as long when the air-chamber was disconnected as when it was connected. The above facts, in connection with the fact that the siphon with a rise of 27.5 ft. and a head of 4.33 ft. ran continuously for 27 hours after all the water had been lost from the air-chamber, caused the attempt to make a systematic determination of the amount of air which would accumulate under different conditions of rise and head, to be discontinued in the later experiments.

4. Cause of Stoppage. In all cases where the siphon

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*Proposed by Wm. E. Foss in *Journal of Assoc. of Eng. Soc.*, June, 1894.

stopped flowing the change in flow was rapid. This decrease in flow was immediately shown by the inlet tank running over. In no case was it longer than 5 minutes from the time this overflow took place until the flow had entirely ceased, and in most cases the overflow and stoppage occurred almost simultaneously. This was quite different from the manner in which the New Rochelle siphon stopped its flow. In that, the flow decreased gradually from the time the air-chamber became filled with air until it stopped.

To see if the stoppage could be caused by the accumulation of air or by an air bubble, the following experiment was made: A bottle was connected to the pet-cock at the top of the inlet leg by means of glass and rubber tubing. On opening the pet-cock, air was drawn from the bottle into the pipe. This air would expand to 6 times its original bulk with a vacuum of 25 in. and thus completely fill the pipe for a considerable length. With a bottle having a capacity of 50 cu. in. the water in the inlet tank overflowed at the moment of admitting air, but the siphon recovered itself and the flow continued as usual until the air bubble had had time to reach the horizontal pipe at the top of the outlet leg, when the inlet tank again overflowed and the flow entirely ceased. The experiment was repeated several times with the same results.

The fact that the same phenomena were observed when the siphon was stopped by an air bubble as when the siphon stopped under ordinary conditions led the experimenters to conclude that the cause of the stoppage must have been the same in each case. In a working siphon the air bubble might be formed by a small bubble starting from or near the inlet and growing by the addition of successive increments until it reached the summit when the siphonage would be broken, or the air might collect at the summit and throttle the flow, causing it to decrease gradually as in the case of the New Rochelle siphon. Where the pipe at the summit is smooth it is believed that for ordinary velocities the air will not collect, but will be carried over in suspension when the bubbles are not large enough to fill the entire cross-section of the pipe.

Conclusion. The experiments seem to show that the following conditions should be fulfilled as nearly as possible: (1) There should be a summit at which an air-chamber, connected with the siphon by two vertical legs having, preferably, as great a cross-section as the main pipe, should be placed to facilitate the removal of the air in the siphon in charging, and to act as a storage chamber for air due to leaky joints or air taken up from the water under the negative pressure; (2) The siphon should have no abrupt turns or bends; (3) The siphon should not have an inclination less than the friction gradient at any point between the summit and the outlet. The pipe should in no case be horizontal; (4) All valves should be of such a design and so placed as not to interfere with the passage of air along the top line of the pipe nor form air pockets. Gate valves placed sidewise more nearly fulfill these conditions than do any others.

After making a careful study of all the available data on the subject and the foregoing experiments, the author is of the opinion that where the design is properly made and the material and workmanship of the very best quality, using every precaution to obtain smooth pipe and guard against leaky joints, there is no reason why a siphon will not give satisfactory results even under the most extreme conditions.

ALTERNATE CURRENT MOTORS.

By Bernard V. Swenson, '93, Assistant Professor of Electrical Engineering.

Although Faraday, as far back as 1821, discovered that it was possible to produce continuous motion by the agency of the electric current, it was not until after the discovery that a conductor cutting lines of force would have an electric current generated therein, and after the substitution of electro-magnets for permanent ones in the dynamo, that it was possible for the electric motor to exist in any other than an experimental form.

Up to the time of the Industrial Exhibition at Vienna, in 1873, the current from the dynamo had never been used for energizing a motor, it being supposed that only a primary or secondary battery was capable of furnishing the requisite kind of current. But at the Vienna Exposition, where two Gramme generators were on exhibition, either by accident or design, (a disputed question), one of the generators was connected with the other and for the first time a dynamo-electric machine operated another as a motor. The subject of the transmission of power has occupied for many generations the attention of engineers and scientists, but it is only within the last twenty years that the problem of transmitting power in large quantities over great distances has met with even apparent success. The greatest advance in this branch of engineering has undoubtedly been made since the introduction of electricity for commercial purposes.

When the dynamo had ceased to be a laboratory machine, and the electric motor had become an assured success, the scientific public at once jumped at the conclusion that the problem of the transmission of power had reached its ultimate solution. But they were destined to disappointment, for as in the case of transmission of power by means of wire ropes, compressed air, and steam, great losses were encountered along the line, not to mention those losses due to the transformation of energy, which are inherent in all systems. The loss due to the heating of the conductors at once presented itself as a serious objection to the use of large currents. It was therefore necessary to increase the

E. M. F., but it was soon found commercially impracticable to use very high pressure with direct currents. It was at this juncture that the alternating current system was pushed to the front, and because of its great flexibility and the ease with which the E. M. F. can be transformed up and down, it soon surpassed its direct current rival as a means of transmission of power. The extensive introduction of alternating currents has consequently caused an imperative demand for efficient, and at the same time, commercially convenient, alternating current motors. In the twelve years which have elapsed since a motor capable of working with alternate currents was first in demand, great progress has been made, and to-day there are several varieties of alternate current motors which are much simpler in design, easier to care for, and more efficient than the best direct current motors.

COMMUTATING MOTORS. Any direct current motor may be operated by an alternating current, provided the fields are laminated sufficiently to prevent the destruction of the motion by Foucault currents. Hysteresis losses are large and commutator troubles are liable to be severe in motors of this class operated at ordinary frequencies. When the frequency is very low they may be operated with success and with a fair degree of efficiency. A large number of motors of this type have been built and are in operation at the present time. For the most part, however, they are small sized and of low efficiency, being used principally to operate small fans from the ordinary lighting circuits.

About nine years ago a large number of experiments were made upon motors of this kind. At that time serious difficulties were met with in the attempts to produce motors of fair output at a reasonably high power factor and with a good commutator behavior. The results obtained were not satisfactory, and since that time but little has been done in this direction.

SYNCHRONOUS SINGLE PHASE MOTORS. *Dr. Hopkinson in 1884 was the first to show that the ordinary alternating dynamo, if first brought up to speed, would run as a motor synchronously with the generating dynamo. It is a well-known fact that the current in the armature coils of a direct current dynamo is being constantly reversed, although because of the commutator the

*"On the theory of alternating currents, particularly in reference to two alternate-current machines connected to the same circuit."—Journal Society Telegraph Engineers, Vol. XIII, p. 496.

current is rectified in the external circuit. It is also easily seen that when a direct current enters the armature of a motor it is transformed by the commutator into an alternating current. Suppose now, that there are two similar direct current machines and that one is driven as a motor at exactly the same speed as the other which acts as a generator, it is evident that if this be the case there is no need of the commutators, as the current being alternating is rectified by the commutator of the generator and transmitted to the commutator of the motor, and is again transformed into an alternating current wave of the same frequency as was first generated, the flow of current in the armature of the motor, corresponding exactly to the flow of current in the armature of the dynamo. It is therefore evident that when two similar single phase alternate current machines are running at such speeds that the frequency is the same, one may be made to act as a generator driving the other as a motor.

The motor E. M. F. will always be nearly 180° different in phase from the generator E. M. F., and the current which flows

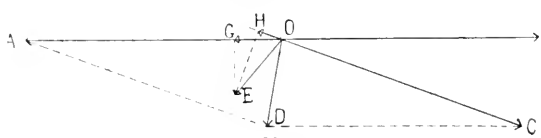

Fig. 1.

in the armature circuit will always be due to the E. M. F. which is the resultant of the generator and motor E. M. F's., the relative phase angle of the current depending upon the amount of self-induction in the circuit. Let us designate by E_1 the generator E. M. F., by E_2 the motor E. M. F. and by E_3 the resultant E. M. F. Take the case of the motor having the same E. M. F. as the generator and consider the circuit as having both resistance and self-induction. At the instant that the circuit is closed (which would be at the point of true synchronism) the motor E. M. F., represented by OB, would be 180° behind the generator E. M. F. represented by OA. As E_1 and E_2 are equal, the result would be that no current would flow and consequently the motor would tend to slow down and would drop back to some position as C such that the line OC would represent its E. M. F. A resultant E. M. F., OD, would then be formed and the current in the armature would be represented by some line OE lagging behind OD on account of the self-induction in the armature circuit. The product of this current and the generator E. M. F. multiplied by the cosine of the angle of their phase difference is the amount of power given out by the generator. The projection OH of this current upon the line of motor E. M. F. (produced) multiplied by the motor E. M. F. E_2 is equal to the total mechanical power developed, the negative sign showing that the motor is doing work. It will be found that this value will, at a certain position, attain a maximum, beyond which it will again decrease. The consequence is that if the motor is loaded beyond this point, it will be thrown out of synchronism and will quickly come to rest.

If we took E_1 equal to E_2 and considered that the circuit containing resistance but no self-induction, it would be found that at no position could power be developed by the motor, and consequently it would immediately fall out of synchronism. If we should consider the case of resistance but no self-induction with E_1 greater than E_2, we would find that the motor armature would take up a position slightly advanced in phase and the maximum load would be that which would retard its armature to the point of true synchronism beyond which the motor would promptly come to rest.

If we take E_1 equal to E_2, and neglect resistance, but assume self-induction to be present, it will be found that at the instant of synchronism, no current will flow and the motor armature will immediately lag in position to such a point that the resultant E. M. F. E_3 will establish a current (90 degrees behind itself) which will have a component which is negative with respect to E_2, showing that the motor is developing mechanical power. It will be found that the motor will operate well up to a certain maximum load, at which the angle of lag has become so great that the projection of the current upon the E_2 line (in a negative direction) has become a maximum. Beyond this load the motor will immediately drop out of synchronism.

If we take E_1 greater than E_2 and neglect resistance but assume self-induction to be present, we will find that at the moment the circuit is closed, although current will flow, no power will be developed (the current being at 90 degrees from E_2) and the motor will act as in the case just considered.

By taking up a number of different cases in this way, assuming certain conditions and constructing the diagrams, the complete theory of the synchronous motor may be easily deduced. In all cases in which the motor will operate at all it will be found that it will run in absolute synchronism with the generator up to a certain maximum load, beyond which it will immediately fall out of synchronism and come to rest.

In the practical operation of synchronous motors the E. M. F's., E_1 and E_2 are determined by the field excitations and the current established in the armature circuit, producing reactive effects upon the fields, which tend to equalize the E. M. F's., E_1 and E_2.

The old style alternator with smooth cored armatures and flat "pan-cake" armature coils made very poor synchronous motors, but the later alternators with toothed armature cores and the armature coils wound in the grooves of the core, have been found to make very good synchronous motors, largely because of the increased self-induction of the armature and the useful effect of the armature current on its own field. A synchronous motor having the same number of poles as the generator, will run absolutely at the same speed as the generator. The motor may be designed to run at a different speed from the generator by altering the number of poles, a motor having twice as many poles as the generator running at one-half the speed of the generator. That is, the speed of the motor will be to the speed of the generator as the number of pairs of poles of the generator is to the number of pairs of poles of the motor.

It is well known that if the current of an alternator is not in phase with its E. M. F., there will be two short intervals in each complete period during which the machine will act as a motor. In like manner we will have the sychronous motor, during two short intervals in each period, acting as a generator. The only source of this power is the fly-wheel effect of the motor armature and its load.

SYNCHRONIZERS. It has been stated that in order to operate a single phase synchronous motor it must be brought up to the proper speed before closing the armature circuit. It is also necessary that the motor E. M. F. should be exactly opposite in phase to the generator E. M. F. In order to accomplish this result various methods have been devised.

Figure 2 shows one form of synchronizer. It consists mainly of two small transformers, the primaries of which are connected to the terminals of the generator and motor respective-

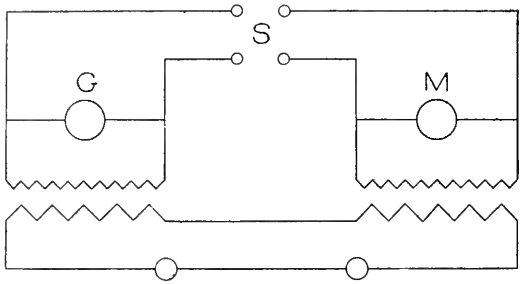

Fig. 2.

ly. The secondaries of the two transformers are connected as shown, and into the circuit are placed some incandescent lamps. By following out the connections it is easily seen that if the E. M. F's. of the machines are in such phase relations that the machines would be short circuited upon each other, the lamps will be brightest, and that when the E. M. F's. are at 180° from each other, the lamps will be dark. But complete brightness or complete darkness will only occur when the frequencies are absolutely the same. Generally the frequencies will be different and the lamps will flicker. Thus, suppose the generator is running at its normal speed, and the motor is started. At first there will be rapid flickering in the lamps, and as the speed approaches to true synchronism the flickering becomes less rapid, and regular beats occur which get longer and longer. The switch S must be thrown in the middle of a beat when the lamps are dark. The machines are then so nearly in synchronism that the first rush of current throws them dead into step, and they remain, as it were, interlocked in that condition.

In single phase synchronous systems we have several prominent and distinguishing features. (1) The motors are usually separately excited to serve the complications of commutators. (2) The motor must be raised to a synchronous speed before the generator circuit can be closed. (3) There is always a certain maximum load beyond which the motor will immediately fall out of synchronism. (4) Motors must be designed with regard to the frequency of the current as well as the E. M. F. of supply, and hence are only suitable for working on particular circuits.

(5) Motors may be made to run at different speeds from the generator by altering the number of pairs of poles. (6) Motors have dead points occurring in each period and the fly-wheel effect must be sufficient to carry the armature past these points.

SYNCHRONOUS POLYPHASE MOTORS. An ordinary single phase alternator may be run as a synchronous motor if placed across two of the mains of a polyphase system; but preferably the polyphase synchronous motor is identical in construction to the polyphase generator and connected to all the lines. It is identical with the synchronous single phase motor in that its field magnets are separately excited by means of a continuous current, and that when the armature of the motor is in synchronism with the generator and the circuit closed, the motor tends to run absolutely in perfect synchronism with the generator. The ordinary single phase motor must be run up to speed by some independent source of power; but in a polyphase system the rotary field set up in the armature, acting upon eddy currents in the poles of the field magnets, is sufficient in most cases to start the motor. It is thus possible to so far combine the principle of a polyphase asynchronous motor with a truly synchronous motor, that it will be capable of starting itself, and after running up to speed, will keep its speed at all loads as constant as the periodicity of supply. However, synchronous polyphase motors are not always self-starting, and like single phase synchronous motors, may require some external source of power to bring them up to synchronism.

INDUCTION MOTORS. The production of rotation by means of a rotary magnetic field was a discovery of no recent date, but the real beginning of induction motors probably dates back only to 1879, when Baily exhibited his polyphase motor to the Physical Society of London. In 1880 Deprez brought out an interesting device for effecting the synchronous rotation of two armatures electrically connected. This apparatus bears a remarkable resemblance to the later induction motors. It was operated, however, by commutated direct currents, and it is not clear that Deprez ever realized its possibilities or even had any definite idea of the nature of its action. In 1887 Professor Ferraris described an apparatus for producing a true rotary field by combining, at right angles to each other, two alternate currents, which differed by a quarter-period from one another. This is believed to be the first time the principles of the rotating field were definitely stated.

The work done by Tesla between the years 1887 and 1891 is of itself sufficient, had no other workers been occupied in the same field of research, to have established the rotary field motor upon a solid basis. In 1888 he constructed and described the first operative induction motor. He also described the application of two and three phase currents to his apparatus. The development of this class of motors was not rapid for the next three years. In 1891 the Frankfort-Lauffen three phase transmission plant, exhibited during the Frankfort Electrical Exhibition, gave a great impetus to the development of multiphase power apparatus, and during the last five years the subject has been so rapidly developed that to-day large numbers of induction motors, working upon two and three phase systems, are in practical and successful operation.

Under the term induction motor should be classed all those alternating current motors in which either the field or armature current, as the case may be, is derived, not directly from the working circuit, but by induction from that member of the motor, whether field or armature, which does receive current directly from the line. In other words, induction motors differ from all other motors in that the E. M. F. of the line is applied to but one of the elements, the primary, the E. M. F. that generates the current in the other element, the secondary, being produced by the magnetic flux due to current set up in the primary by the resultant E. M. F. at work in that winding. The induction motor combines then the functions of a direct current motor and a static transformer.

One might state with accuracy that the rotary field motor works in virtue of the Foucault currents of which it is the seat. The Foucault currents would be zero if the armature were stationary with regard to the field. That is to say, if the armature revolved at the same speed as the field; and it is to fulfill this condition of relative immobility that the armature turns within the field and in the same direction.

Let us consider a two phase motor having for the primary its stationary or field part, and for the secondary its rotary or armature part, and let the windings be exactly similar in both primary and secondary, and of very low ohmic resistance. Let the armature be wedged so that it cannot revolve. When the motor is thrown into circuit the currents flow into the two circuits of the primary just as into any transformer. The secondary coils (or armature conductors) are either short circuited on themselves or through a starting resistance. Therefore the primary currents will flow in amount not only sufficient to bring up the magnetization, inducing in the armature conductors an E. M. F. equal (less magnetic leakage drop) and opposite to the primary E. M. F., but enough to balance the ampere turns, which this secondary E. M. F. will at once establish through its closed circuits. If the secondary is short circuited upon itself, then with low ohmic resistance, the self-induction component of impedance will be the principal limit to the secondary ampere turns, and if this is not sufficiently great, an excessive current will flow in both primary and secondary and they will burn out. If the starting resistance is in, only the maximum safe currents will flow in the primary and secondary circuits.

The efficiency of transformation depends upon three important factors, viz:—the self-induction of the armature or secondary coils, the magnetization of the motor, and the self-induction of the field or primary coils. On account of the air gap in the motor between armature and field, the transformer action is similar to that of an open magnetic circuit transformer. A certain primary current is required for magnetization. Its phase position is therefore 90° behind the primary E. M. F. The current flowing in the secondary will lag behind the secondary E. M. F. due

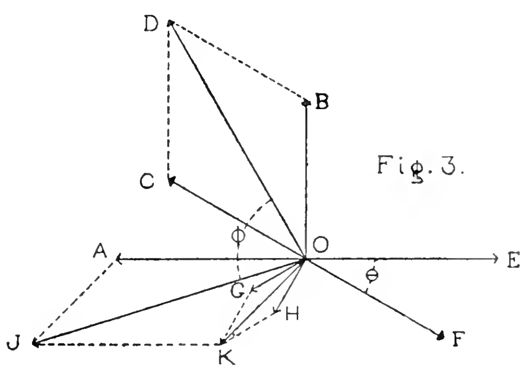

Fig. 3.

to the self-induction of the secondary or armature coils. The primary work current, flowing to supply the opposite ampere turns of the seconday current, will be bonded to the secondary and exactly opposite in phase position. It will therefore lag by the same angle as the secondary current. The total primary current will be the resultant of the magnetizing and the work current. The impressed E. M. F. necessary to overcome the self-induction of the primary will be 90° in advance of the primary current. The primary will therefore be advanced in phase from its normal condition. This may be made more clear by reference to Fig. 3.

OA=Effective E. M. F. of the primary.

OB=Magnetizing component of primary current.

OC=Work component of primary current.

OD=Primary current.

OE=Secondary E. M. F.

OF=Secondary current.

OG=E. M. F. to overcome self-induction of the primary.

OH=E. M. F. of self-induction established by the secondary.

OK=Resultant of OG and OH.

OJ=Resultant of OK and OA and is the impressed E. M. F. on the primary.

φ=Angle of lag of the primary current behind the primary impressed E. M. F.

θ=Angle of lag of the secondary current behind the secondary E. M. F.

The primary impressed E. M. F. must compensate for the E. M. F. of self-induction in the primary and also for the E. M. F. of self-induction in the secondary. Consequently, in the diagram this compensating E. M. F. for the primary is drawn 90° in advance of the primary current, and for the secondary this compensating E. M. F. is drawn 90° behind the secondary current. The primary E. M. F. will be divided into two components, viz:—the resultant of these two self-induction E. M. F's., and an E. M. F. effective in producing the secondary E. M. F. The primary impressed E. M. F. will therefore be represented by the line OJ and will be in advance of the effective E. M. F., as stated above. The current flowing in the armature coils is most effective in producing torque when it is in phase with its E. M. F. This can be shown to be true from any view we take of the induction motor, either two or three phase. The lag of the armature current causes a like lag in the primary work current. This is always detrimental, because it necessitates an increased current in the lines and generators, with increased C^2R losses, besides taking up the capacity of the plant.

The ampere turns necessary to establish the field magnetization are determined from the fundamental equation of the transformer:

$$B(max.) = \frac{E \times 10^8}{\sqrt{2}\, \pi\, n\, T\, a}$$

They will, of course, vary as the reluctance of the magnetic circuit varies. It must also be evident that the magnetization current should be as small as possible, both because of the current consumed when running light, corresponding to the "leakage current" in a static transformer, and because of the bad effects of a lagging primary current under all conditions of working.

Self-induction in the primary cuts down the induced E. M. F. in the secondary, and the more the primary current lags the greater will be this injurious effect. It also advances the primary E. M. F. from its normal position and thus lowers the power factor, and for a given power delivered, increases the line current with all its bad effects. Self-induction in armature coils, reluctance in the magnetic field circuit, and self-induction in the field coils should all be made as low as possible with good mechanical construction.

The induction motor resembles in a way the ordinary direct current shunt motor in that it requires a certain current from the line when it is in circuit, but not developing any power, and that at starting from rest, a rush of current in the armature conductors may take place that would burn them out if a starting resistance were not used. Induction motors tend to run very nearly up to synchronism, or at the speed of the rotary field. They cannot run at synchronism, because at that speed the induction threading the armature coils is constant, and there is no induced impressed E. M. F. on the armature coils, therefore no current flowing in the armature and no torque and work developed. Successful regulation for varying speed has not yet been obtained for commercial motors, but it is possible that some method of changing the periodicity of the rotary field from that of the line current may accomplish a successful regulation for varying speed.

Induction motors may be designed to start with any desired torque. It is quite customary to make induction motors, which have a starting torque of about 50 per cent more than the full load running torque. The great advantage in the use of the induction motor is that it may be operated with no movable contacts whatever, either in armature or field. Consequently, these motors can advantageously be used in places where, due to fire insurance restrictions, no continuous or alternating current motor with collector rings would be allowed, on account of the danger due to sparking.

THE MONOCYCLIC SYSTEM. The monocyclic system was brought out about two years ago for the purpose of running induction motors from single phase mains. The monocyclic generator is simply a single phase generator with a slightly different armature, the monocyclic armature having a small winding, called the "teazer" winding, connected midway between the main coils. The object of this teazer winding is to supply E. M. F's. of different phase for use in starting and running motors. The lighting circuits are run exactly as in any other single phase system. The teazer coils contain only one-quarter of the number of turns of the main coils and consequently give only one-quarter the E. M. F. One end of the teazer winding is connected to the middle of the main winding and the other end is connected to the third ring as shown in Fig. 4. With this arrangement the teazer current has to return over the main coil, and thus meets, besides the self-induction of the teazer, also the self-induction of the

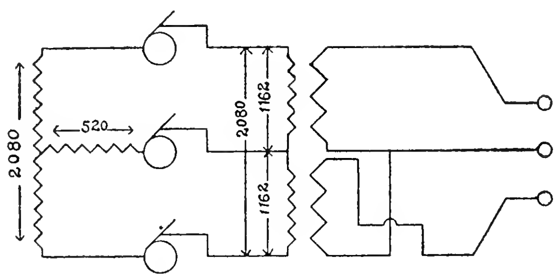

Fig. 4.

main winding. This feature, in combination with the higher impedance of the teazer line as compared with its voltage, is made use of to limit the flow of current in the teazer circuit, by dropping the voltage of that circuit as soon as the current is taken off, and thereby to maintain the flow of power fluctuating in the same way as in the single phase system. To run induction motors from a monocyclic generator, the E. M. F's. generated by the machine are transformed to three other E. M. F's. of approximately three phase relations, it being however unessential to have the three phase condition. Two phase, or in fact any multiphase condition of E. M. F's. can be gotten in a manner similar to that of obtaining the three phase relation. To get three phase E. M. F's. two transformers are used. These have the primaries connected in series across the mains, and the secondaries reversed in their relation to one another. The common terminal of the primaries is connected to the teazer line, and the three secondaries go to the motor terminals.

This system is used where the power generated is mainly intended for lighting purposes. This however does not imply that only a limited number of moters can be operated from a monocyclic generator, but the full current capacity of the latter can be used for motors, for instance, as day load. Where, however, only power distribution is intended, the two or three phase systems are preferable.

The subject of alternate current motors is far too vast to be treated fully in an article of this nature. The writer regrets that he has been compelled to omit diagrams and descriptive matter which would have set forth the theory and operation of alternating current motors much more clearly. As alternating current motors become more generally used they will constantly be looked upon with more and more favor on account of their simplicity of construction and operation.

THE ALTERNATE CURRENT TRANSFORMER.

By J. D. Morse '96, and J. E. Pfeffer '96, School of Electrical Engineering

During the past twelve years there have been extensive developments in the use of the electric current for the transmission of energy for lighting and power purposes. One of the fundamental requirements for success in the extension of these uses of the electric current consists in the use of a limited amount of copper in the conductors. To meet this requirement it has been necessary to adopt methods that enable electric currents to be used that are transmitted at high pressures. Energy developed in the form of the alternating current is best suited for transmission over great distances because of the simplicity of the transforming apparatus, by means of which the proportions of current and pressure are arranged in any position in the working system to suit the requirements of transmission and utilization.

The fundamental phenomena of practical importance in alternate current working results from the pressures produced in closed circuits in which the currents vary from instant to instant, causing corresponding magnetizations that in turn produce the required E. M. F. Upon this principle depend all induction coils, and therefore all the different forms of alternating current transforming apparatus.

The modern alternate current transformer for electrical lighting is an induction apparatus in which the primary coil is of high, and the secondary of low resistance consisting of two ring coils of insulated copper wire enclosed in iron so subdivided as to prevent the formation of local currents in the iron when subjected to the influence of the alternating current in the coils. The terminals of the primary are kept at a constant mean difference of potential.

The secondary circuit includes the lamp circuit, and is of varying resistance. The iron is so situated with respect to the coils that there is no free magnetism. Modern transformers all have a closed core so as to compel, as far as possible, all the lines of the magnetic circuit to pass through the electric circuit, consisting of the primary and secondary coils.

The action of the alternate current transformer depends upon the mutual action between two circuits in no way electrically connected, this mutual action taking place through the agency of the intervening medium, i. e., the magnetic circuit of the transformer.

Lines of force are conventionally used to indicate the intensity of a field of force at each point, as well as its direction; we consider that the number of lines of force which pass through each sq. cm. of area at right angles to the direction of the lines of force represents the intensity of the magnetic field.

Iron is used in a transformer to increase the influence of the primary upon the secondary, i. e., to increase the number of lines which the primary current will set up in the magnetic circuit, so as to thread the secondary circuit of the transformer; the E. M. F. induced in the secondary being directly dependent upon the amount of magnetic induction, which is thus caused to pass through the convolutions of the secondary circuit. The secondary E. M. F. is likewise dependent upon the number of secondary turns or conductors and the frequency of alternation.

When a current is flowing in the primary a magnetic field is set up consisting of a definite amount of magnetic flux threading the circuit and forming closed curves. If the permeability of the medium is constant, the magnetic flux is directly proportional to the current, any change in the current being accompanied by a corresponding change in the induction. If there are S turns in the circuit, the flux N passes through each one of the S turns, and consequently there are $S\ N$ lines threading the circuit. The quantity $S\ N$ is usually termed the number of "linkages" or "flux turns."

If the magnetic induction through any circuit be changed, due to any cause whatever, an E. M. F. is developed in the circuit proportional to the rate of change of magnetic induction, as first shown experimentally by Faraday. The change in the induction to which this induced E. M. F. is due, may be produced by a change in the current flowing in the circuit itself, in which case the induced E. M. F. is dependent upon the time rate of change of the current, i. e.

$$e = -L\frac{di}{dt} = -S\frac{dN}{dt}$$

Here the coefficient L is a constant of the circuit, termed the "coefficient of self-induction," depending on the form of the circuit. This E. M. F. is called the counter E. M. F. of self-induction, and always (as indicated by the sign) opposes any change in the value of the current, in accordance with the principle of the conservation of energy. The coefficient of self-induction is constant when the permeability of the medium is constant, as is generally assumed in theoretical discussions.

In the case of the transformer we have two coils to consider, the primary and the secondary, with S_1 and S_2 convolutions respectively; if a current i, is flowing in the primary, which is changing, lines of magnetic induction will be set up through the secondary, and in accordance with Faraday's law an E. M. F. will be set up in the secondary. The E. M. F. is also dependent upon the time rate of change of the current in the primary which produces it; and we may write

$$e_2 = -M \frac{d\,i}{d\,t} = -S_2 \frac{d\,N}{d\,t}$$

Here M is the coefficient of mutual induction of the two circuits, and is also constant when the permeability of the medium is constant.

Evidently where no induction from the primary circuit of a transformer threads the secondary circuit, there can be no E. M. F. induced in the secondary due to a change in the primary current. The relations between the two circuits is strictly a mutual one, the coefficient of mutual induction having the same value with either circuit as primary or secondary.

Every closed circuit transformer consists then of one or more coils of copper wire interlinked with one or more cores of laminated iron. Suppose the primary connected to the alternating current mains with the secondary open. The action of the transformer is now the same as though the secondary were entirely removed. Take as a starting point an instant when the E. M. F. is zero. As the E. M. F. rises a current flows in the primary and magnetizes the core. The increase of magnetic induction in the iron induces an E. M. F. opposing the main E. M. F. and thus opposing the increase of the primary current. Assuming for the moment, that the primary coils have no resistance, the core induction at any instant is then such that it increases fast enough to produce a back E. M. F. just equal to the main E. M. F. The current at any instant would be just enough to produce that induction in the iron. The instantaneous current thus depends on the induction of the core at that instant. If the iron is never nearly saturated the *magnetizing* current in a closed magnetic circuit transformer is trifling. As the primary coils do have resistance, the *core* induction, consequently, does not increase quickly enough to give a back E. M. F. exactly equal at each instant to that of the main, but less than it to the minute extent needed to pass the *magnetizing* current against the resistance. This small correction may be disregarded.

As the primary E. M. F. gradually increases from zero to its maximum, the core induction also increases so as to produce the necessary counter E. M. F. This back E. M. F. is not proportional to the induction but to the *rate* at which the induction increases. When the main E. M. F. begins to fall from its maximum value the induction does not begin to fall but goes on increasing at such a rate as to produce the proper back E. M. F. It will thus go on increasing till the main E. M. F. is zero. The core induction will then be at its maximum. The main E. M. F. now begins to have a negative value, causing the iron core to be demagnetized at a rate which produces an opposing back E. M. F. The induction thus decreases, its *rate* of decrease at any instant being proportional to the negative E. M. F. on the primary. When the primary E. M. F. is at its extreme negative value, the *rate* of increase of the core induction will be greatest, but the induction will go on decreasing till the main E. M. F. again arrives at the zero point, at which we started. If the main E. M. F. follows the same curve in both halves of the period, it is clear that at the end of the period, the induction is the same as at the beginning. The induction has, therefore, its maximum and minimum values at the instants when the main E. M. F. is at its zero values.

In the case cited above there was at any instant a current sufficient to produce the induction in the core found at that instant. We may thus call the current absorbed by the primary coil, to produce a field sufficiently strong to balance the voltage of the primary the "magnetizing" or "core" current, and it is of course necessary to have this current small.

Suppose now that the secondary circuit is closed on a group of lamps. The primary current alters the induction of the core, and this alternation produces a back E. M. F. in the primary circuit; but it also produces an E. M. F. in the secondary circuit. Now that the secondary circuit is closed, a current is produced, whose effect on the core is opposite to that of the primary current. The excitation of the core now no longer depends only on the ampere turns in the primary, as there are opposing turns in the secondary. The core is thus magnetized by the difference. Leaving out the resistance of the primary, it is clear that the back E. M. F. is equal to the main E. M. F.

If the secondary coils have the same number of turns as the primary, the internal or whole E. M. F. of the secondary will be equal to that of the mains, but there will be a loss over the resistance of the secondary coils, so that the terminal E. M. F. will be less by the product of the secondary resistance and the secondary effective current. As the primary coils also have resistance, whose effect, though negligible when considering the *magnetizing* current only, is not so when we consider the full load primary current; the back E. M. F. due to the alternation of the induction in the core does not need to be quite equal to the main E. M. F., being just sufficiently below it to allow the current to flow. The back E. M. F. of the primary is thus less than the main E. M. F. by the product of the effective primary current and the primary resistance. These two products may be written $I_2 R_2$ and $I_1 R_1$. As the total secondary E. M. F. is equal to the primary back E. M. F., if the turns are equal, and is proportional to it and to the ratio of their turns if not, the secondary terminal E. M. F. is:

$$E_2 = (E_1 - I_1 R_1)\frac{S_2}{S_1} - I_2 R_2.$$

Where S_2 and S_1 represent the number of turns in the secondary and primary respectively.

At no load, neglecting the effect of the *magnetizing* current as inappreciable, the terminal E. M. F. is proportional to the turns in the coils. At full load there is a fall in the secondary E. M. F. due to the copper resistance and the leakage of magnetism across the air space of the primary, this leakage being proportional to the strength of the primary current.

With reference to magnetic leakage it is well known that the action of a condenser and of magnetic leakage are opposed, and that magnetic leakage may be thus compensated for. In fact, the secondary circuit may be given a capacity which will over-compensate for magnetic leakage, and thus cause a rise in the secondary E. M. F. when the transformer is loaded, despite the "drop" due to magnetic leakage and ohmic resistance.

If we neglect the primary current which is the difference between the instantaneous primary and secondary currents, the primary and secondary E. M. F's. increase and diminish simultaneously, and correspond exactly. When the secondary is working on resistance, the current and E. M. F. vary together, while if the secondary is on a motor, or work with self-induction, the secondary current does not correspond with the secondary E. M. F., but the primary and secondary E. M. F's. correspond, as do also the primary and secondary currents. For practical purposes we may assume the secondary to work on resistance so that the primary and secondary E. M. F's. and currents all vary together, if we leave the magnetizing current out of the question.

We may thus call the primary current at any instant less the instantaneous magnetizing current, the useful current, as it may be considered to be converted and given out by the secondary. The useful primary current thus corresponds with the primary E. M. F. and has its maximum and minimum at the same instants. The *magnetizing* current has its maximum and minimum when the primary E. M. F. is at its zero values. The *magnetizing* current may thus be considered to lag a quarter of a period behind the useful primary current and the whole primary current is compounded of the two. A closed circuit transformer may thus be considered to transform the primary into an exactly similar secondary, with different E. M. F. and current, the effect of the resistance of the coils being represented by a resistance put into one of the circuits.

Iron Losses. Besides the variable losses due to the resistance in the coils known as "copper losses" we also have the "iron losses" originating in the magnetic circuit, and like the magnetism, are constant for the whole range of the transformer capacity. However while the use of iron proves of a great advantage in increasing the induction, we shall find that there are objections to its use in too great quantities.

There is a loss of energy in the iron itself caused by the repeated reversal of its magnetism, which is known as the loss of energy due to "Hysteresis." This energy appears in the form of heat and causes a lagging of the magnetic induction with relation to the magnetizing force as the iron is carried through a cycle of magnetization. This loss is a definite amount for each alternation, depending very considerably, upon the quality of the iron.

In selecting iron for transformer cores Prof. Ewing has shown that the first consideration is smallness of hysteresis losses; high permeability being comparatively a secondary desideratum. These two good qualities do not necessarily go together, as the curve of the **B-H** cycle may have a relatively easy slope, and yet enclose a relatively small area. The loop depends upon the degree of magnetization to which the iron under consideration is taken. Mr. Steinmetz has emphatically shown this loss thus:

$$\text{Hysteresis per cycle for each cu. cm. of iron} = n\,\mathbf{B}^{1.6}$$

The coefficient n being a quantity depending upon the quality of the iron, varying from .002 to .003, for sheet iron of good quality, such as used in transformer work.

There is also a loss of energy in the iron, even when it is carefully laminated, due to the so-called "Faucault currents" which are merely currents set up in the iron itself. The iron, being a good conductor of electricity, forms within its own body many little closed circuits which act as secondary circuits, and allow electric currents to circulate around them and thus cause a loss of energy due to heating, which may be minimized by careful lamination in the plane of the lines of force, as can-not the Hysteresis loss.

For the calculation of the core losses in a transformer Dr. J. A. Fleming has modified a formula given by Prof. Ewing, viz:

$$T = \frac{0.88\,n\,\mathbf{B}^{1.55}}{10^8} + 1.4 \times 10^6 \left(\frac{t\,n\,\mathbf{B}}{10^8}\right)^2$$

Where t is thickness of sheet iron in inches, n the frequency, **B** the induction per sq. in. of iron and T the total loss in watts per lb. The first term of this equation represents the loss due to hysteresis and the remainder that due to Faucault currents.

With reference to laminating the iron, Prof. Ewing and J. J. Thomson have shown that it is no use to employ a thinner iron sheet than 0.001 of an in., and that it is no use to laminate the core at all unless the laminæ are at least as thin as 0.04 of an inch. The thickness to which makers of transformers confine themselves almost entirely range between 0.012 and 0.016 of an inch.

Because the use of iron is in some ways such a great advantage in the transformer, and in others has its disadvantages, there have been many conflicting opinions advanced by men of greatest ability, as to the proper proportion between the iron and copper in a transformer.

EFFICIENCY OF TRANSFORMERS. The cardinal virtue of the transformer is unquestionably its high efficiency. But efficiency, when applied to transformers distributed in installations or in central stations, has a different meaning to that usually accepted in the case of dynamos and motors.

The loss which takes place in a transformer must be distributed over the whole daily working period, probably 24 hours, during only a relative short portion of which time, even in winter, does the full load come on. By the average efficiency of the transformer we are to understand, then, the ratio of the all-day useful output in watt-hours, to the watt-hours delivered to the transformer.

By this mode of computation the efficiency will depend upon the curve of current consumption during the day, the unfavorable effect of which the transformer builder cannot help. It is, however, possible to plot a curve of mean all day consumption for separate localities or towns, and on that basis to determine the all-day efficiency of the transformers.

The efficiency of the transformer at any output is given by the expression:

$$\frac{\text{Secondary watts}}{\text{Secondary watts} + \text{watts lost in copper} + \text{watts lost in iron.}}$$

Where secondary watts stands for the actual power supplied to the circuit from the secondary terminals.

Since the copper losses increase as the square of the output, it follows that the most economical load for a transformer is that which makes the copper losses equal to the iron losses. This is why, in a transformer with comparatively small iron loss, the maximum efficiency frequently occurs before the full load is reached.

A rise in temperature, if not sufficient to soften or injure the insulation, does not necessarily make the transformer inefficient. It has the disadvantage of increasing the resistance of the copper circuit and consequently the copper losses; but the Faucault current losses are reduced by the heating of the iron core on account of the increased resistance of the iron.

DESIGN. In designing a transformer, its cost, efficiency, and durability must always be borne in mind. In getting out cost of material it must be remembered that copper costs about 2½ times as much as iron. By sufficient weight of material in a transformer, almost any efficiency can be obtained; but it is a mistake to go too far in this direction, as the cost increases very rapidly for a comparatively small gain in efficiency. No transformer should be considered by itself, but always in connection with the whole system of which it forms a part. If this is done it will frequently be found that a considerable reduction of the open circuit losses in the transformers, will really produce very little change in the all-day coal consumption at the central station. It is, therefore, a mistake to reduce these losses beyond certain limits.

In beginning the design of a transformer we have merely to select the section of the core and the induction. Having done this, and knowing that the whole induction in the core of the transformer cuts the coil 4 times during each period we have

$$E(volts) = 4\, A\, \mathbf{B}\, S\, n \times 10^{-8}$$

Where A is the cross sectional area of the core in sq. cm., $\mathbf{B}$ the effective induction in C. G. S. units, S the number of turns in the coils and n the frequency. This really gives the back E. M. F. in the primary, or the internal E. M. F. of the secondary, which may be taken here instead of the terminal E. M. F.

If the induction is taken very low the result is that a great deal of iron must be used for a given number of turns of wire, each turn of wire must be longer and consequently a loss of power in the extra length of copper. Moreover the extra iron is expensive, so is the copper. On the contrary, if the iron be subjected to a high induction there is great loss of power in the reversal of magnetization. At high induction the *magnetizing* current is increased, due to the decrease in the permeability of the iron. In closed circuit transformers, however, on a continuous supply system, the question of heating is of much more importance

The loss from Faucault currents varies as the square of the frequency, and as before stated, can be made very low by sufficiently laminating the iron.

In regard to the relation of induction to the loss in iron, Prof. Ewing has shown by experiment, on iron bars that if the induction be increased the loss in the iron is increased somewhat more rapidly; so that with a given number of turns, if the core is decreased and the induction increased to make up for it, the total waste of power in the core is greater unless the alternation in dimensions reduces the volume of the iron more quickly, in proportion, than the cross section.

The design of a transformer is like most other designs, a sort of a compromise. The highest efficiency combined with the lowest cost of manufacture and the greatest durability are the ends we wish to obtain. The last requirement means that the transformer must be of a shape that admits of perfect insulation and it must be well enough ventilated not to get hot.

The dimensions of the transformer are, to a certain extent determined by the punchings of thin soft iron generally used by makers, for it would be too expensive to make a different set of punches for every type of apparatus made. The punches are designed so that the coils can be wound separately, and the punchings then slipped over them; but though they differ in the ways in which this is allowed for, they may all be divided into two or three classes. When put together they either make punchings with a rectangular hole for the coils, the coils, returning on one side or on two sides or they make a double hole with a tongue between them, the coils being wound over the tongue.

With a given cross section, of iron core and copper coil, and a given induction, it is obviously best to have the copper and the iron circuits as short as possible, provided always, that the surface of the transformer is not made too small to get rid of the heat generated. The double link is therefore better than the single so far as the iron is concerned; it has, therefore, to be settled, whether the transformer should be made with the double iron link or double copper link, and this in turn depends on which gives the largest saving.

The almost universal practice, it seems, is to make the cross section of the iron core the same all around. There would undoubtedly often be a slight gain in efficiency by using a higher induction in the part of the core that is within the coil. The loss of power in the iron is of much more importance than that in the copper, even if the transformer were never on except at full load. We may therefore conclude that the double iron link type is the best in general.

DISTRIBUTION. It is quite as necessary to arrange the transformer for any particular distribution so as to obtain the most economical performance at all times as to secure transformers of high efficiency in the first place.

The drop in the secondary voltage due to leakage and ohmic resistance of the coils must be compensated for at the station to insure good service. A good transformer, however, supplied with constant E. M. F. should give very nearly constant E. M. F. on the secondary for all loads within its capacity.

The loss of energy in distribution by alternating currents is remarkably small and is proportional to the square of the current employed, while the weight of copper required varies inversely as the square of the E. M. F.

It is evident that a small converter will not be nearly as efficient as a large one, because the *magnetizing* circuit cannot be as short, relatively speaking, or the copper coils as compactly arranged, and will heat far more; it is also plain that a small converter will cost more per lamp than a larger one. From these two most vital considerations large transformers are both cheaper and more economical. The regulation of large transformers is also superior; they are much lighter for their output and cost less to install.

Summing up the conclusions arrived at, it is apparent that to fulfill the requirements of most economical operation, transformers of the highest all-round efficiency under varying load should be used and so far as circumstances permit, let them be large in size and few in number.

TESTING. In order to obtain independent data representing all the different American transformers of moderate capacities a long and carefully carried out series of tests was made by the authors in the electrical laboratory of the University of Illinois. For these tests, transformers of 1 500 watts capacity, as nearly as possible, were procured directly from the manufacturers within about a year, so that the tests may be presumed to represent the latest and best design which are now on the market. These transformers are from the most prominent makers and, in fact, include all important makes of American transformers.

The transformers were in all cases supplied with current from a *T-H* alternator at 132 periods per second. The machine was driven by a high speed automatic engine, that has a very fair speed regulation.

The drop of secondary pressure due to load was observed by taking simultaneous readings of the effective pressure at the terminals of the primary and secondary when the transformer was under different loads, with a maximum of one-third over load. In this way any errors due to drift of speed of the engine are eliminated. Two voltmeters, a Cardew, and an electrostatic, were used to indicate this effective pressure at the secondary.

As single transformers only, of each type were at our dis-

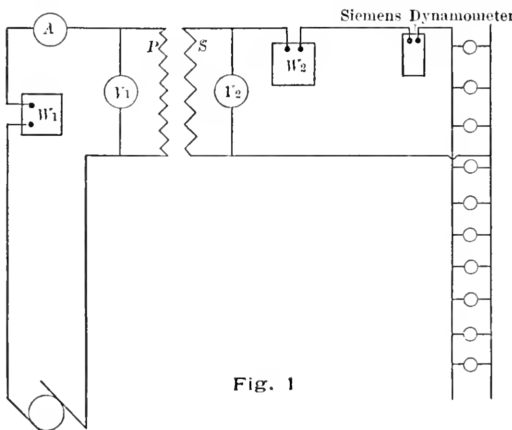

Fig. 1

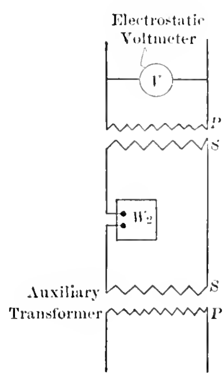

Fig. 2

posal, we entered on a preliminary investigation on the degree of accuracy to be obtained with using such methods as the 3 voltmeter, and the two circuit wattmeter, for measuring the power taken up by transformers with open, or loaded secondary circuits.

The connections employed for the latter method in measuring the power taken up with loaded secondary circuits is diagrammatically shown in Fig. 1 and was the method which gave the most reliable results.

In each case the Weston wattmeters, which were used, were standardized on a non-inductive resistance and the readings taken as when placed on the circuit of the transformer.

The transformers had gradually increasing loads of lamps put upon their secondary circuits, and while the power supplied to the primary was measured by a wattmeter placed in circuit, that given up by the secondary was also measured by a wattmeter placed in the secondary circuit. The value of the primary current in amperes was also measured for each corresponding definite load on the secondary circuit.

We obtained therefore, for every transformer, the volts,

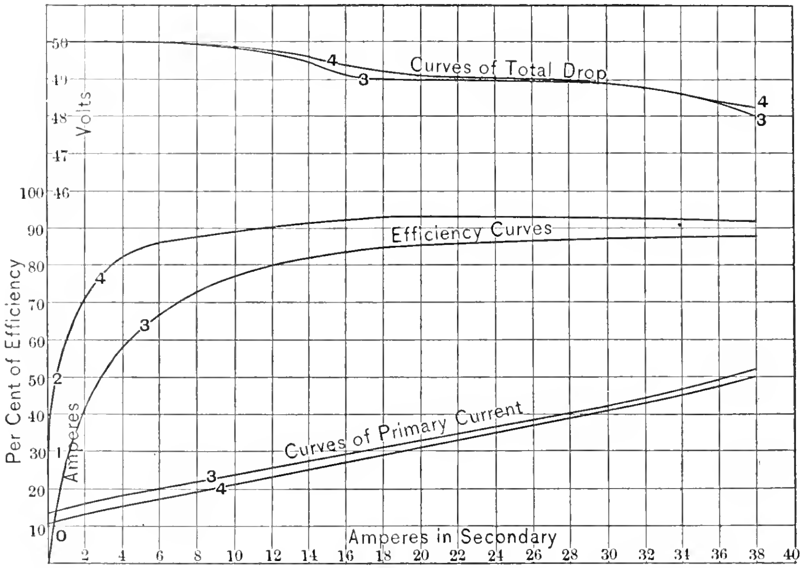

FIG. 3.

across both terminals, the ampere current, and the watts output of the secondary circuit, and at the same time the ampere current and power absorbed in watts by the primary circuit; and hence the power lost in the transformers is also known for each secondary load. Finally, also, the ratio of the power given up to that supplied, in percentages, can be calculated and gives us the efficiency. In all these experiments the potential difference on the primary terminals was kept carefully constant by varying the excitation of the alternator.

From the measured value of the resistances of the copper circuits (taken when the transformer was warm) and the measured currents, the copper (C^2 R) losses in both circuits were calculated separately and together; and from the primary volts and current, the value of the "apparent watts" given to the transformer at each stage was obtained; and from the "apparent" and "true" watts given to the primary circuit we could deduce the "power factor" corresponding to any secondary output. The values of the secondary terminal volts gave us also the "total

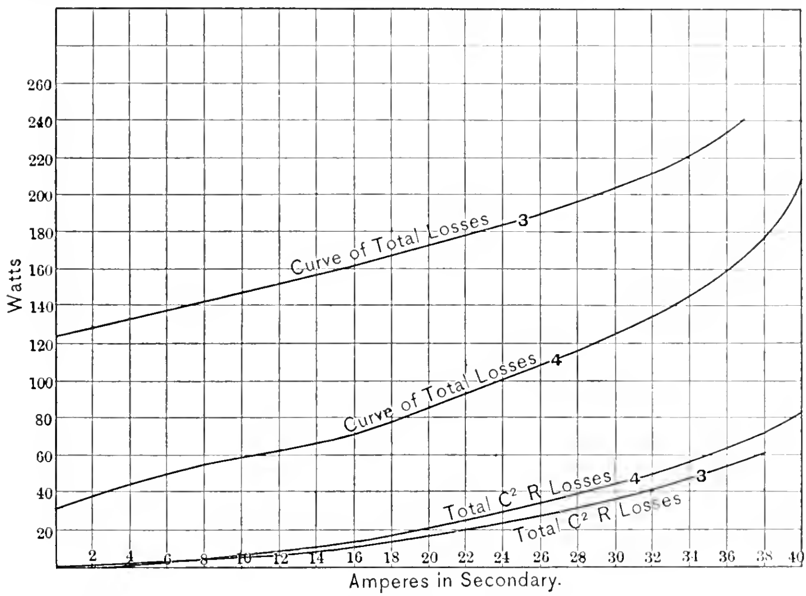

FIG. 4.

secondary drop" at each load, and from the resistances and currents could be found the "copper drop" or volts lost by ohmic resistance.

Some of the principal observations and calculations are given in the Table on the following page, which sufficiently explain themselves.

The results of these numerous observations are set out graphically, and thus represented to the eye, in a series of diagrams. Two diagrams are here given; one containing the efficiency, primary current and regulation curves of two different transformers (designated by number as in the table) as shown in Fig. 3, and another containing the "total lost watts" curves and the curves showing the total copper losses in the transformer

SUMMARY OF RESULTS.

Number.	Watts Capacity.	Secondary E.M.F. at no load.	Primary E. M. F. at all loads.	Per cent. E. M. F. drop at full load.	Division of drop in per cent. Primary Resistance.	Secondary Resistance.	Magnetic Leakage.	Resistance in Ohms. Primary.	Secondary.	Magnetizing Current.-Amperes	Watts Lost on Open Secondary.	Losses at full load. Total.	C^2 R.	Per Cent. Efficiency. Full Load.	¾ Load.	½ Load.	¼ Load.	$\frac{1}{10}$ Load.	All Day.
1	1500	50	1040	4.84	.97	1.08	2.79	7.03	.018	.09334	50.6	139.	30.6	92.	92.2	91.8	86.8	73.0	81.8
2	1500	50	1010	3.9	.96	1.66	2.62	7.007	.0277	.06946	50.	139.	40.0	91.8	91.6	89.5	85.7	64.5	82.02
3	1500	50	1025	2.76	.79	1.46	.51	5.889	.0243	.2427	125.	204.	37.0	87.4	86.0	83.0	71.5	51.0	68.74
4	1500	50	1030	3.0	1.46	1.38	.16	9.96	.023	.0433	31.7	125.	44.2	92.1	93. 0	91.4	87.3	78.0	85.93
5	2000	50	1025	4.0	1.18	1.22	1.6	6.0	.0153	.0919	50.	236.	50.0	89.	90.08	92.0	88.	77.8	82.44
6	1500	50	1028	3.0	.76	1.41	8.3	4.63	.0235	.0892	61.	108.	28.0	92.6	92.6	91.9	83.5	67.0	81.5
7	1500	50	1020	4.3	1.36	1.38	1.56	9.7	.023	.1187	54.	138.2	43.0	90.8	90.0	89.8	83.	68.0	81.4
8	1500	50	1030	3.8	1.21	1.5	2.09	8.5	.025	.0893	62.2	157.	42.2	90.	90.02	89.0	82.6	67.5	79.2
9	1250	50	1030	3.7	.98	1.02	1.7	8.038	.0204	.065	48.	104.	14.0	91.5	91.2	89.5	82.5	69.5	81.4
10	1250	50	1000	4.2	1.48	1.38	1.34	11.3	.0275	.04175	28.	105.	38.0	92.4	92.2	91.1	87.6	75.5	85.5
11	1500	50	1030	2.9	.73	1.2	.97	5.248	.02	.1005	72.	134.	30.0	91.5	91.0	89.4	82.8	64.0	78.6
12	2000	50	1030	2.2	.78	.89	.53	4.259	.0111	.176	95.	166.	19.7	92.	92.6	90.03	83.	69.0	79.1

in both circuits together is shown in Fig. 4. The difference of the ordinates of these two curves gives the value of the losses other than those due to ohmic resistance in the transformer.

The regulation curves give the "total observed drop," the "drop" due to secondary and to primary resistance, and the surplus or "leakage drop" due to leakage of induction.

The "magnetizing" or "leakage" currents given in the Table were carefully determined by means of a Thomson centiampere balance, which was previously calibrated by the deposition of copper method, and found to be accurate to within .2 of one per cent.

All the current measuring instruments used were standardized with Thomson balances at different times throughout the test.

In Fig. 2 is shown the plan of connections for the method employed, to determine the power of the transformer at no load. As is seen two transformers were used with their low pressure coils connected in series, and a wattmeter so placed in circuit as to measure the power supplied to the secondary of the transformer under test. The auxiliary tranformer being used, simply, to permit using the normal voltage of the alternator.

For the determination of the all-day efficiency, when the primary pressure is kept up at all hours of the day, as given in the table, it was assumed that the transformer would have a working output equivalent to the rated capacity in watts for 5 hours out of every 24.

CONCLUSION. There are very many derivative matters which, if space permitted, might be discussed as consequences of facts observed in the course of the above described researches. It is evident, for instance, that the last word has by no means been said on the subject of design of transformers. From the relation between iron loss and regulation, it follows that what is best on one plant may not be the best on another, and consequently when station managers in general begin to inquire for a transformer suited to their particular needs, manufacturers will put on the market transformers of different iron efficiency, much as we now have lamps of different efficiencies to suit different conditions.

In the matter of transformer testing, the experience gained in obtaining the facts brought before you has established, in the writer's mind at least, that the character of the measuring instrument must be strictly examined before trusting too implicitly to the results obtained by it.

The facts and measurements thus obtained have in all cases been sifted and repeated with great care, with the desire to arrive at conclusions which should be worthy of confidence, and useful to those interested and engaged in transformer work.

AN INVESTIGATION OF THE RELATIVE STRENGTH OF HYDRAULIC CEMENTS.

By H. C. Estee, '96, School of Civil Engineering.

The data used in this investigation consists of reports of tests made by about twenty city engineers and by several cement dealers. The reports by the dealers give results of tests of their cement as compared with others, showing their own at a good advantage. The reports by the city engineers are apparently impartial. They agree with each other as closely as could be expected, with the exception of the reports by the city engineer of Toronto, Canada, for '94 and '95, which agree very well relatively with the values given in the other reports, but are about 20 per cent. lower. This is probably due to peculiarities of the conditions under which the tests were made. These reports are not considered in this discussion.

The Portland cements are classified as German, English and American. The Rosendale, or natural, cements are classified according to the locality of their manufacture.

Portland Cements. Fig. 1 shows the relative strength of Portland cements, and also the effect of time upon the rate of increase in strength. The curve for each class represents a mean of values given by ten or more of the best known brands. There were not sufficient data on the strength of all the mortars to warrant a curve for each class, and hence the curves which are designated simply Portland represent the mean for all the brands of Portland cement irrespective of class. In all cases where a mean was taken of the results by several experimenters, attention was given to the relative reliability of the data.

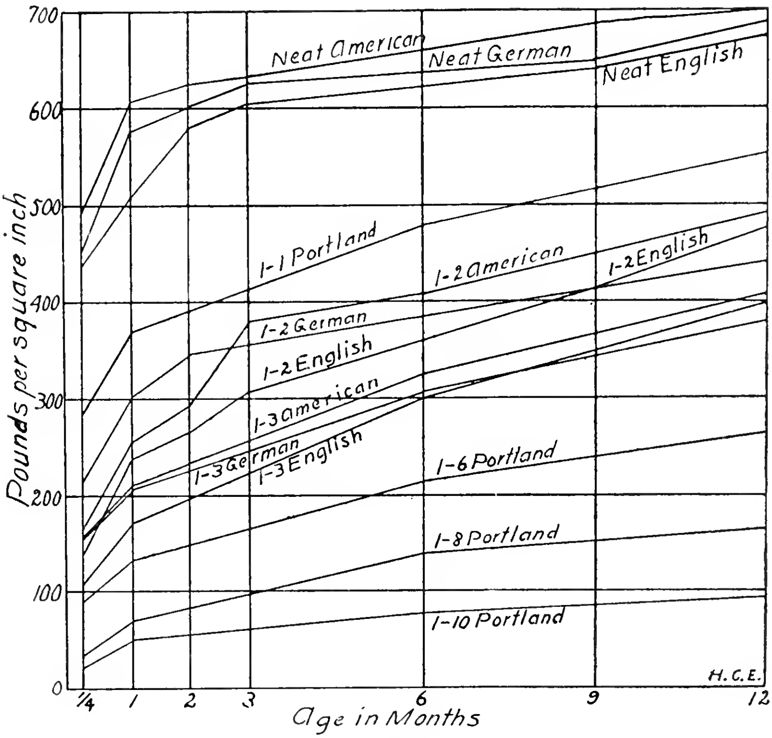

FIG. 1. THE RELATIVE STRENGTH OF PORTLAND CEMENT MORTARS.

A comparison of the above curves shows that as the mortars increase in age, the tensile strengths of the different classes become more nearly equal. This is still more evident in the two year tests, which are not shown on the diagram. When judging the value of a cement it is better to consider the curve showing the strength of the sand and cement mortar, rather than the curve showing the strength of the neat cement mortar, because the former more nearly represents the conditions under which the cement is actually used. The diagram shows that for the first few weeks the mortars made from the German cements attain a greater strength than do those of the other classes. This is a property which would recommend the German cements for all places where the load comes upon the mortar as soon as laid. These German cements, however, do not attain quite as great ultimate strength as do other Portlands. The curves show a much greater range in the tensile strength of the one to two than of the one to three mortar. This variation may be accounted for partly by the scarcity of data on the one to two mortar, and partly by the fact that the one to three is not so strong and hence may have a less number of pounds range and still have as large a per cent variation as the other. All the mortars, especially those mixed with a large proportion of sand, acquire considerable ultimate strength but gain it very slowly.

ROSENDALE CEMENTS. Fig. 2 shows the relative strength of Rosendale cements and the effect of time upon the rate of increase of their tensile strengths. The curves in the diagram were obtained in the same manner as were those in Fig. 1.

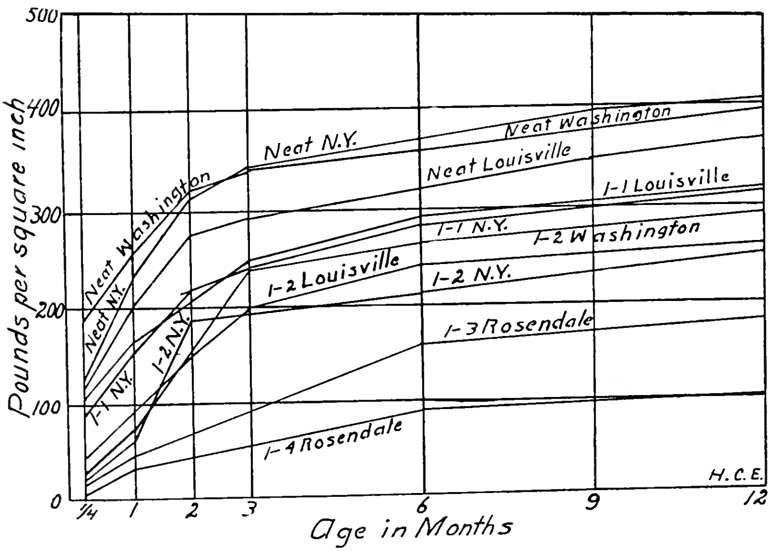

FIG. 2. THE RELATIVE STRENGTH OF ROSENDALE CEMENT MORTARS.

The curves for the strength of the cements manufatured in Pennsylvania, Illinois and Colorado were omitted in Fig. 2 because of the confusion that would be produced in the diagram by the use of so many lines. The Pennsylvania cements run a little higher, and the Illinois a trifle lower than the Washington cements. There was but one cement from Colorado. It averaged about fifteen per cent higher than the Washington cements, thus making it appear the best of all Rosendales. The cements manufactured near Washington appear to give the best general results, although the New York cements give results a trifle higher when tested neat.

PORTLAND AND ROSENDALE CEMENTS COMPARED. Several interesting facts may be brought out by a comparison of Figs. 1 and 2. The groups of Rosendales show a much greater relative variation than do the Portlands. This is because the chemical constituents of the Rosendales vary greatly, and because the method of their manufacture has not been brought to as high a degree of perfection as has that of the Portland. The Rosendales gain very little, if any, in strength after the first year, while the Portlands increase in strength till the third or even the fourth year.

An inspection of Figs. 1 and 2 shows that the mortars increase in strength less rapidly as they grow older. It also shows that the richer mortars require a longer time to develop their ultimate strength than do those mixed with large quantities of sand. This is true of both Portland and Rosendale cements.

Fig. 3 shows the relative tensile strengths, at four different

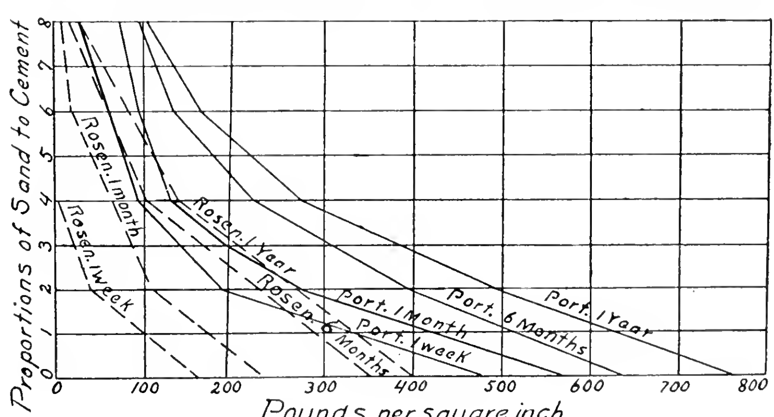

FIG. 3. THE RELATIVE STRENGTH OF ROSENDALE AND PORTLAND CEMENT MORTARS.

ages, of Portland and Rosendale cements. The curves represent mean values from all the different experiments previously used.

They are similar to those found on page 90 of Baker's Masonry Construction.* The lines in both diagrams have the same relative direction, but Fig. 3 makes Portland about 200 pounds, and Rosendale about 100 pounds stronger than the diagram in Baker's Masonry Construction. The reason for this difference may be that the cements used in these experiments are better than those from which Professor Baker deduced his diagram, or that the later experimenters use methods that produce stronger briquettes, or that the data from which Baker's curves were plotted was by different observers.

The table on page 89 gives the average strength, plus or minus a probable error, of each class at different ages. The probable error is the number of pounds that the strength of a cement may be expected to vary from the mean of its class. It is computed by the formula: Probable error $= 0.845$ F, in which F is the mean of the differences between the tensile strengths of the different brands of cement and the average strength of the class. For an example of the application of the table, take any ordinary brand of German cement. The tensile strength to be expected of it at the end of seven days would be the mean strength of the class at that age, 495 pounds, plus or minus a probable error of 42.5 pounds.

The probable errors of the strength of the English and German cements as given in the table are about the same, while that of the American cement is much larger. The cause of the larger variation in the American cements is due to the fact that, although the majority of the cements in this class are of excellent quality, there are some of poor grade. These poorer ones make large differences from the average value of the class, and thus increase the probable error. The same reason applies to the high values given for the Washington cements. That of the Louisville cements runs the lowest because all cements put under this class are made from practically the same quality of rock by mills located in the same vicinity.

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* Professor Baker has frequently told his students that the curves in his book were probably not correct, and it was at his suggestion that this discussion was undertaken.

Strength of Cement Mortars at Various Ages.

Results in Pounds per Square Inch.

Ref. No.	Kind of Mortar.	7 Da. Mean.	7 Da. Probable Error.	28 Da. Mean.	28 Da. Probable Error.	2 Mo. Mean.	2 Mo. Probable Error.	3 Mo. Mean	3 Mo. Probable Error.	9 Mo. Mean.	9 Mo. Probable Error.	12 Mo. Mean.	12 Mo. Probable Error.
	Portlands.												
1	Neat German	495	42.5	605	46.7	625	35.7	624	30.1	650	42.9	688	46.7
2	Neat American...	455	47 3	563	49.3	595	34.4	630	29.0	690	40.8	710	37.8
3	Neat English......	434	43.9	505	66 3	578	57.0	604	42.2	644	66.3	680	70.0
4	1 to 3 German	152	12.3	207	27.0					357	32.2		
5	1 to 3 English	101	18 4	169	33.1					349	29.3		
6	1 to 3 American ..	163	11.4	210	18.9					372	25.2		
	Rosendales.												
7	Neat Washington	168	32.0	254	46.1	312	21.2	343	26.1	371	11.9	376	26.3
8	Neat Louisville...	117	25.1	194	16.4	242	13.1	290	16.2	353	25 5	366	22.6
9	Neat New York ..	135	22.7	231	36.2	316	12.0	343	16.9	399	36.5	407	31.0
10	1 to 2 Washington	41	18.1	81	23.9								
11	1 to 2 Louisville...	52	10.2	95	15.6								
12	1 to 2 New York...	35	14 0	69	20 1								

THE EFFECT OF GRINDING MIXED SAND AND CEMENT.

By H. E. Reeves, '95, School of Civil Engineering.

A Swedish experimenter has asserted that if sand and cement be mixed in the ordinary proportions, then ground very fine and mixed with more sand, the resultant mixture will be stronger than the same proportions of sand and cement mixed in the ordinary way.

To determine the truth of this assertion a series of experiments was undertaken in the Cement Laboratory of the University of Illinois during the spring term of 1895. The plan of the experiments was to mix sand and cement in various proportions, grind the mixture, add unground sand, and if practicable grind a second time, and mix with another portion of unground sand. Briquettes were tested from each mixture, both before and after grinding. The main consideration while conducting the experiments was to secure uniformity of conditions, so that a proper basis of comparison would be secured. Care was taken to thoroughly mix all materials before dividing into the portions which were to be treated differently.

The cement used was a good German Portland. The sand was standard crushed quartz, passing a No. 20 sieve and retained on a No. 30 sieve. The quartz was pulverized by the use of an ore crusher, which consisted of a semi-cylindrical casting weighing about 100 pounds, having a handle fastened on the upper or flat side at right angles to the axis of the cylinder, and resting on a heavy cast-iron plate 24×36 in. having flanges one inch high on the sides. The grinding was done by spreading the materials upon the plate, and rolling the crusher backward and forward. In this manner almost any degree of fineness could be obtained; but after a certain limit had been reached, the results were not commensurate with the extra time and labor required. The fineness of grinding was determined by sifting through the ordinary cement sieves,—No. 50, 75, and 100.

The briquettes were molded with a Russell lever molding machine.* In this machine a plunger, operated by a lever and working through a casting, forces the cement mortar into the molds. A briquette mold is placed on top of the casting. The plunger is depressed by raising the lever, and the mold and space in the casting above the plunger are filled with cement mortar. A cast-iron arm is then swung over the top of the mold and clamped. This closes the top of the mold and holds it firmly in position. The mortar is then forced into the mold by depressing the lever.

To secure a uniform pressure, a weight of 60 pounds was hung on the end of the lever. As the ratio of power-arm to weight-arm was as 1 to 7, this made a pressure of 420 pounds on the plunger. This pressure was applied four times for each briquette.

After molding, the briquettes were covered with a wet cloth, and after 24 hours were placed in water.

The briquettes were tested with a Riehle cement testing machine having rubber-tipped grips.

A summary of the results is presented on the following page. In the table the term "sand-cement" is employed to designate a mixture of cement and sand which has been re-ground after mixing. For example, the term "1-3 sand-cement" means a mixture of 1 part cement and 3 parts standard sand which has been re-ground. The per cent of the fineness after re-grinding is omitted for brevity.

There are three reasons why grinding sand and cement and then mixing with more sand, should increase the strength of the mixture: 1. Crushing of the sand grains makes them more angular, and therefore the cement adheres more strongly. 2. The sand is then of different sizes, having less voids and thus requiring less cement to fill them. 3. The cement itself is ground finer, which increases its covering power and also its strength when used with sand.

The time available did not permit the completion of the experiments on the plan contemplated, and consequently the data are too meager to warrant any valuable deductions. However, the following conclusions may be drawn:

1. With ordinary proportions, a mortar having all the sand re-ground is weaker than one having none re-ground.

*For an illustrated description, see *Trans. Am. Soc. C. E., Vol. 27*, p. 441.

This agrees with former experiments in which it has been found that a fine sand makes a weaker cement than a coarse one.

2. With large proportions of sand, a mortar in which part of the sand is re-ground is stronger than one in which none of the sand is re-ground or one in which all the sand is re-ground.

3. The most striking results from the experiments are that

SUMMARY OF RESULTS.

REF. NO.	KIND OF MORTAR.	PER CENT OF WATER.	AVERAGE WEIGHT OF BRIQUETTES. GRAMS.	TENSILE STRENGTH. LBS. PER SQ. IN.	NO. OF BRIQUETTES TESTED.
	1 day in air, 6 days in water.				
1	1 to 0 (neat cement)	22	144	511	9
2	1 to 2 (not re-ground)	13	141	156	11
3	1 to 3 (not re-ground)	11	130	69	12
4	1 to 2 (re-ground)	13	127.5	144	8
5	1 part "1-3 sand-cement" 3 parts standard sand resulting mixture, 1c to 15s	9	132.5	40	5
6	1 part "1-15 sand-cement" 3 parts standard sand	9	124.5	15	10
	resulting mixture, 1c to 63s (re-ground)	8	124	8	5
	1 day in air, 13 days in water.				
7	1 to 3 (not re-ground)	11	134	112	9
8	1 to 3 (re-ground)	11	128	74	11

a mixture of 1 part cement and 15 parts sand has a strength at 7 days of 40 lbs. per sq. in.; and that a mixture of 1 part cement and 63 parts of sand has a strength at 7 days of 8 lbs. per sq. in. These results show clearly that re-grinding the cement and sand adds strength.

4. An increase in the proportion of sand much beyond that contained in the 1 to 15 mortar is certainly not practicable.

5. The question of cost still remains to be settled. It is very probable, however, that under ordinary conditions the cost of grinding will nearly or quite neutralize the extra strength gained by re-grinding.

IMPACT AND ABRASION TESTS OF PAVING BRICK.

BY H. J. BURT, '96, SCHOOL OF CIVIL ENGINEERING.

Tests of paving brick are frequently made at the Laboratory of Applied Mechanics of the University of Illinois for manufacturers, contractors and engineers. In many cases no specifications are furnished, so it has become necessary to establish some standard for the laboratory. There is little variation in the requirements for absorption and cross-breaking tests specified by engineers, but there is a great variation in the requirements and in the methods of conducting the tests to determine the ability of the brick to withstand impact and abrasion.

Most engineers require a rattler test for this purpose. This test is made by putting the samples of brick in an ordinary foundry rattler or tumbler together with an amount of scrap iron or foundry shot, and revolving for a specified time. The details of the tests required by different engineers are widely at variance. Specifications from 15 cities show the following ranges:—

Length of Rattler........................24 to 54 in.
Diameter.................................15 to 40 in.
Speed, revolutions per minute................15 to 55.
Duration of tests....................30 to 360 minutes.
Weight of iron..........................50 to 800 lbs.
Loss permissible in one hour..........3 to 10 per cent.

The above exhibit emphasizes the necessity of establishing standard specifications for general use. It was to assist in the selection of such standards for impact and abrasion tests that experiments by the writer were made.

In making these experiments a 13-sided rattler 24 in. in diameter and 36 in. long was used. The inside was smooth, there being no ribs on the inner surface of the staves. The shaft did not extend through the barrel. Instead of the ordinary foundry shot or miscellaneous scrap iron, the shot used consisted of two sizes of cast-iron bricks. The larger size was $2\frac{1}{8}\times3\frac{1}{8}\times5\frac{1}{4}$ in. with the corners rounded to a radius of about $\frac{1}{2}$ in., and weighed approximately 8 lb. each. The smaller size was $1\times1\frac{1}{2}\times2\frac{1}{2}$ in. with rounded corners, and weighed 1 lb. each. In one or two tests scrap iron in pieces ranging in weight from ⅛ to 3½ lb., was used.

The bricks used in most of the experiments were a good quality of repressed paving bricks, selected from material for a pavement near by. In outward appearance they were quite uniform.

The first series of tests was made to determine the relative effect of different amounts and kinds of shot. In each test 12

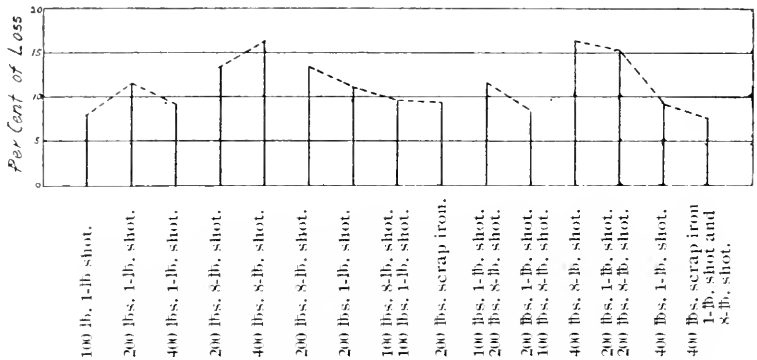


Fig. 1. Effects of Different Kinds and Amounts of Shot.

bricks were used. The results are shown in Fig. 1, and may be summarized as follows:—

1. The 1-lb. shot gave a maximum loss when 200 lbs. were used. The losses from 100 lbs. and 400 lbs. were nearly equal.

2. The 400 lbs. of 8-lb. shot gave a greater loss than 200 lbs. of 8-lb. shot. Whether the rate of loss would continue to increase with an increase in amount of shot was not determined.

3. Charges, each containing 200 lbs. of shot, gave losses nearly equal for 1-lb. shot, 1 and 8-lb. shot mixed, and scrap iron. The 8-lb. shot alone gave a loss about 25 per cent greater than the others.

4. A charge containing 100 lbs. of 1-lb. shot and 200 lbs. of 8-lb. shot gave a loss nearly 40 per cent greater than a charge containing 200 lbs. of 1-lb. shot and 100 lb. of 8-lbs. shot.

5. Tests using 400 lbs. of shot gave a maximum loss with 8-lb. shot, and a minimum with a mixture of 1-lb. shot, scrap iron and a half dozen 8-lb. shot. A mixture of 200 lbs. of 1-lb. and 200 lbs. of 8-lb. shot gave a result near the maximum, and 400 lbs. of 1-lb. shot gave a result near the minimum.

The rates of loss at different times during tests are shown by the curves in Fig. 2. These indicate a loss during the first half hour about twice as great as that during the second half hour. In all cases the rate becomes nearly constant after the

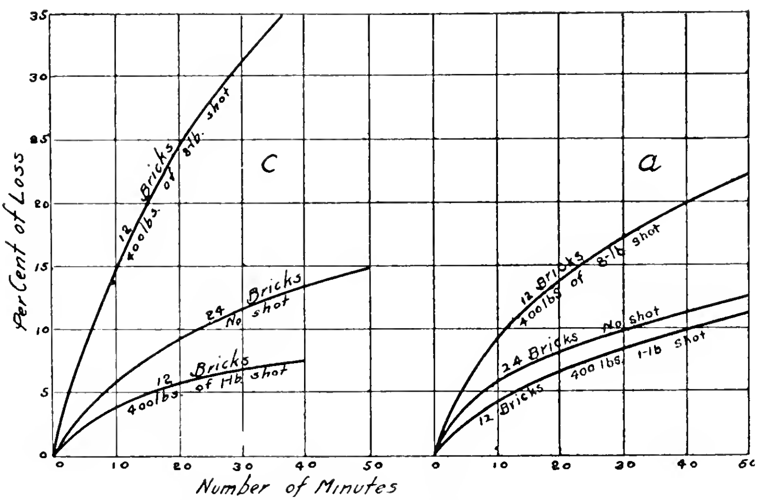


FIG. 2. LOSS AT DIFFERENT TIMES DURING TEST.

first twenty minutes. The two sets of curves in the diagram are for two kinds of brick, quite different in character. The results are similar for the two kinds shown, and for a third kind not shown in the figure. The reason for the excessive loss at the beginning of the experiment appears to be due largely to the chipping off of the edges and corners.

Tests were made to determine the effect of using different numbers of brick in the rattler, with a given amount of iron. The results are shown in Fig. 3. In each test 200 lbs. of

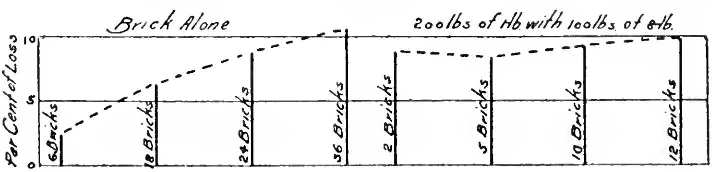


FIG. 3. EFFECTS OF THE NUMBER OF BRICKS IN A TEST.

1-lb. shot and 100 lbs. of 8-lb. shot were used. Within the limits of 2 and 12 bricks, there did not seem to be any material variation in the rate of loss. Similar tests using bricks alone showed an increase in the rate of loss with the increase in the number of bricks used, as far as the experiments were carried.

To determine whether different tests would give the same relative results for different kinds of brick, tests were made with four different makes. The kinds used were: *a*, repressed brick 2½×4¼×8 in.; *b*, side-cut brick, 2¼×4×8 in., used locally for paving, very hard burned, and badly cracked, square edges; *c*, end-cut bricks, 3¾×2¼×8 in., long edges rounded by die, very hard burned; *d*, repressed brick, 4⅛×2½×8 in. Each kind was tested (1) without iron, (2) with 400 lbs. of 8-lb. shot, and (3) with 400 lbs. of 1-lb. shot.

As shown by the diagrams in Fig. 4, the general effects

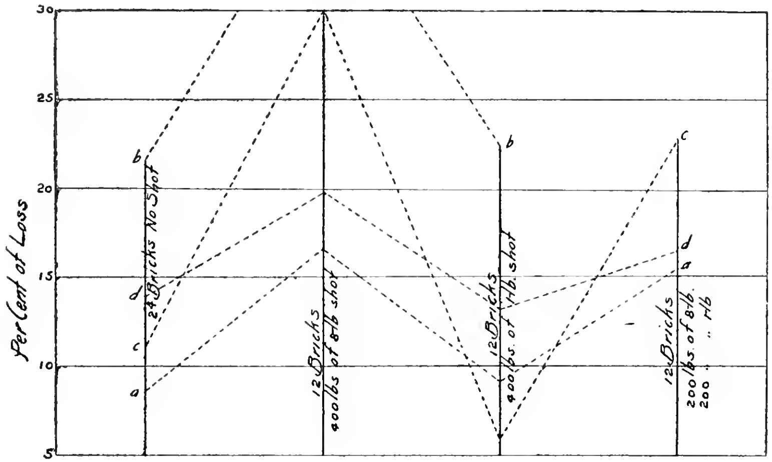


FIG. 4. EFFECTS OF DIFFERENT MAKES OF BRICK.

were quite similar. In the test without iron 24 bricks were used and the loss was about the same as that in the test with 400 lbs. of 1-lb. shot. Neither of them availed in determining the character of the kind designated *d*, which was a very brittle brick and lost heavily by chipping when rattled with 8-lb. shot. In all cases the loss when tested with 400 lbs. of 8-lb. shot was much larger than when tested with 400 lbs. of 1-lb. shot. An experiment with a mixture of 1 and 8-lb. shot showed results between those of 1-lb. shot and of the 8-lb. shot.

The difference in the manner of testing makes a decided difference in the ranking of the different kinds. This is shown very plainly by arranging them in the order of the least per cent of loss:

24 bricks with no shot..........................*a*, *c*, *d*, *b*.
12 bricks with 400 lbs. of 8-lb. shot..............*a*, *d*, *c*, *b*.
12 bricks with 400 lbs. of 1-lb. shot..............*c*, *a*, *d*, *b*.
12 bricks with 200 lbs. each of 8-lb. and 1-lb. shot...*a*, *d*, *c*.

In most cases rattler tests are used simply as comparative tests for the selection of the best brick submitted for a certain work. It might have seemed that the details of the test would make little difference, but such a presumption is not borne out by the above discussion. There is as much reason for having standard and accurate specifications for comparative tests as for absolute tests.

The action taking place in the rattler is two-fold; viz., impact and abrasive. By impact is understood the blows which the specimens receive in falling against the sides of the barrel, and in being struck by the other bricks and by the filling material. By abrasion is understood the wearing due to sliding along the surface of the barrel and the sliding of the filling material over the bricks. The loss due to impact is, for the most part, in the form of small chips or spawls. The loss due to abrasion proper is of course in the form of a fine dust. The former is a maximum with hard, brittle bricks, and the latter with soft ones. These facts are clearly shown by examination of specimens after being tested.

Tests made with the 8-lb. shot give losses due largely to clipping away of the edges of the brick and are essentially impact tests. They are effective in discovering the brittle specimens, but are not certain, nor in fact likely, to discover the softer ones. For impact tests the 8-lb. shot are quite satisfactory.

The loss from the use of 1-lb. shot is much smaller than that from the use of 8-lb. shot. The examination of specimens thus tested, shows them to be worn away as by rubbing or grinding. There is very little chipping of corners and edges. Hence, this is essentially an abrasion test. It would be interesting to know whether its results are parallel to those of abrasion tests made with grinding or rubbing machines. It seems probable that they would be.

In tests made with bricks alone, no shot being used, the loss is due to both clipping and wearing. The relative amount due to each will depend upon the character of the bricks tested. The test is neither purely an abrasion nor an impact test, but is a combination of the two.

This test of brick alone has been proposed for the standard rattler test, but does not seem to be altogether satisfactory. In a test of 24 brick without shot there was about the same per cent of loss as with 12 bricks tested with 400 lbs. of 1-lb. shot. The loss in the first instance was due to both clipping and wearing and in the second, chiefly to wearing. So although the two tests gave nearly the same results in the experiments made, the losses may not have been due to the same physical properties of the brick. The curve in Fig. 3, showing that the larger the number of bricks used in this test the greater the rate of loss, indicates the importance of specifying a definite number of bricks to be used in such a test. It also suggests the possibility of variation when different kinds and different sizes of bricks are used together. If large and small bricks were tested together, it is probable that the heavy blows of the large brick upon the small ones would cause undue loss of the latter. Hence if this standard were to be used, it would be necessary to test each kind by itself, and even then there would be a doubt as to its fairness of a comparison between large and small bricks. In order to get a considerable rate of loss it would be necessary to use quite a large number of bricks in each test. The use of a large number is also necessary to eliminate the effects of accidental loss, for it was noticed that in these tests quite large pieces frequently were broken from the corners. The above conditions require the use of about 25 bricks, but the use of so many bricks makes the test cumbersome, and is another objection to it.

A rattler 24 in. in diameter and 36 in. long is of convenient size. Foundry rattlers are frequently of this size. A slight variation from the dimensions given, probably would not have a noticeable effect. A change in length could be compensated for by a proportionate change in the amount of shot used. Any city constructing brick pavements can well afford to own such a machine. Since it is not always easy to get a certain speed it is better to state the duration of the test by prescribing the total number of revolutions required. Though the basis for this is not well established, it is believed that for speeds ranging from 20 to 30 revolutions per minute, there will be no appreciable change in the per cent of loss for a given number of revolutions.

It frequently happens that one or two bricks will lose much more rapidly than will the others of the set. This effect may be due to a poor sample or to the accidental losses which may occur to a particularly unfortunate specimen. To partially eliminate this effect, not less than six bricks of a kind should be tested together. It is not desirable to use more than 12 bricks, since a larger number might affect the rate of loss.

In order to have standard tests, it is necessary to adopt kinds and sizes of shot that can be easily duplicated. The castings used in these experiments meet this requirement and are recommended for standards. The loss in the abrasion tests occurs rather slowly, hence it is advisable to use an amount of shot that will give a maximum rate of loss. This amount for 1-lb. shot has been found to be 200 lbs. The rate of loss in the impact test made with 8-lb. shot is much larger, so it is not necessary to use an amount of shot giving a maximum loss. For this test the amount can be fixed arbitrarily at 200 lbs. in order to conform to the amount used in the abrasion test.

The duration of the abrasion test should be long enough to wear into the soft interior of the brick. A speed of 25 revolutions per minute, for one hour making a total of 1,500 revolutions is sufficient for this. The impact test being much more severe, need be continued only half as long.

Examination of bricks in pavements shows that they lose by clipping off of the corners and by grinding off of the tops. Probably the former is responsible for the larger part of the loss. It would then seem advisable to have tests showing the resistance of the bricks to both these actions and to be able to distinguish the one from the other. This leads the writer to recommend the two tests above described, believing that in that manner a safer estimate of the value of the paving material can be made.

The following specifications are recommended for these tests: The writer does not feel qualified to insist on the above limits of loss, since he has not experimented with enough kinds of brick. The limits set may also vary with local conditions, depending upon the quality of brick required.

1. Impact and abrasion tests shall be made in a rattler 24 in. in diameter and 36 in. long.

2. Not less than six specimens of a kind shall be used in a test. Not more than 12 bricks shall be placed in the rattler at one time.

3. The speed of the rattler shall not be less than 20 nor more than 30 revolutions per minute.

4. The shot used in the abrasion tests shall be 200 lbs. of castings, 1x1½x2½ inches, having rounded edges and weighing about 1 lb. each. The samples shall not lose more than 12 per cent. of their original weight in 1 500 revolutions.

5. The shot used in the impact tests shall be 200 lbs. of castings 2¼×3×5¼ inches, having corners rounded to a quarter-inch radius, and weighing about 8 lbs. each. The samples shall not lose more than 15 per cent. of their original weight in 750 revolutions.

STREET IMPROVEMENTS AT THE UNIVERSITY OF ILLINOIS.

By John C. Quade, '95, School of Civil Engineering.

During the past summer considerable work was done in improving the grounds of the University of Illinois, chiefly paving Green street and building cement walks. The work was under the direction of A. N. Talbot, Professor of Sanitary and Muncipal Engineering, and the writer was inspector.

Paving. Green street in front of the University, is divided into two parts by a row of shade trees through the center. In improving the street a 32-ft. pavement was built through the south part, and the north part was parked. The street railway track was shifted to the middle of the north half.

The length paved, from Mathews avenue to Wright street, was 860 ft. The pavement is brick on a 6-in. concrete foundation. The cross-section is circular, with a 6-in. crown (Fig. 1).

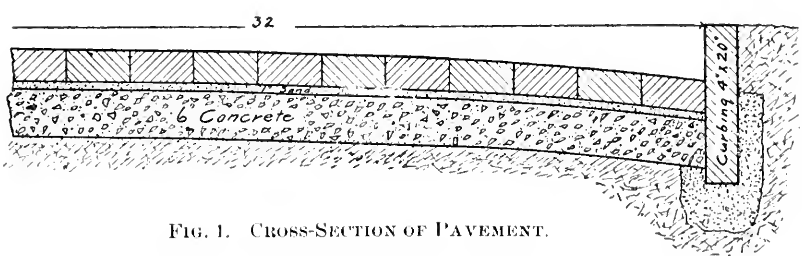


Fig. 1. Cross-Section of Pavement.

The curbs are Cleveland sand stone 20 in. deep and 4 in. thick, set in 6 in. of sand. The top of the curb is 7¼ in. above the gutter. The pavement is drained by means of McDonald curb inlets placed at intervals of 300 ft. on each side. At the principal foot-crossing, cast-iron plates were used to span the gutters. These plates are ½ in. thick; one end rests on the pavement curb and the other on a short false curb set parallel to and 10 in. from the pavement curb (Fig. 2). The pavement along the crossing is brought up to the level of the crossing plates, across the entire width of the roadway.

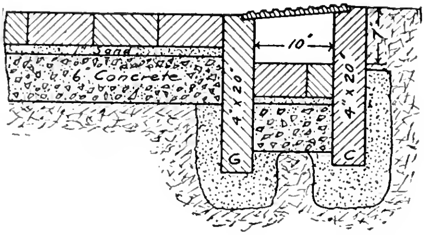


FIG 2. GUTTER AND CROSSING PLATE.

The roadway after being excavated to sub-grade, was rolled with a seven-ton roller, all soft spots being carefully filled in and re-rolled. Directly upon the earth roadbed was placed 6 in. of concrete, which was thoroughly tamped and surfaced. The specifications required that the concrete should be of such consistency that, when tamped, free mortar should flush to the surface. In some instances this clause was fulfilled by tricks of the trade which it would be desirable to prohibit. By one method, the soft cement mortar adhering to the mixing board was so shoveled as to appear on the top and, of course, did not require much tamping to make it show up. Again by shoveling the concrete up higher than the finished grade and bringing it down with a rake, the stones were raked out, leaving the mortar on top. In order to protect the concrete from too rapid drying by the sun and wind, a 1-in. layer of sand was spread upon it as soon as it was tamped This sand covering was surfaced to form a cushion for the brick. The bricks were laid closely and rolled with a seven-ton roller in order to make the surface even and to give them a firm bearing in the sand cushion. The joints were filled with fine dry sand, well broomed in.

Utica cement was used for the concrete. In laboratory tests this cement proved to be of excellent quality, twenty-four-hour briquettes giving an average tensile strength of 65 to 70 lb. per sq. in., and seven-day briquettes giving an average of 125 pounds per sq. in.

The stone used in the concrete was hard Kankakee limestone with a limit of 2½ in. for the greatest dimension. It was clean and of good quality.

The bricks were repressed paving brick, 2½×4½×8 in.

They were furnished by the Clinton Paving Brick Company of Clinton, Indiana. A series of tests in the Laboratory of Applied Mechanics gave the following result: Three specimens when tested on edge developed an average modulus of rupture of 2 600 lbs. per sq. in. When revolved in a 16-in. rattler for one hour at the rate of 27 revolutions per minute, with 200 lb. of smoothly worn foundry shot, the loss by abrasion was 3 per cent. The absorption in 48 hours averaged 1½ per cent.

The contract prices were: Pavement $1.35 per sq. yd., curbing 35 cts. per lineal foot, and excavation 25 cts. per cu. yd.

The following was given by the contractor as the cost to him of various items:

Laying brick, per sq. yd.	$0.0546
Water for concrete per sq. yd.	0.0023
Laying concrete per sq. yd.	0.1085
Brick per thousand delivered on ground	9.75
Brick per sq. yd. of pavement	0.54
Broken stone per cu. yd. delivered on ground	1.95
Cement per barrel	0.70
Sand per cu. yd.	0.75

CEMENT WALKS. About 15 000 sq. ft of cement walks were constructed. The contract price was 15 cts. per sq. ft., which included all excavation, material, and labor. The walks consist of an 8-in. cinder foundation, 3 in. of concrete, and a 1-in. wearing coat (Fig. 3). With the exception of a small quantity of "Ger-

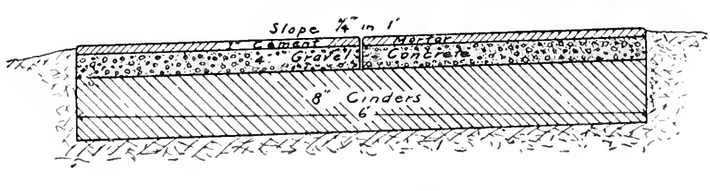


FIG. 3 CROSS-SECTION OF CEMENT WALK.

mania" and "Laegerdorfer," Alsen's German Portland cement was used. The gravel used was of fair quality. The voids in it amounted to 20 per cent.

After excavating to sub-grade, cinders were dumped in and thoroughly wetted and tamped to a final thickness of 8 in. The form for the concrete was made by setting two 4-inch scantlings firmly to grade and line of each side of the walk. The 3-inch layer of concrete was then filled in and tamped. This layer consisted of 6 parts of screened gravel and 1 part of cement. On it was spread the wearing coat, consisting of 2 parts of sand and 1 part of cement. The surface was carefully finished by floating and troweling. This was done with great care in order to give a dense wearing surface. As soon as laid the concrete was cut into blocks which were usually 4 ft. long, and for a 6 ft. walk were 3 ft. wide.

In the construction of a good walk it is extremely important that the wearing coat be applied as soon as possible after the concrete is put down and before it has set, in order to secure a firm bond between the two. About 15 lineal ft. of concrete were laid at a time, after which the wearing coat was added and thoroughly troweled.

A gang of twelve experienced men well organized and managed, laid about 900 sq. ft. of walk per day.

CONCRETE BRIDGE. The cement walk is carried across Boneyard Branch on a concrete bridge. The bridge is built in the form of an arch; it is stiffened with four light 6-inch I beams bedded in the concrete. The arch is a segment of an ellipse. It has a span of 16 ft., a rise of 1 ft., and a thickness at the center of 9 in. The bridge is 6½ ft. wide, and is built on a skew of 1 to 2. The abutments are 2 ft. thick and extend to a depth of 2½ ft. below creek bottom. Gas pipe railings were fastened to the outer I beams.

THE TEMPERATURE ENTROPY DIAGRAM.

By G. A. Goodenough, Instructor in Mechanical Engineering.

Several recent English writers on the steam engine have paid some little attention to the representation of thermal relations by means of the temperature-entropy ($T\varphi$) diagram; among these we may mention Macfarlane, Gray, Ewing and Cotterill. In this country, detached papers bearing upon this subject have appeared from time to time in the technical journals. Perhaps the most pretentious effort in this direction is an article of some length entitled "Notes on the Refrigeration Process," by Geo. Richmond. (*Trans. A. S. M. E.* Vol. XIV *p.* 183).

There is no question that the $T\varphi$ diagram materially aids the student of thermodynamics in obtaining a clear idea of complex interchanges of heat; and it would be a desirable thing if our text books on heat should use this diagram more freely. It is the purpose of this article to give a brief resume of some of the most interesting properties of the $T\varphi$ diagram; to show how the $T\varphi$ curves may be obtained from the corresponding $p\,v$ curve; and to show some of the practical applications of the diagram. Some of the demonstrations have been suggested by Mr. Richmond's article; other portions of the article have been developed by the writer.

Most thermodynamic questions concern the changes of state of a working fluid. The change may be an expansion or compression of a gas; the change of a liquid to a vapor upon the addition of heat; the expansion of a vapor. Usually the object of the investigation is to find: (1) the external work done during the change of state; (2) the quantity of heat transferred during the operation.

The work done by an expanding fluid is a function of the pressure and volume of the fluid. If W represents the work of expansion, we have the following general equation:

$$W = \int p\,dv \qquad (1)$$

In any given case, the expression (1) can be integrated if we know the law of expansion, that is, the relation between p and v. If, for example, the pressure p is constant, we have

$$W = p\int_{v_1}^{v_2} dv = p(v_2 - v_1) \qquad (2)$$

The graphical representation of this operation is shown in Fig. 1. The line ab represents the constant pressure p, and the area $a\ b\ c\ d$ the work done. It is to be noted particularly that there must be a change of volume in order that work may be done. If the pressure is increased at constant volume the operation is represented by the vertical line $m\ n$, and the area included between this and the V axis is, of course, zero. This graphical method of representing the work of an expanding gas on the $p\ v$ plane is so familiar that it need not be further considered.

It is of interest to find the quantity of heat transferred during a change of state of the working fluid. This heat will be a direct function of the temperature of the fluid, but will be only indirectly related to the pressure and volume of the fluid. We should be able therefore to express the heat transferred in terms of temperature and some other property of the fluid in somewhat the same way as work is expressed by equation (1).

Experience shows that heat may be added to a body at constant temperature; also, we know it is possible to raise or lower the temperature of a body without the addition or abstraction of heat. Usually the addition or abstraction of heat is accompanied by either a rise or fall of temperature.

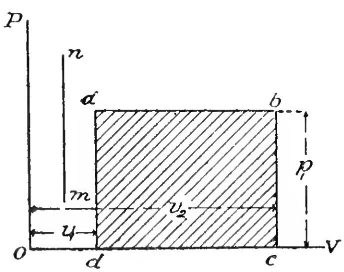


FIG 1.

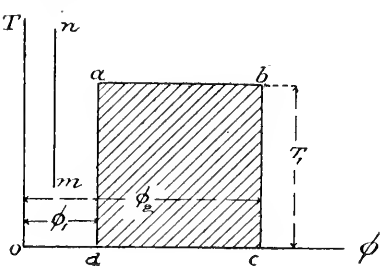


FIG. 2.

To represent these changes graphically draw a pair of rectangular axes $O\ T$, $O\ \varphi$ Fig. 2, and let the ordinates represent absolute temperatures; the function represented by the abscissa as is yet undefined.

If a change of state occurs in which the temperature remains contant, this operation will be represented by a horizontal line *a b* at a height T_1 above the axis $o\ \varphi$. We may consider the heat added as proportional to the length of *a b* and it may be represented therefore by the area *a b c d*. A rise in temperature unaccompanied by addition or abstraction of heat wonld be represented by a vertical line *m n*.

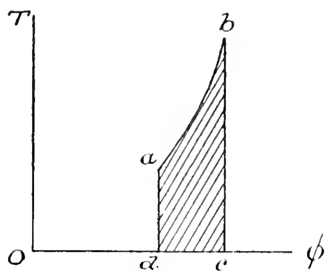


FIG. 3.

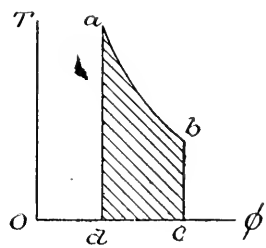


FIG. 4.

In Fig. 3, the line *a b* represents a rise in temperature accompanied by an addition of heat shown by the area *a b c d*. The operation *b a* would indicate a fall in temperature accompanied by an abstraction of heat. In Fig 4, line *a b* represents a fall of temperature accompanied by an addition of heat, while line *b a* represents a rise in temperature accompanied by an abstraction of heat; the area *a b c d* representing the transfer of heat in each case.

We have not yet defined the abscissa φ in Figs. 2, 3 and 4. It is evident that φ must increase when heat enters the body. In Fig. 2, the heat added is

$$H = \text{area } a\ b\ c\ d = T_1\ (\varphi_2 - \varphi_1). \tag{3}$$

In general, when T and φ both vary

$$H = \text{area } a\ b\ c\ d = \int T\ d\ \varphi. \tag{4}$$

It is apparent that φ is a function which bears much the same relation to the heat added as volume does to the work done. To this function the name "entropy" is given.

Equation (4) may be written

$$d\ H = T\ d\varphi \text{ or } d\varphi = \frac{d\ H}{T} \tag{5}$$

Entropy may be defined as that property of a substance which must change when heat is added to or abstracted from the body. Equation (5) shows that the increase of entropy is directly proportional to the heat added and inversely proportional to the absolute temperature.

It is evident that the $T\,\varphi$ diagram is particularly useful when we wish to observe the heat transfers during the change of state of a working fluid. We will first turn our attention to the perfect gases, and endeavor to transform the $p\,v$ curves into corresponding curves on the $T\,\varphi$ plane. The $p\,v$ diagram will give information concerning the work done during any change of state, while the $T\,\varphi$ diagram will show graphically the transfer of heat during the same operation.

The change of state of a perfect gas can usually be represented by an equation of the form

$$pv^n = \text{const.} \tag{6}$$

The exponent n may have any value, fractional or integral, positive or negative. The experimental laws of Mariotte and Gay Lussac are expressed by the equation

$$\frac{p\,v}{T} = \text{const.} = R \quad \text{or } pv = R\,T. \tag{7}$$

Finally, we have for a perfect gas

$$dH = C_v\,dt + A\,p\,dv \tag{8}$$

that is, if we add a quantity of heat dH to a gas the portion $C_v\,dt$ goes to perform internal work, while $Apdv$ is the heat equivalent of the external work done.

We have now to combine equations (5), (6), (7) and (8), eliminate p and v and find the relation between T and φ.

Dividing (6) by (7),

$$T\,v^{n-1} = \text{const.} = \text{B, say.}$$

$$v = \left(\frac{B}{T}\right)^{\frac{1}{n-1}} = \left(\frac{T}{B}\right)^{\frac{1}{1-n}},$$

$$d\,v = \frac{1}{1-n} \cdot \frac{T^{\frac{n}{1-n}}}{B^{\frac{1}{1-n}}}\,dt$$

$$\frac{dv}{v} = \frac{1}{1-n}\,T^{-1}\,dt = \frac{1}{1-n}\,\frac{dt}{T} \tag{9}$$

From (7) $p = \frac{R\,T}{v}$. Substituting this in (8),

$$d\,H = T_v\,dt \times A\,R\,T\frac{dv}{v}$$

$$\text{But } C_p - C_v = A\,R,$$

$$\text{and } \frac{C_p}{C_v} = k = 1.41$$

Substituting in the above,

$$d\,H = C_v\,d\,t \times (C_p - C_v)\frac{T\,dv}{v}$$

$$= C_v\;d\,t + \frac{(C_p - C_v)}{1-n}\,d\;t, \text{ from (9)}$$

$$= C_v\left(1 + \frac{k-1}{1-n}\right)d\;t$$

$$d\,H = C_v\left(\frac{k-n}{1-n}\right)d\;t \qquad (10).$$

From (5). $$d\;\varphi = \frac{d\,H}{T} = C_v\left(\frac{k-n}{1-n}\right)\frac{d\,t}{T} \qquad (11).$$

Hence $$\int_{\varphi_1}^{\varphi_2} d\;\varphi = C_v\,\frac{k-n}{1-n}\int_{T_1}^{T_2}\frac{d\;t}{T}$$

$$\text{or } \varphi_2 - \varphi_1 = C_v\left(\frac{k-n}{1-n}\right) log\ nat.\ \frac{T_2}{T_1} \qquad (12).$$

For the sake of brevity put $C_v\left(\frac{k-n}{1-n}\right) = m$. Then (11) and (12) become respectively:

$$d\;\varphi = m\,\frac{d\;t}{T} \qquad (11a)$$

$$\varphi_2 - \varphi_1 = m\ log\ nat.\ \frac{T_2}{T_1} \qquad (12a)$$

From (11*a*), we have

$$\frac{d\;t}{d\varphi} = \frac{T}{m} \qquad (13).$$

Equation (13) shows that when m is positive, the entropy and temperature increase simultaneously. If m is negative, the entropy decreases as the temperature rises. An inspection of the coefficient m reveals that it is negative for all values of n lying between 1.0 and k or 1.0 and 1.41. This shows that for these values of n heat must be abstracted from the gas as the temperature rises.

For all other values of n, the coefficient is positive, and heat is added when the temperature rises.

Below are tabulated some of the more important values of the exponent n.

Name of Curve.	Exponent n.	$m = C_v\left(\frac{k-n}{1-n}\right)$	T φ Equation.	$p\,v$ Equation.
Adiabatic.	1.41 ($=k$)	0	$\varphi=$Const	$pv^{1.41}=$Const.
Isothermal.	1	∞	$\varphi=$Const.	pv = "
Isopiestic.	0	$kC_v=C_p$	$\varphi_2-\varphi_1=C_p \log_\varepsilon \frac{T_2}{T_1}$	p = "
Isometric.	∞	C_v	$\varphi_2-\varphi_1=C_v \log_\varepsilon \frac{T_2}{T_1}$	v = "

That the equation of the curves is $T=$const., in the second case, is readily seen from (12 a). Since $m=\infty$, the other factor,

$$\log \text{nat.} \frac{T_2}{T_1}=0, \text{ or } T=\text{const.}$$

Differentiating (13), we have

$$\frac{d^2t}{d\varphi^2}=\frac{dt}{d\varphi}\,\frac{1}{m}=\frac{T}{m^2} \qquad (14)$$

Since the second derivative is positive in all cases, the curve is always convex to the φ axis.

In Fig. 5 several curves are shown plotted accurately to scale. It will be noticed that the curves approximate very closely to straight lines, and in practice it is sufficiently accurate to draw a straight line. The direction of the line is obtained from(13); that is, the tangent of the angle which the line makes with the φ axis is equal to $\frac{T}{m}$. It is necessary to choose different scales for T and φ; in Fig. 5, one of the larger divisions represents a rise of 10° of temperature; on the φ axis, the same division represents $\frac{1}{100}$ of a unit of entropy.

It will be noticed that for $n=1.1$ and 1.2, heat is abstracted as the temperature rises; it is also of interest to note that the area under the $p\,v^\infty$ curve is less than that under the $p\,v^0$ curve for the same rise of temperature, showing that less heat is expended in raising the temperature of the gas when the volume is constant than when the pressure is constant.

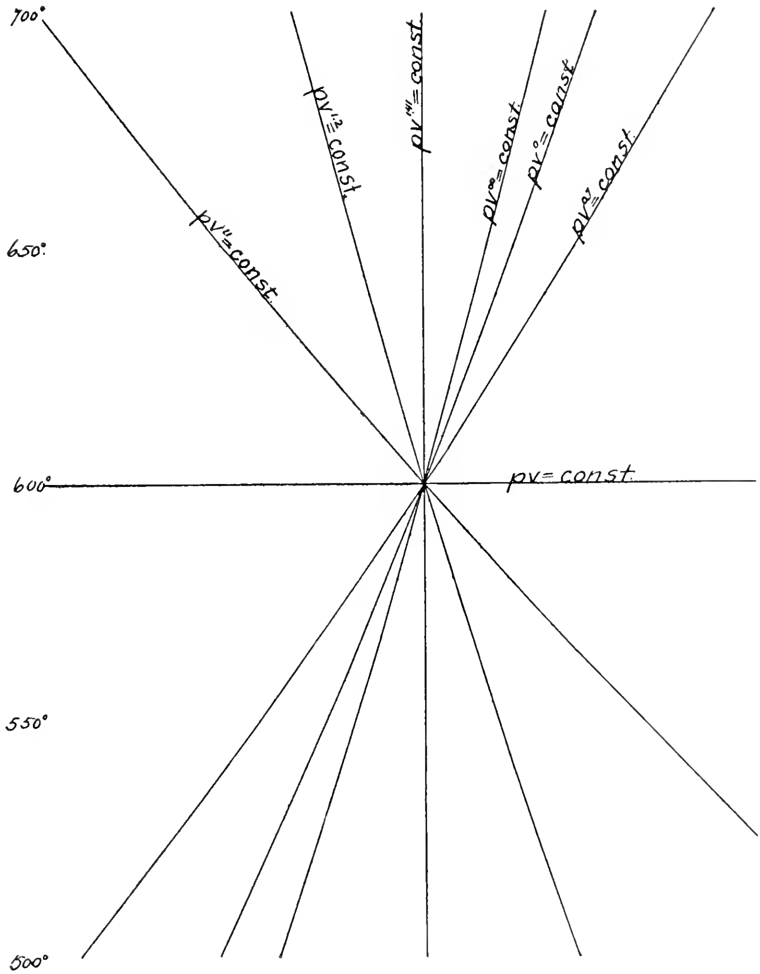


FIG. 5.

For a practical application of the $T\ \varphi$ diagram for perfect gases we will study the action of an air compressor with a water jacket. Suppose the air is taken in at 14 lbs. pressure absolute and compressed to say 70 lbs. per sq. in. absolute. Assume the temperature of the entering air to be 40° F. or 500° F. absolute.

If there is no water jacket, the air will be compressed adiabatically, the equation of the compression curve being $p\,v^{1.41} =$ const. If, on the other hand all the heat could be removed as fast as generated, the air would be compressed isothermally and the water jacket would be perfect. In practice the curve lies somewhere between these two limiting cases; the exponent n is usually about 1.3, though under favorable conditions it may be made smaller. With the data given it is easy to find the final temperature at the end of compression for any value of the exponent n we have.

$$\left(\frac{p_2}{p}\right)^{\frac{n-1}{n}} = \frac{T_2}{T_1} \qquad (15)$$

or

$$\left(\frac{70}{14}\right)^{\frac{n-1}{n}} = \frac{T_2}{500}$$

For $n=1.1$, $T_2=578.8°$ F.
$n=1.2$, $T_2=653.8°$ F.
$n=1.3$, $T_2=725.0°$ F.

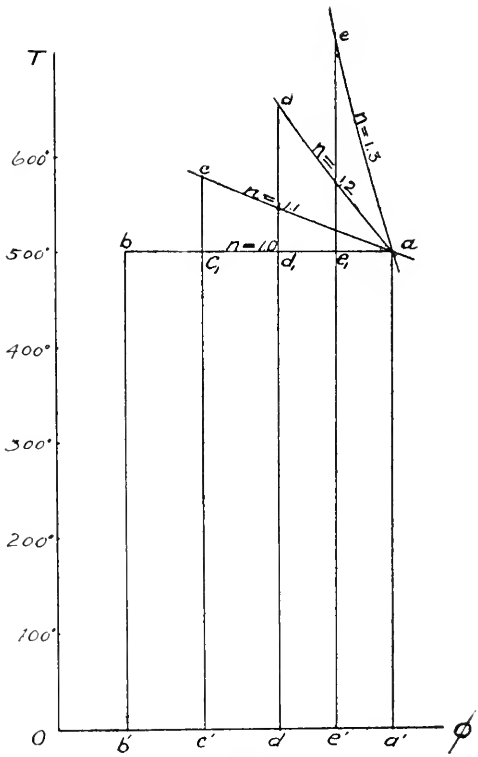


FIG. 6

The curves for these three values of n are shown in Fig. 6. For $n=1.3$, the line aa' represents $T_1 (=500°)$, and line ee' represents $T_2 (=725°)$, while ae_1 represents (to a different scale) the decrease of entropy. The area $aee'a'$ represents to a different scale the quantity of heat abstracted by the water jacket during the compression. Similarly $add'a'$ represents the heat that would be abstracted by a water jacket if the compression should follow the law $pv^{1.2}=$const. For the isothermal case, equation (12) becomes indeterminate; we know that the isothermal is a horizontal line through the point a, but we do not know the length of the line, that is, the decrease of entropy. We may proceed as follows: If T is a constant, formula (8) becomes

$$dH = Apdv \qquad (16)$$

$$\text{But } v = \frac{R\,T}{p},$$

$$\text{and } dv = -\frac{R\,T\,dp}{p^2} \quad \text{remembering that } T = \text{const.}$$

$$\text{Substituting, } dH = -A\,R\,T\frac{d\,p}{p} = -(C_p - C_v)\,T\,\frac{dp}{p}$$

$$d\,\varphi = \frac{d\,H}{T} = -(C_p - C_v)\,\frac{dp}{p}$$

$$\varphi_2 - \varphi_1 = -(C_p - C_v)\log\text{nat.}\frac{p_2}{p_1} \qquad (17)$$

In the present case,

$$\varphi_2 - \varphi_1 = -(.2375 - .1684)\log\text{nat.}\frac{70}{14} = -.1112$$

This value gives us the length ab on the scale adopted; hence $a\,b\,b'a'$ represents the heat abstracted by the water jacket supposing the compression to be isothermal or the water jacket to be perfect. It is evident that the fraction, $\dfrac{\text{area } a\,e\,e'\,a'}{\text{area } a\,b\,b'\,a'}$, is the efficiency of the water jacket when the exponent n is 1.3. Similarly the efficiency of the jacket can be found for any other exponent.

It may be of interest to note that the mechanical equivalent of the heat abstracted during compression is

$$\frac{H}{A} = \int p\,d\,v. \text{ from (16).}$$

But $\int p\,d\,v$ is the work of compression. Hence, when air is compressed isothermally, all of the work done by the piston upon the air is immediately abstracted by the water jacket.

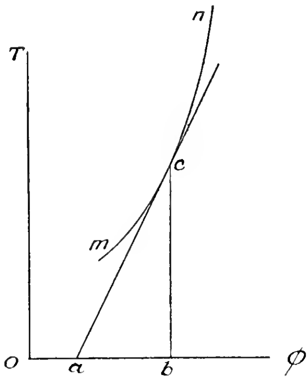


FIG. 7.

In Fig. 7, let $m\,n$ be any $T\varphi$ curve. Draw a tangent $c\,a$ at any point c of the curve; drop the perpendicular $c\,b$ on the φ axis. Then $a\,b$ is defined as the subtangent of the curve.

$$ab = c\,b\ tan\ acb = T\frac{d\,\varphi}{d\,T}$$

$$\text{But } \frac{d\,\varphi}{d\,T} = \frac{m}{T} \text{ from (13),}$$

$$\text{Hence } a\,b = m = C_v \left(\frac{k-n}{1-n}\right)$$

When $n = \infty$, the $p\,v$ curve is $v =$ const. and $m = C_v$. The operation consists in adding heat to a gas at constant volume. In this case, the subtangent to the $T\varphi$ curve represents C_v the specific heat under the given conditions. Similarly, if $n = o$, $p = const.$, $m = C_p$, and again the subtangent is the representative of the specific heat under the given conditions. Whatever may be the character of the change of state, the coefficient m is the specific heat of the gas under those conditions and the subtangent of the curve is the linear representative of this specific heat. The subtangent of the curve is the linear representative of this specific heat. The subtangent is constant when the specific heat is constant; it is well known that the curve whose subtangent is constant is the logarithmic curve as has been shown.

The $T\varphi$ diagram may be profitably applied to the case of saturated steam. Suppose we have one pound of water in the

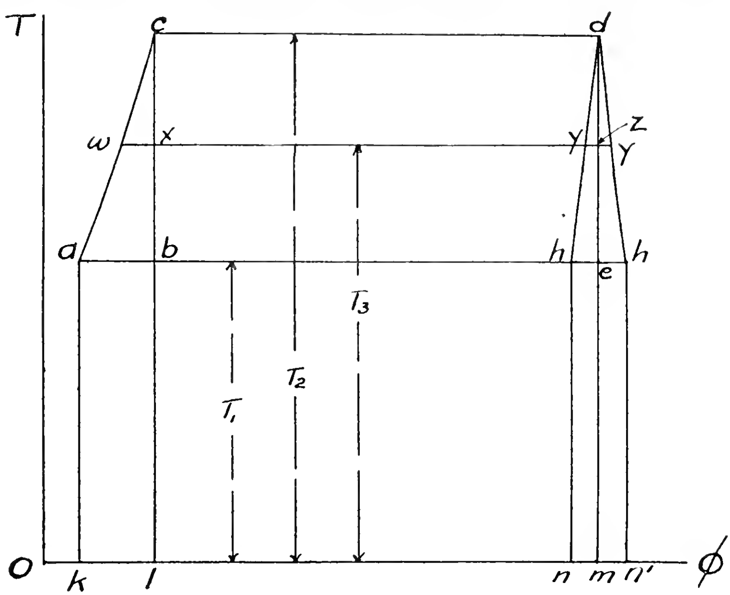


FIG. 8

condition represented by the point a, Fig. 8; the temperature is T_1, and the entropy may be represented by the distance OK. Heat is applied and the temperature rises to T_2, the increase of entropy being represented by $a\,b$. This increase is

$$a\,b = \varphi_2 - \varphi_1 = \int_{T_1}^{T_2} \frac{dH}{T} = \int_{T_1}^{T_2} \frac{C\,dt}{T}$$

Suppose c to be the boiling point: if any more heat is added the water will vaporize at constant temperature and the operation will be represented by an isothermal cd parallel to $O\varphi$. If the water is all changed to steam there must have been r_2 heat units added; hence the increase of entropy is $\frac{r_2}{T_2}$ where r_2 is the latent heat of steam at the temperature T_2. Suppose now the steam expands adiabatically from the point d: the operation is represented by the line de parallel to OT. If, on the contrary the steam expands so as to remain continually saturated the operation may or may not be adiabatic. Let us assume for a moment that during such an expansion the steam gives up heat;

that is, loses entropy. In this case the expansion will be represented by a line dh lying to the left of de. When the expansion has proceeded to the temperature T_3, the decrease of entropy is yz. Call this θ.

$$\text{Now } yz = wx + ed - wy.$$

The distance wx represents the increase of entropy due to heating the water from T_3 to T_2, or

$$wx = \int_{T_3}^{T_2} \frac{C\,dt}{T}$$

$$ed = \frac{r_2}{T_2}$$

Similarly $wy = \frac{r_3}{T_3}$ considering T_3 the boiling temperature.

Substituting these values:

$$\theta = \int_{T_3}^{T_2} \frac{C\,dt}{T} + \frac{r_2}{T_2} - \frac{r_3}{T_3} \qquad (18).$$

If the line wz is made to approach line ed until only an infinitesimal distance separates them, T_2 and T_3 will practically coincide, and we may pass to the differential votation and write (18),

$$d\theta = \frac{C\,dt}{T} + d\left(\frac{r}{T}\right)$$

$$\text{whence } \frac{d\theta}{dt} = \frac{c}{T} + \frac{d}{dt}\left(\frac{r}{T}\right)$$

The specific heat of the steam is represented by the subtangent to the curve dh. Call the spcific heat h.

$$\text{Then } h = T\frac{d\theta}{dt} = C + T\frac{d}{dt}\left(\frac{r}{T}\right)$$

$$= C + \frac{T}{dt} \cdot \frac{T\,dr - r\,dt}{T_2}$$

$$\text{or } h = C + \frac{dr}{dt} - \frac{r}{T} \qquad (19)$$

Equation (19) is the general expression for the specific heat of any saturated vapor. In the case of steam, this expression may be simplified as follows:

$$r = H - q$$

where H is the total heat of vaporization and q the heat of the liquid.

For steam, $H = 1091.7 + .305\,(t-32)$

$$r = 1091.7 + .305\,(t-32) - q.$$

$$\frac{dr}{dt} = .305 - \frac{dq}{dt} = .305 - C,\ \text{since}\ C = \frac{dq}{dt}.$$

Substituting this in (19),

$$h = .305 - \frac{r}{T}. \qquad (20)$$

For ordinary temperatures, h is negative; hence our curve would be $d\,h$ on the right side of $d\,e$ Fig. 8, the area $d\,m\,n'h$ representing the heat added to keep the steam saturated, while the temperature falls from T_2 to T_1. At some temperature, the tangent to the saturation curve $d\,h'$ becomes vertical; this is the so-called "critical temperature." Above this temperature the tangent will incline to the left and be positive in sign, and the specific heat h will at the same time become positive.

Interesting applications of the $T\varphi$ diagram to the cycle of the steam engine may be found in Ewing's Steam Engine and in Cotterill's Steam Engine. There is also an instructive article in London Engineering, Oct. or Nov. 1894.

ROMANESQUE ARCHITECTURE.

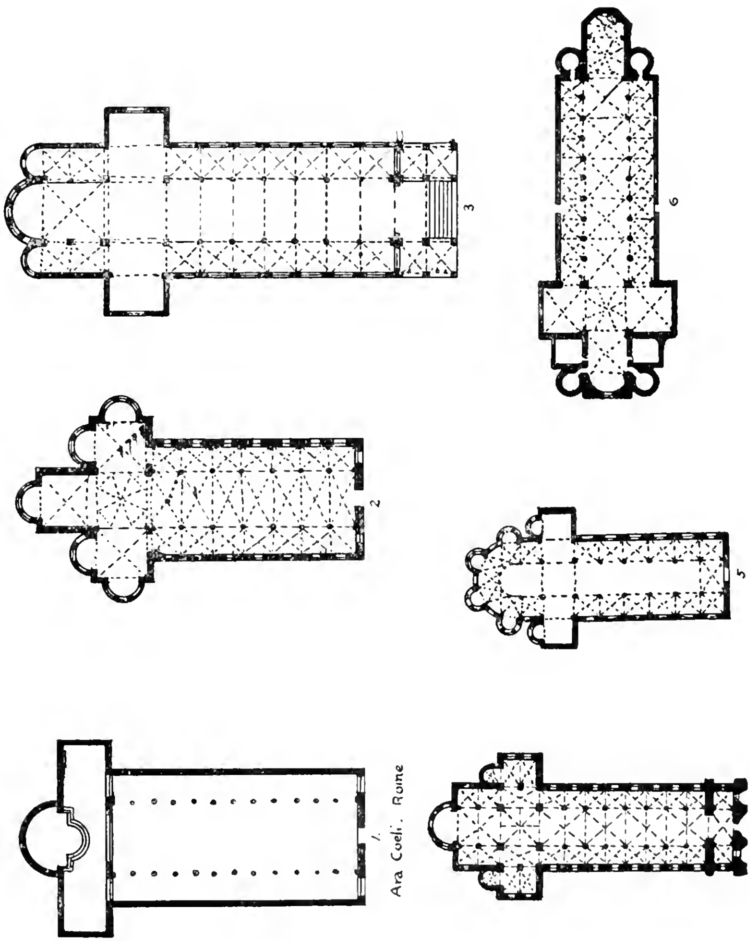
By Grant C. Miller, '94, School of Architecture.

The word Romanesque means Roman-like. According to Quicherat: "Romanesque architecture is that which has ceased to be Roman, and though not yet Gothic contains much that is Gothic." It was inspired mainly by the monuments of Rome which covered the land and were remodeled under the Byzantine influence to suit the new customs and forms of religion. The Byzantine style certainly took its elementary details and its fundamental forms from Rome and on the other hand there are to be found in the Romanesque style elementary details from Byzantium, though the two styles are different in their general character. The Byzantine style was more local while the Romanesque became the style of the whole Christian world.

Very early in the middle ages commercial relations existed between the east and the west, and Byzantium became so powerful that ambassadors were sent there from France, Germany and Italy. Many people from all nations were making pilgrimages to the Holy Land and as they passed through Constantinople and other important places of the Byzantine empire they were inspired to rival the east in art. In consequence of this, their aspirations and ideas were spread into Italy, France and Germany, and Greek monks who had established themselves in these countries also assisted materially in developing the influence. For several years the south of Italy was connected by religion, government and language with the empire of Constantinople. Venice, to the north, maintained her independence, but her merchants continued to carry on trade with the Byzantine empire and brought back many ideas on art.

Just as languages formed from the old Latin were national transformations from the original language, so the Romanesque style varied considerably in different countries. It was more like the Roman buildings in the vicinity of Rome, had more of the Byzantine influence in the neighborhood of Venice, and showed most originality farthest from Rome, as in Germany and France.

The ancient Christian Basilica, Fig. 1, is the starting point for all the Christian architecture of the middle ages, and it in turn was derived from the old Roman basilica, which was used for the market and judgment hall. It is not the intention, however, to trace out each step of the development and alteration of the



simple primitive form, or to prove that it had an independent origin, but to accept its examples as we find them in the Romanesque edifices from the eleventh to the thirteenth century. It certainly would be useless to go back farther than the tenth century to study this style, for the first buildings were made only of wood or with wooden ceilings, and were, from the nature of the material, soon destroyed. It is true, that history tells us of basilicas of a much earlier date, but only the buildings belonging to the eleventh, twelfth, and thirteenth centuries can be studied with certainty.

The typical basilica is similar to the Latin cross in plan, the short arms being called the transepts, and the long arm the nave, with an aisle on either side. The part lying beyond the transept is called the choir. The nave extended from west to east and the transept from north to south, which brought the choir facing the east. This orientation was invariably practiced at this period. The nave was broad and high, the side aisles half as broad and half as high, with the transepts of the same breadth and height as the nave. These proportions were retained, with four exceptions, in all the buildings of the period. Rows of columns or piers separated each aisle from the nave, being spaced a distance equal to or half the width of the nave. Semi-circular aisles united every two adjacent columns and supported the side walls of the nave, which in turn supported the roof. Churches with two aisles on either side were sometimes used, but not very frequently.

The east ends of the nave and side aisles were terminated by three semi-circular arches, that of the nave being of a much larger span than the other two. Each side of the square space formed by the intersection of the nave and transept was bounded by arches of the same span as the nave arch and supported by piers at the four angles. Over this was placed some form of a tower. The clerestory walls of the nave and transept were supported by these arches and were visible on the exterior. On the right and left, or north and south of this square, was a similar square of the same height and enclosed by three walls and one of the large arches.

The choir was generally several steps above the level of the nave and side aisles, and sometimes the raised portion extended farther, including all of the transept, as in the cathedral of Parma, which was built in the eleventh century. In the rear of the choir and in front of the apse was placed the altar, and the priest stood behind it facing the congregation. The choir, which frequently extended forward into the square space formed by the intersection of nave and transept, was enclosed by a screen or balustrade. Behind this were placed two pulpits from which the gospels were read.

This is the plan of the simplest basilica as we find it in the earliest stages of its development, but it was considerably changed before being superseded by the Gothic style in the thirteenth century, especially in the choir end of the church. The first modification was the addition of small apses (Fig. 2) intended for side altars, to the east side, as well as the ends of each arm of the transept. Sometimes the side aisles were continued beyond the transept (Fig. 3) on each side of the church and terminated in small apses, which were used for side chapels. In a few cases we find this plan simplified by the omission of the apses, especially the end ones. There were also small apsides for altars adjoining the chapels which were at the extremities of the side aisles.

A very pleasing arrangement of the choir was attained by continuing the side aisles as corriders around the choir and apse, the walls of the apse being supported by columns or piers, and the ceiling vaulted. A still more pleasing plan, and one which was very common in the Gothic period, was the addition of small semi-circular radiating chapels, extending out from the corridor around the main apse (Fig. 5). Another derivation from the simple plan of the basilica, which was used chiefly in the Rhine districts of Germany, was the adding of another choir to the west end of the church, and sometimes, also, another transept with chapels (Fig. 6). Towers were placed on the exterior at both ends of the churches.

The crypt was a vaulted apartment constructed under the choir and main apse of the church, and was used as the burial place for bishops, abbots and persons of high rank, and also for the preservation of the relics of the saints. Perhaps it was also retained as a remembrance of the catacombs in which the early Christians were obliged to secretly hold their meetings. The vaulted ceilings were supported by columns or piers which divided the plan up into aisles of equal height and an apse which contained the altar. Sometimes the crypt extended farther than under the choir and apse, and included all of the space under the transept. The entrance to the crypt was generally placed in front of the choir, between the steps leading up to the same. In some of the larger churches the side aisles were surmounted by galleries opening into the broad, high, central nave. This was brought about by the requirement for more space in the populous places. A gallery or loggia is sometimes found at the west end of the nave, resting on columns or piers, with a vaulted roof, and was occupied either by nuns or people of note. The space under it was generally used as a vestibule or entrance hall. In a few cases galleries were built in the north and south ends of the transepts.

The vaulting of churches is one of the principal characteristics of the Romanesque style. Page after page has been written to prove when and where the first vault was used in Romanesque architecture, but that does not matter to a practical architect though he should be familiar with the vaults used from the eleventh to the thirteenth century. History tells us that the vault was known to the Egyptians, the Assyrians, the Greeks, the Etruscans and the Romans. The cylindrical or barrel vault is the simplest, and the most ancient, for it was used at Rome from the time of the Tarquins. The conical vault was used in Greece, before the time of Homer, in the tombs and treasuries at Mycenae. There is also the groined vault, which is the intersection of two cylindrical vaults at right angles used by the Romans in the baths of Titus and Caracalla at the beginning of the third century. The baths of Caracalla were the last expression of Roman art in its highest development and were an inspiration to many of the early Christian architects. The Greeks knew of the dome constructed of horizontal layers in corbels, the true dome being perfectly developed later in the Pantheon at Rome. The bacilicas were at first ceiled and roofed with wood, but as history tells us, they were constantly being burned, thus destroying the walls and the christian altars. They were either set on fire by the torches of the processions in the churches or by lightning. To prevent these oft-recurring fires which destroyed the holy relics and Christian altars, they gradually developed the system of vaulting until we find it in its perfect form in the Gothic style. All attempts at vaulting were at first timidly made and did not at once come into use in the churches. First they used the old Roman system of vaulting and confined it in the beginning to the choir, apse and side aisles. Then they included the transept and finally the nave, but this was not successfully accomplished until the close of the Romanesque period, or during the period of transition into the Gothic style. In the vaulting of the nave the height and breadth were so great as to render the thrust of the vault exceedingly dangerous. This made it necessary to reduce its width and to strengthen the supporting walls and piers of the lower arcade. This was accomplished by increasing their size.

A very ingenious method of buttressing the barrel vault was employed in the church of St. Savia, in France. The nave was formed of two rows of cylindrical columns, and the side aisles were groin vaulted. The barrel vault of the nave sprang from a point just above the crown of the arches, turned between the columns in the direction of the nave, and the wall which in the later churches was called the clerestory was continued above the springing line so that its weight tended to neutralize the thrust of the vault and it also served to support the roof. The cylindrical vault, thus resting through its entire length on the walls, was found to be too heavy, and it was impossible to use the bays for lighting the interior. The groined vault, resting on four points of support, was employed to overcome these difficulties, and to give greater stability to the vault, a transverse rib was thrown across on its under surface from one engaged column or pier to another. The next great step was the addition of wall and diagonal ribs, each set supporting itself. By this system a frame work was obtained for the vaulting, which formed four spherical triangles which could easily be filled in with light material, thereby making a much more stable vault. The ribs could be made as heavy as desired, while the vaulting or filling could be light, as stated above, thus making the covering of larger areas possible. When once this system came into use it was necessary to buttress the points of support, which was done by lessening the width of the openings and increasing the thickness of the walls and piers. This gave a crowded appearance to the interior, the acoustic properties were bad, and lighting through such thick walls was practically impossible. Common sense called a halt. To oppose the thrust of the central vault, half tunnelled vaults were turned over the side aisles to the springing line of the central vault; the walls of the side aisles being buttressed on the exterior. It is quite probable that from this came the flying buttress. Up to the last few years of the period only the semi-circle had been employed, but a further development came in the use of the pointed arch. The groined vault had been used mainly for covering square areas, the diagonal ribs being semi-circles, but when the pointed arch came into use these diagonals could be either pointed or semi-circular in form. Thus a rectangular area could be vaulted by arches of the same radius, the diagonal rib having the same height at the apex as the arch spanning the greatest aisle.

A further development was made in the way of vaulting a square area by raising a dome over the middle square of the transept, which appears outside in the form of an octagonal tower. The transition from the square to the octagon was made by vaulted niches, i. e., small arched pendentives in the four corners. The large apse and semi-circular niches were vaulted over with half domes which were covered externally by conical wooden roofs.

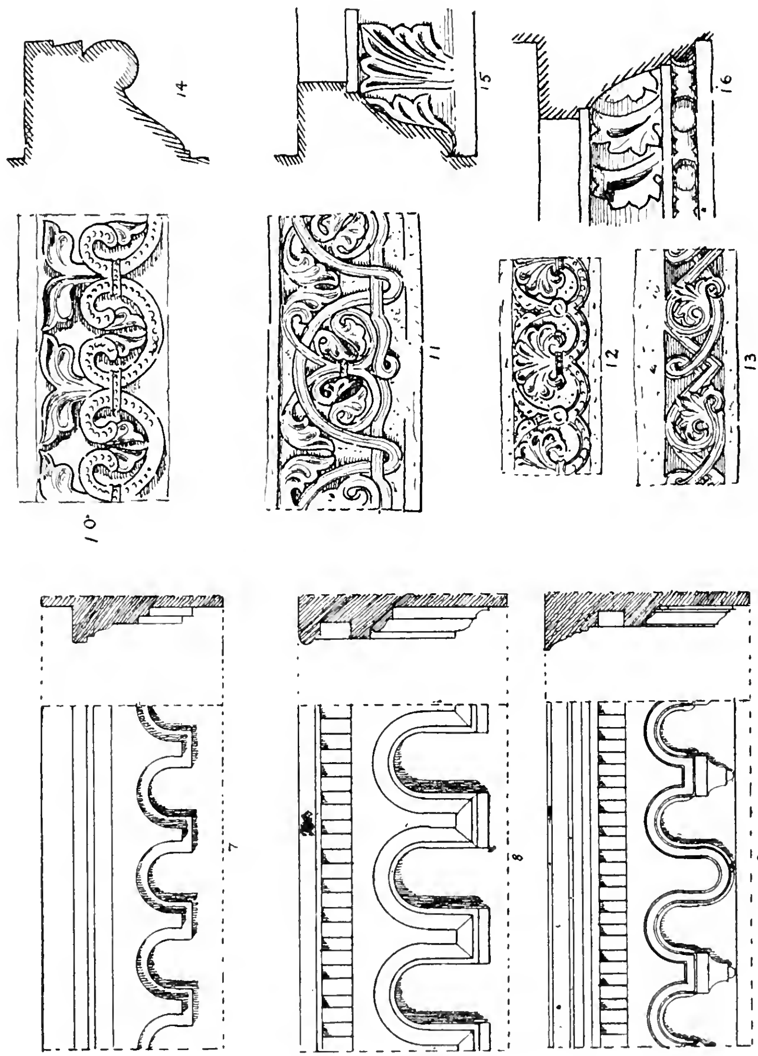
In covering the outer aisle around the apse the groined vault was used, but this necessitated the stilting of the inner arches, or the use of segmental arches on the outside, to bring their crowns in the same horizontal plane. Neither of these looked well, but the former was preferable and most commonly employed.

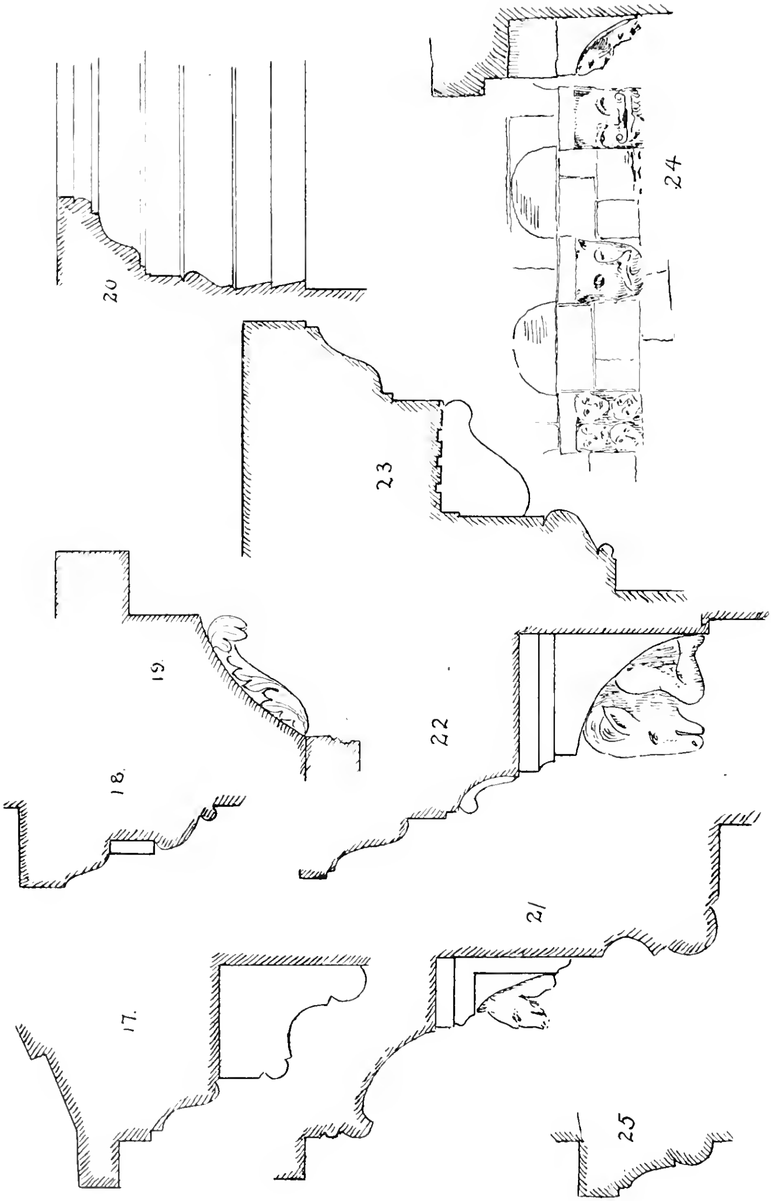
The star vault was also conceived by the Romanesque architects, but more fully developed by those of the Gothic period. It is similar to the groined vault, except that the diverging arches spring from each angle of the bay instead of one, their ends intersecting the transverse and longitudinal ribs, thus forming a four pointed star on the plan.

All this being accomplished, the next step was to transfer the buttress from the interior to the exterior, so as to clear from the interior the mass of masonry which was placed there by the Romanesque architects, and to place it on the outside in the form of flying buttresses.

The exteriors had at first a very heavy and massive appearance, but became lighter and more refined until, at the close of the twelfth century, as the transition period drew near, they were much more delicate and harmonious. The horizontal lines, such as water tables, cornices, belt courses and friezes, diminished and gradually disappeared, while at the same time the vertical members, such as buttresses, pilasters, engaged columns and arcades, began to predominate and attract attention.

On the whole the general expression of the exterior was one of repose. The windows were small in proportion to the size of the buildings, but the masses were proportionate and well treated. The principal facade and also the facades of the tran-

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septs, were terminated by gables the inclination of which varied with the locality and the system of construction. The principal facade contained the main entrance and sometimes a porch. A round opening or bull's-eye window was used in the gable, and served to light the nave, and was the origin of the beautiful rose window of the Gothic style. A tower was nearly always attached to the church, excepting in Italy, and it was built up of several stories of arcades or windows, which were separated by string courses.

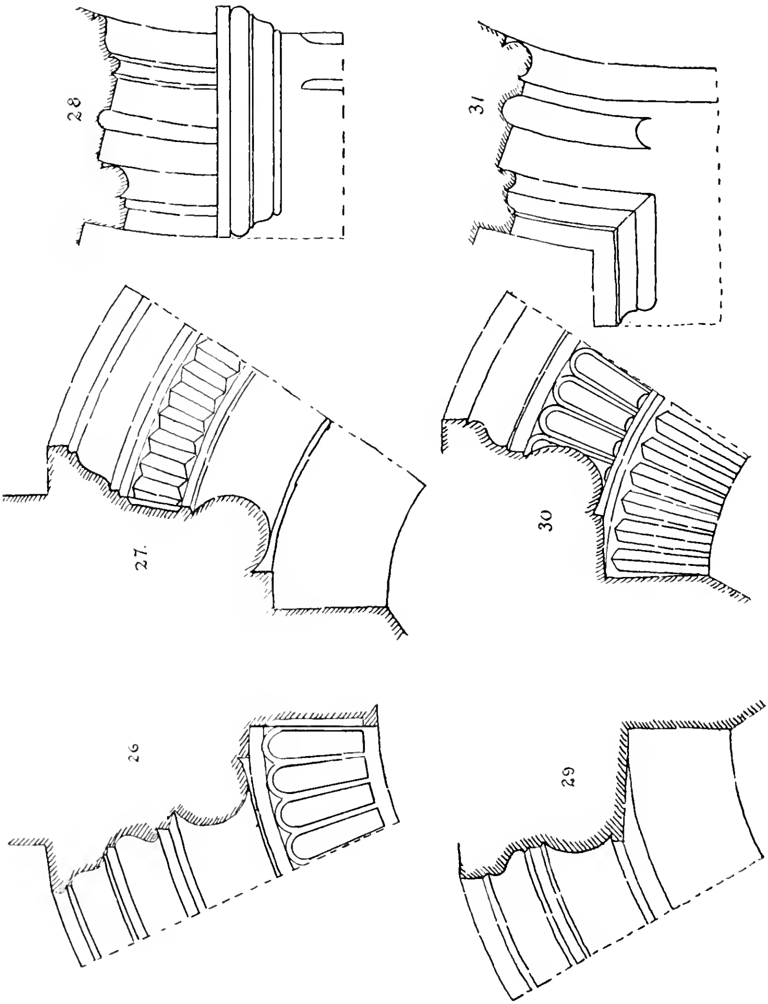
Slightly projecting pilasters were used to a considerable extent on the exteriors, and were connected at each story by horizontal moulded string courses (Figs. 14-25 inclusive) or by rows of semi-circular arches supported by corbels of various forms (Figs. 7, 8, 9) and sometimes in the form of heads grotesquely treated (Figs. 21, 22, 24). Occasionally half-columns or pilasters, with capitals, were placed on the exterior wall, and connected at the top with semi-circular arches forming blind arcades. The projecting pilaster strips supported by string courses were used mainly on the side walls, the arcades being employed mostly on the facades and choir. The apse is generally covered externally by a conical or octagonal wooden roof.

The open arcades or galleries formed in the frieze under the cornice and composed of detached columns, connected by semi-circular arches, are an excellent feature of the style. The galleries were not found all around the church, but in those places which were intended to be most highly ornamented, as the choir and transept, when ending in a semi-circular or octagonal apse, and in the octagonal tower over the intersection of the nave and transept. This feature is found mostly in upper Italy and along the Rhine in Germany.

The bays which were formed by the pilaster strips or engaged columns were pierced by semi-circular-headed windows which were sometimes grouped in twos or threes, separated by small engaged columns.

Towers for the first time became an integral part of the church, but continued detached in Italy. It is thought by M. Viollet-le-Duc that the tower was at first a work of defense intended to protect the church from possible attack, but during this period we know of their being used as a place to hang the bells for calling people from a distance to worship. Generally towers were square and had pyramidal wooden roofs of different inclinations, varying with the country. Many different forms of towers were employed in the Rhine districts of Germany, sometimes round, as in the Worms cathedral, or octagonal, as in the Church of the Holy Apostles at Cologne, or square, changing to octagonal and then to round. In Germany the roofs covering these towers varied greatly.

The principal entrance was generally placed in the center



of the west facade excepting in the double ended churches found in Germany. Owing to the very great thickness of the walls it was necessary to employ recessed doorways, placing tangent columns in the angles, the number increasing with the richness of the style.

The full semi-circular arch is always used in spanning the doorways and openings, its archivolt being ornamented by mouldings (Figs. 26-31 inclusive), and geometric carvings. These doorways, therefore, give opportunity for the richest decoration. In the first part of the eleventh century the arches were very simply treated, but became more and more ornamental as the style was developed. The semi-circular space above the door was filled with a stone slab set flush with the inner surface of the wall and was called the tympanum. This space was nearly always ornamented with bas-reliefs representing the saint of the church. The door was composed of heavy planks dowelled together and hung on large metal hinges in the form of scrolls.

Window openings were usually semi-circular at the top, and at first quite small, being splayed on the inside to allow the light to enter more easily. They became larger as the style was developed and were splayed on both sides. Small columns were sometimes used in the steps of the recessed jambs, as in the doorway, the arch mouldings springing from the capitals of these columns. When the columns were omitted, these mouldings continued down the sides and stopped on the sill course of the window. The windows are often grouped in twos and threes and separated by columns supporting the arches. In the later period when groups of three were used the central one extended higher than the others.

The wheel window was a large circle placed over the front entrance way for the purpose of lighting the interior of the west end of the nave. These were at first simple openings, more or less ornamented, but toward the close of the twelfth century they were divided into several parts; such as lobes, trilobes, quatrefoils, etc. It is evident that the Romanesque architects understood the decorative motive which the Gothic architects so fully developed in the beautiful rose window. The windows were sometimes, at first, left entirely open, but later they were filled with circular or diamond shaped glass, leaded together and stayed by wrought iron bars. In a few cases, in the west, the openings were filled with designs of intersecting circles in perforated stone.

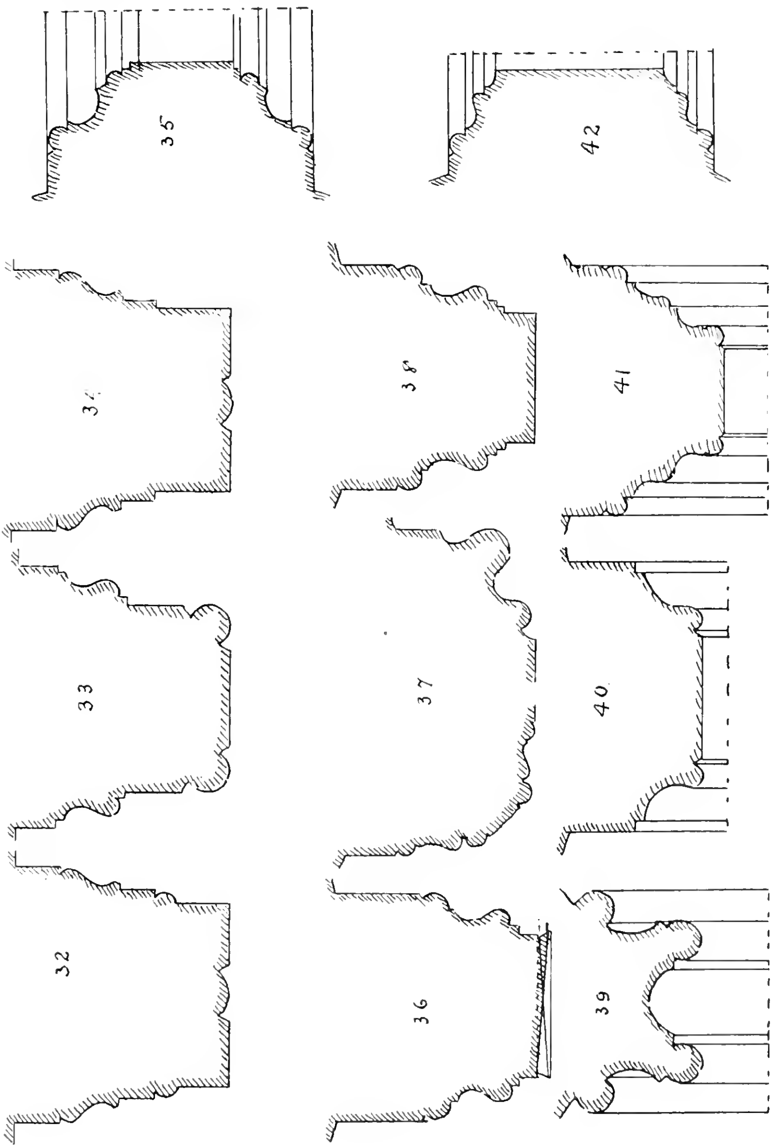
In the design of the cornice the Romanesque architects left the classical traditions, thinking the entablature was not necessary for each repetition of the orders, and used a single entablature at the upper part of the building, employing only a plain belt course to separate the orders. It was this custom of suppressing the horizontal and accenting the vertical lines which gave such a powerful influence to the Gothic style.

The cornice was at first quite simple, being only a plain moulding (Figs. 18, 19, 20), but to add to the effect an arched frieze or a row of corbels supporting a projecting table was employed. The arched frieze consisted of a row of semicircular arches, arranged one after the other and connected continuously (Figs. 7, 8, 9), and received the greatest variety of treatment and refinement. The ends of each arch either terminated in rectangular projections, or the single arches rested on corbels of alternating designs. These arches were often formed of richly profiled mouldings. Sometimes there was added to each arched frieze another frieze (Figs. 10, 11, 12, 13), or broad horizontal bands of square projections and hollows, arranged like a checkerboard; or a band of scale-like ornaments; or, more frequently, a zigzag band.

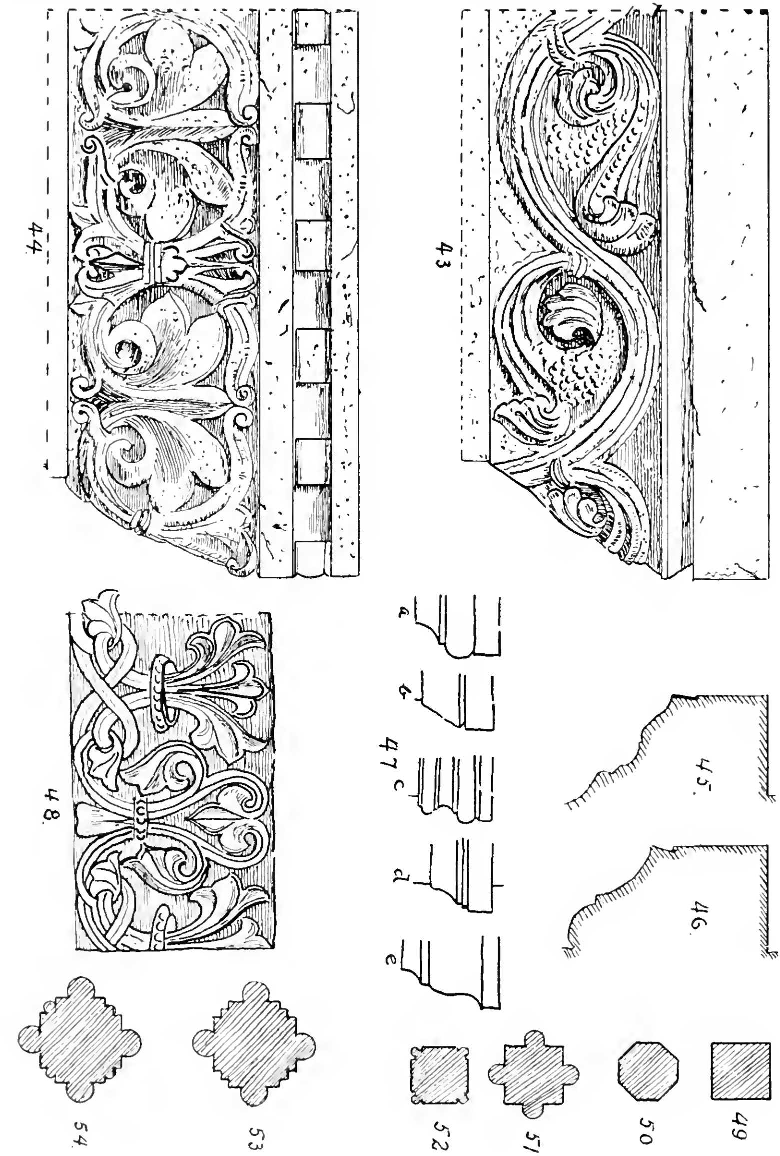
The Romanesque cornice is generally composed of a row of stone corbels supporting a projecting table (Figs. 17-23 inclusive). According to Viollet-le-Duc the sculptors of the tenth, eleventh and twelfth centuries understood that the corbel was the place most proper for displaying sculpture. These corbels were sometimes carved into heads grotesquely treated. Corbels were also employed to relieve the lintels of the doors. Heavy projecting corbels (Fig. 70) were sometimes used to carry columns which supported arches.

In upper Italy and along the Rhine in Germany the arcade gallery was frequently introduced instead of the corbel-tables of the frieze. These galleries consisted of small detached shafts connected by arches which made a dark shadow under the cornice and afforded a pleasing effect. In Italy these arched friezes extended parallel to the inclined cornice of the gable, but were not always detached.

The pier was employed to separate the aisles and to support the vaults and roof. These piers exhibited a great variety of form. At first they were perfectly plain and square (Fig. 49). Their angles were then chamfered (Fig. 50), or rectangularly in-



dented, ending in grooves a little distance from the top and base (Fig. 81), or small three-quarter columns were inserted in the rectangular recesses (Fig. 76). Half columns were sometimes attached to each face of the square pier (Fig. 51), the square corners still being recessed (Fig. 53). A more beautiful



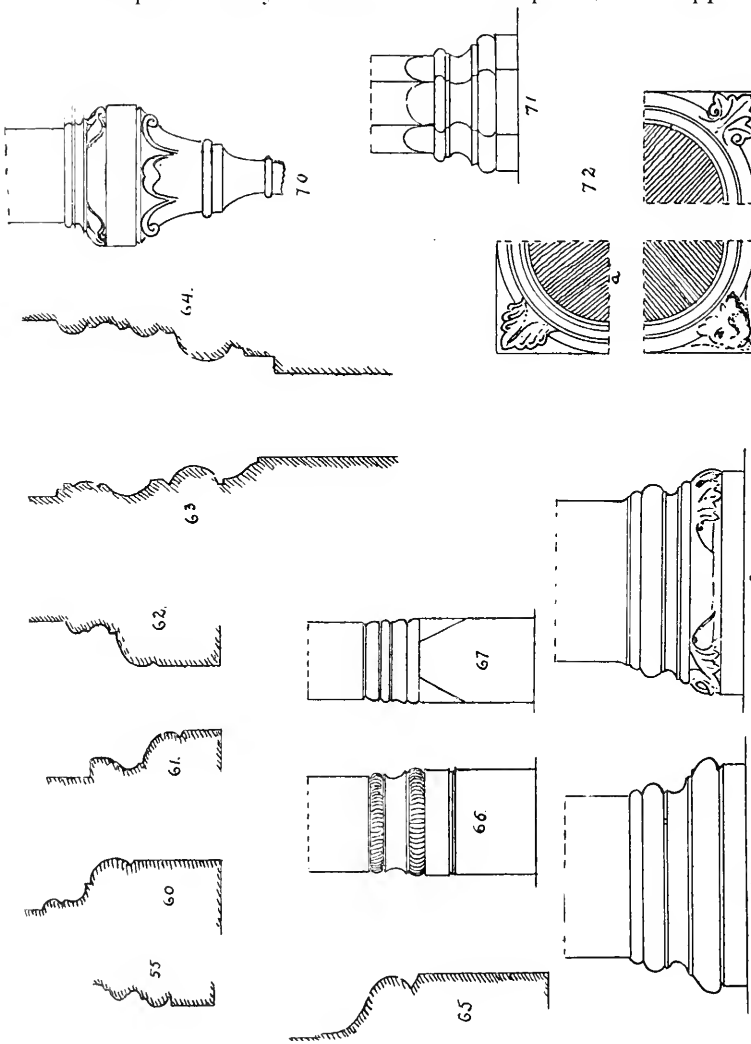
form was obtained by introducing a small half column in place of the center projection (Fig. 54). In this way the whole pier, instead of being plain in form, became moulded. The large column on the face of the pier towards the nave supported the transverse ribs of the vault, while the smaller shafts at the angles supported the groin ribs.

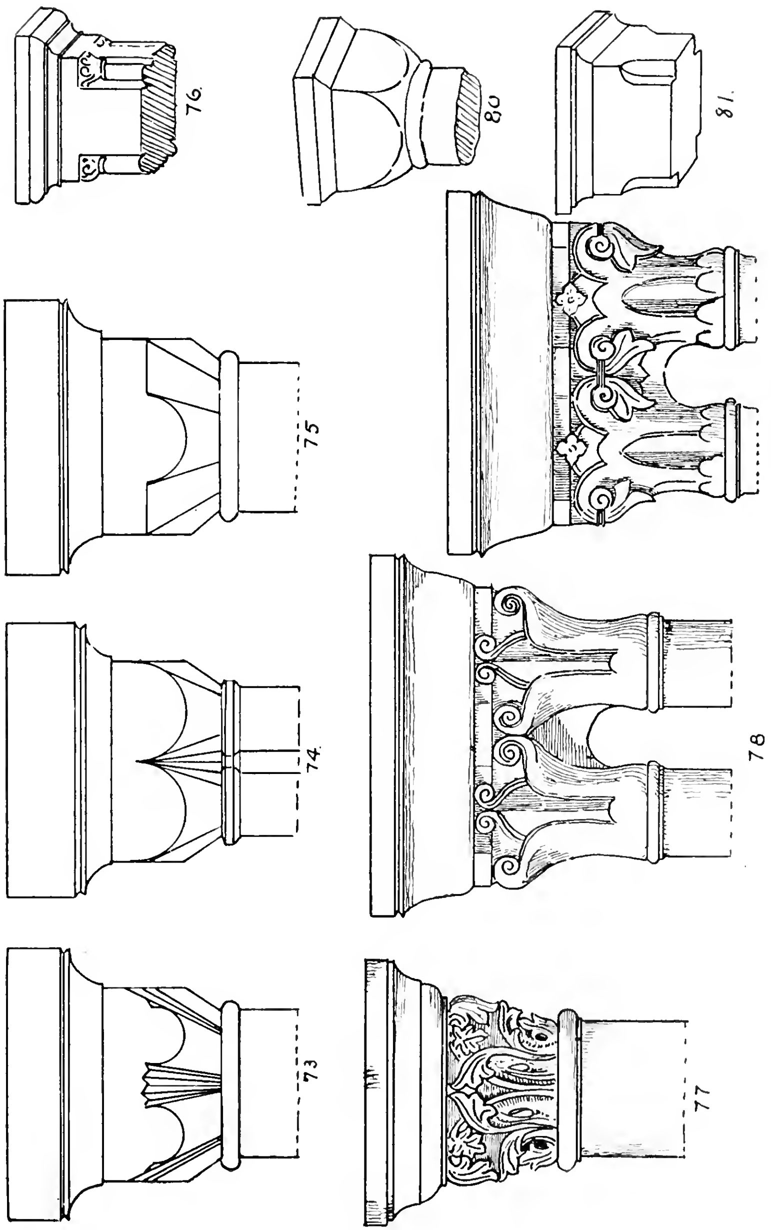
Hand in hand with the development of the pier came that of the ribs of the vault, which were at first perfectly plain, then grooved out at the angles and quarter rounds inserted so they appeared to spring from the abacus of the capital of the pier (Figs. 32-42). Wall piers or pilasters, which likewise served as supports for the groin ribs, were developed in conjunction with the aisle piers.

The Romanesque architects abandoned the proportions established by the Romans and proportioned their columns to suit the needs of their new construction. The proportions were more slender than those of the classical style, there being no fixed relation between the length and diameter of the shaft. The columns were usually built of small blocks of stone, rarely of drums or monoliths. The shafts were circular in section, never diminished and rarely fluted. They were usually plain, but were sometimes decorated in various ways, such as twisted rope mouldings, chevron or zigzag ornaments, and by lozenge shaped panels (Figs. 112-116 inclusive). In order to avoid the heavy appearance of the column when it was required to support a great weight, clustered columns were employed. The middle of the shaft was sometimes also relieved by an annular band or moulding, especially when several columns were grouped together.

The capitals of the Romanesque period varied greatly. In the early epoch of Christian architecture the art of sculpture had declined and the capitals of the heathen temples were borrowed, or new capitals were carved in rude imitation of the antique. After some time the Christians began to invent capitals, the first of any importance being the cubic or cushion capitals (Figs. 73, 74, 75 and 80). If we conceive the lower corners of a cube to be more or less rounded off so that each of its sides presents a semicircular form, we have the cushion capital (Figs. 75, 80, 91). Along with this was introduced the bell shaped capital (Figs. 87-89), and towards the close of the twelfth century a finer and richer transformation of the ancient capital occurred. The cushion and bell shaped capitals, however, were used to the close of the Romanesque period. The scalloped capital (Figs. 73, 74), is another form which was used in England more than elsewhere and appeared like a series of cushion capitals placed side by side. It was employed mostly for the capitals of clustered columns and massive piers.

The capital really consisted of two parts, the upper or

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square portion called the abacus, and the lower portion or bell. The necking was generally omitted, there being just a small ovolo or torus separating the shaft from the capital.

The ornamentation was at first similar to the Roman Corinthian, and Byzantine capitals (Figs. 82 and 85). During the twelfth century antique plant forms were abandoned and geometric plant forms were introduced (Figs. 83 and 84), as also were patterns of plaited ribbon work (Fig. 87) and grotesquely treated animal forms (Fig. 90). Towards the end of the twelfth century antique forms were again imitated (Fig. 86). In cases where they predominated the Corinthian style is often called to mind, although no exact imitation was intended. During the late period of the Romanesque style the bell-shaped capital is covered with foliage of a more natural and graceful character, the stems being carved with ornaments in imitation of jewels, pearls and small geometric figures (Figs. 77 and 88). The late Romanesque architects used many varieties of capitals, but still a certain similarity prevailed which was quite pleasing.

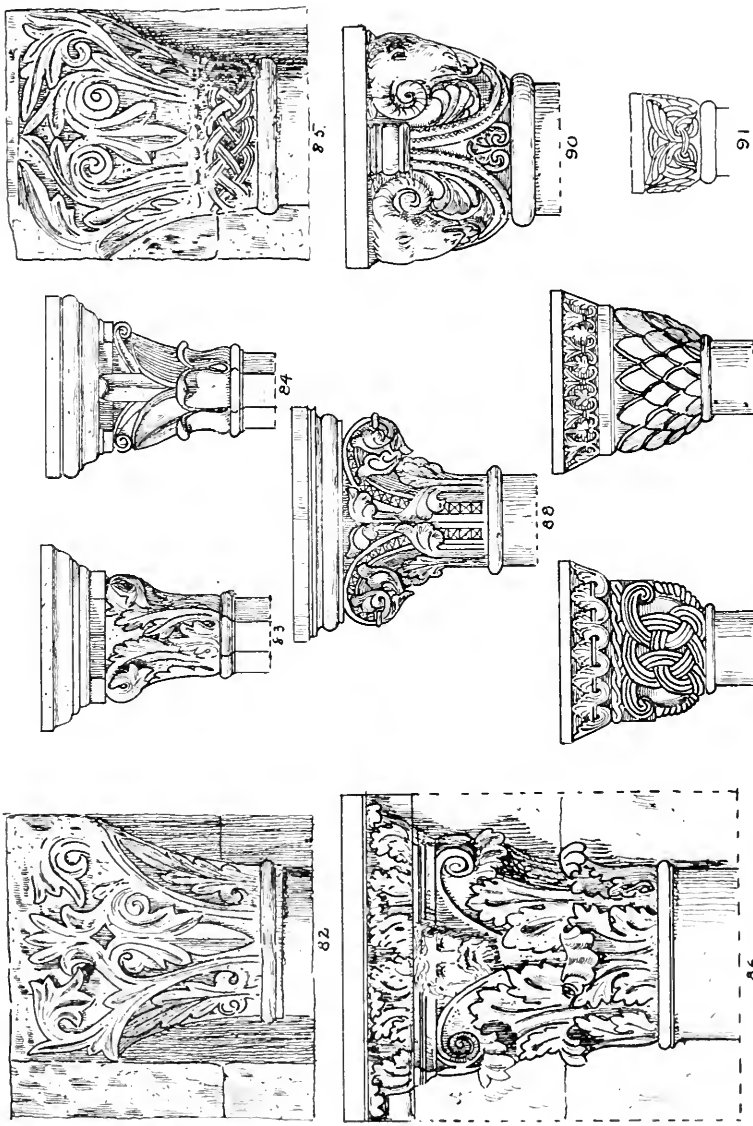
Often when two or more columns were placed side by side their capitals were cut out of one block of stone (Figs. 78 and 79), the ornament continuing from one to another, or they were united by grotesques.

It would be well to note that the nature of the material had a considerable influence on the ornamentation of the capitals. Where the stone was fine and compact the carved work was more finely treated, but where the stone was soft and coarse grained the carving was accordingly ruder.

The abacus was at first quite simple, being merely a square slab or block with its lower edges bevelled (Fig. 47*b*), but later decorated with mouldings, such as the inverted attic base (Figs. 47*a*, *c*, *d*).

One of the chief distinctions of the late Romanesque capitals was in the peculiar form of the abacus. It was much higher and less projecting than in the classical styles, its mouldings consisting of alternate fillets and cavettos, or vertical side faces with decorations (Fig. 108). When a column was connected to a pier the moulded abacus was continued around the pier.

The base of the column is merely an imitation of the classic base resting on a square base or plinth (Figs. 55, 60, 61, 62). It consisted usually of a small upper torus and a larger lower one separated by fillets and a scotia. In order to accomplish the transition from the square corners of the base to the round part of the torus the corners were rounded off and a claw-like ornament, head of an animal, or a leaf was used to conceal the angle of the

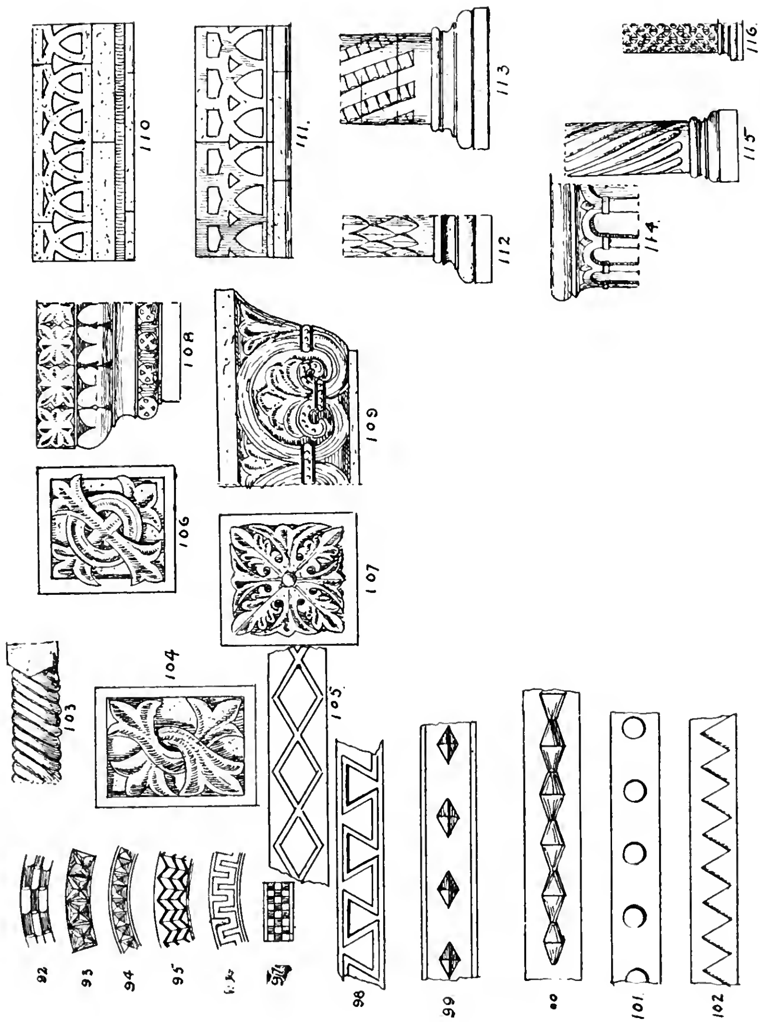


plinth (Figs. 69, 72*a*, *b*, *c*). This was a truly characteristic feature of the Romanesque style, although not always employed. Wherever the corners of the base are rounded off it must be regarded as work of the early period, for it was only in the beginning of the twelfth century that the spur ornament first appeared. Sometimes the torus projected beyond the plinth (Fig. 68) and the corner was left square, entirely omitting the spur ornament. The profile of the base was sometimes quite flat (Fig. 65) and at other times nearly vertical, the torus and fillets being very simple and projecting scarcely beyond the line of the shaft of the column (Figs. 63, 64, 66, 67).

Romanesque ornamentation was, in principle, only a new interpretation of the Byzantine ornamentation. This origin is perfectly established, even by examining a few forms of capitals, decorated shafts and the manner of employing alternating courses of materials of different colors. From the twelfth century the architects depended upon the arrangement of materials as a means of decoration in a manner similar to that employed by the Byzantine architects. In certain countries, as in Auvergne, materials of different colors, such as the brown and volcanic stones, composed large geometrical mosaics on the faces of the walls. This checkered work was also applied to the ornamentation of certain other portions, as the tympanums, gables and string courses, in the form of lozenges, stars, polygons, equilateral triangles, serrate patterns and geometrically divided circles. This ornamentation was mainly used in countries where materials of suitable colors were easily obtained. Scale-like patterns were also found to a great extent in Romanesque architecture, as in the tiles of the roof, the copings of the buttresses and the spires of the towers.

In southern France the roofs were constructed in patterns of stone and plain and enamelled terra cotta of different colors.

The mouldings of the Romanesque style were generally composed of large hollows and rounds, decorated by geometrical patterns but rarely by plant forms. The ornamentation of the mouldings was for the most part simple and rectilinear, and calculated to produce a regular alternation of light and shade. The serrate ornament (Fig. 102) was used to a great extent and the nail-head ornament (Fig. 99) was used in the decoration of the bands of arches. The fillet moulding (Fig. 92) was obtained by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cutting out a part of a round or square moulding at regular intervals and sometimes two or more adjacent mouldings were treated in the same manner. The cable ornament (Fig. 103) is similar to a rope and was used in the arch mouldings. The zigzag ornament (Fig. 95), angular, rectangular and triangular, is formed of a semi-circular moulding making angles with the direction in which the surface to be decorated extends (Figs. 95, 96, 98). The disc ornament is a circular figure, either projecting or sunken into the band. The button ornament is a small spherical bud (Fig. 117) partly opened on the head and used in sunken panels (Fig. 118). Lozenge ornaments were usually formed on a flat surface by half-rounds intersecting so as to form a panel (Fig 105) with opposite angles equal, in pairs. The chess-board ornament is formed by decorating a surface with small squares of stones of different colors, arranged in checker-board pattern. Sometimes the courses were arranged horizontally (Fig. 97) and sometimes diagonally. The star ornament (Fig. 93) is a series of star-like forms produced by sinking inclined planes into a flat surface.

The sculptured ornament was very beautiful in the late period, there being greater liberty left to the sculptor, which resulted in a flood of strange compositions, where queer animals and human figures were interlaced with the foliage. After the Byzantine and even after the Saxon influence, they commenced to imitate the floral ornament which soon resulted in its complete development. The fern leaf was considerably used in flowing ornament, the recurving of its leaves and the adding of bunches of grapes giving it decorative forms. From this modest flora the Romanesque artists composed some magnificent foliage which harmonized well with the recurving of the leaves, and produced beautiful shadows.

THE RAILWAY TRANSITION SPIRAL ON OLD RAILWAY CURVES.

BY ARTHUR N. TALBOT, '81, PROFESSOR OF MUNICIPAL AND SANITARY ENGINEERING.

Transition curves of some form are now generally accepted requirements for our best railroads. The railway transition spiral, which was described in an article in The Technograph No. 5, has met with favor and the method therein described has been adopted by many lines of railroad. In answer to queries in reference to its application to curves in existing railroad track, the writer presents the following as a method which will permit easy computation and little disturbance of the old roadbed. The nomenclature will be the same as that in the previous article, (see The Technograph No. 5, p. 78).

The general case of a compound curve will first be considered.

CASE I. COMPOUND CURVES.

To insert a spiral between the two curves of an existing compound curve by first replacing a part of the sharper curve with a curve of slightly smaller radius.

In Fig. 1, let AB be a D_1° curve and BG a D_3° curve, B being the P. C. C. and the D_3° curve having the smaller radius. It is desired to go back on the D_3 curve to a point D and there compound with a D_2° curve which shall be run to a point E where its tangent shall have the same direction as the tangent to the D_1° curve produced backward to F has at F. The radial distance EF corresponds to the offset of the usual spiral and will be called o. It is desired to locate D and F so that a selected curve, D_2°, will give a calculated or assumed distance EF as o.

The distance EF is made up of FK and KE, the first being the divergence of the D_1 curve from the D_3° curve in the distance BF and the second the divergence of the D_2° curve from the D_3 curve in the distance DE. Call the distance BF (measured in stations, or 100-ft. lengths) L_1, and DE, L_2. For the small angles used these divergences may be calculated accurately enough by the approximate formula for tangent offset, $y = .87 D L^2$, and we shall have

$$EF = .87\ (D_2 - D_3)\ L_2^2 + .87\ (D_3 - D_1)\ L_1^2 = o, \text{ or}$$
$$(D_2 - D_3)\ L_2^2 + (D_3 - D_1)\ L_1^2 = 1.15\ o \qquad (17)$$

Since the amount of D_1° curve in BF plus the amount of D_2° curve in DE (total angle) must be equal to the amount of D_3° curve taken out, we have

$$D_2 L_2 + D_1 L_1 = D_3 (L_2 + L_1) \text{ or}$$

$$(D_2 - D_3) L_2 = (D_3 - D_1) L_1 \qquad (18)$$

Combining (17) and (18) and solving,

$$L_1^2 = 1.15 \frac{(D_2 - D_3)\, o}{(D_3 - D_1)\ (D_2 - D_1)} \qquad (19)$$

$$L_2^2 = 1.15 \frac{(D_3 - D_1)\, o}{(D_2 - D_3)\ (D_2 - D_1)} \qquad (20)$$

Having L_1 and L_2, the points D, E and F may be located, and the D_2° curve may be run in from D as far as necessary. The

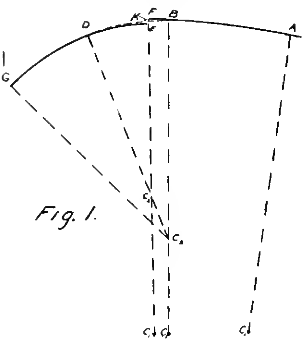


Fig. 1.

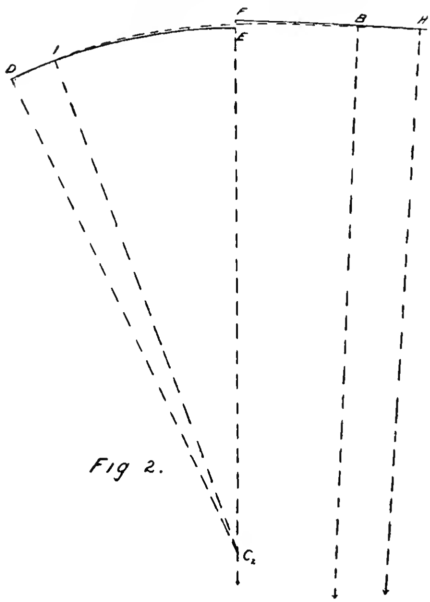


Fig 2.

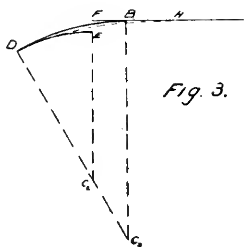


Fig. 3.

problem is then identical with that of putting a spiral between two curves having an offset o (EF) between their parallel tangents.

The principles governing the placing of a spiral between two curves are given on p. 91 of The Technograph No. 5. It is there shown that the length of the connecting spiral L' is that of a spiral for a curve of degree equal to the difference of degree of the two connected; that is

$$L' = \frac{D_2 - D_1}{a}$$

The offset is equal to that for a $(D_2 - D_1)$ degree curve from a tangent or

$$o = .0725\ (D_2 - D_1)\ L'^2 = .0725\ aL'^3 \qquad (21)$$

Half of this spiral will lie on one side of the offset and half on the other, hence in Fig. 2 $\frac{1}{2}L$ to the right of F will give the beginning of the spiral H, and $\frac{1}{2}L$ to the left of E will give the end of the spiral I.

The method of field work will then be as follows: Measure from B, the P.C.C. back on the D_1° curve a distance BH $= \frac{1}{2}L' - L_1$ to locate the point of spiral H. Measure from B on the D_3° curve the distance BD $= L_1 + L_2$ to D, the new P. C C., run in the D_2 curve to I, DI being $L_1 + L_2 - \frac{1}{2}L'$. The spiral is then to be run in from H to I.

The field work for the spiral is simple. The spiral may be run in by offsetting from the D_1° curve HF (Fig. 2), knowing that the offset from the curve to the spiral is the same as that of a spiral from the tangent using the distance from H as the distance on the spiral. Likewise the remainder of the spiral may be offsetted from the D_2° curve IE using distances from I in the calculations. See The Technograph No. 5, p. 83.

If the field work on the spiral is to be done by deflection angles, the spiral may be run in from H by using as deflection angles the sum of the deflection angle for the circular curve HF and the spiral deflection angle from a tangent for the same distance; or the transition spiral may be run backward from I in a similar manner. In either case the work will be no more difficult than for spirals for simple curves. See The Technograph No. 5, pp. 83 and 88.

As an example let us consider that a 2° and an 8° curve are compounded at B. Consider that the degree of the new curve to be run in is 8°30′, and that the value of a to be used is 2. Then $D_1 = 2$, $D_3 = 8$, $D_2 = 8\frac{1}{2}$. For a spiral from 2° to 8°30′, the value of the offset o (EF) is the same as the o for a 6°30′ curve from a tangent. Hence $o = 4.99$. By formula (19), $L_1 =$ .271 and by formula (20) $L_2 = 3.255$. Hence the point D will be back on the D_3° curve 325.5 + 27.1 or 352.6 ft. from B. The length of the spiral to be used will be $L' = \frac{8\frac{1}{2} - 2}{2} = 3.25$. Of this 162.5 ft. will be to the left of E and 162.5 ft. will be to the right of F. Hence H and I, the ends of the spiral, may be readily located and the spiral may be run in.

By this method the value of a may be chosen beforehand, the value of o may be easily calculated, and the preliminary field work is small. It may be stated that the limiting values of D_2 will be, on the one hand, a value so near D_3 that the resulting L_2 will carry the new point of compound curve back to the end of the old curve, and on the other hand such that the length of the D_2 curve shall be at least equal to half the length of the transition spiral, a value which may be shown to be $D_2 = \frac{1}{3}(4D_3 - D_1)$.

CASE II. SIMPLE CURVES.

To insert a spiral between a tangent and curve in existing track by first replacing a part of the existing curve with a curve of slightly smaller radius.

The demonstration for compound curves is general and may be made to apply to simple curves by making $D_1 = 0$. The point B then becomes the P. C., as in Fig. 3, and Formulas *(19)* and *(20)* reduce to

$$L_1^2 = 1.15\ \frac{(D_2 - D_3)\ o}{D_3 D_2} \qquad (22)$$

$$L_2^2 = 1.15\ \frac{D_3 o}{(D_2 - D_3)\ D_2} \qquad (23)$$

L' is the length of spiral for the D_2 curve. H, the point of spiral, is to the right of B a distance $\frac{1}{2}L' - L_1$, and D, the point of compound curve, (D_3° to D_2°) is $L_1 + L_2$ left of B. The end of the spiral is $L_2 - \frac{1}{2}L'$ to the right of D. The spiral may be located in the usual manner.

Thus, for an 8° simple curve, using $a = 2$, replace a part of the curve with 8° 30′. $o = 9.30$. By (22) and (23), $L_1 = .280$ and $L_2 = 4.488$. L', the spiral for an 8° 30′ curve, is 425 ft. The 8° 30′ curve will compound with the 8° curve at D, (Fig. 1), 28 + 448.8 = 476.8 ft. from B, the original P. C., and will connect with the spiral at a point 448.8 — 212.5 = 236.3 ft. from D. The beginning of the spiral will be at H, 212.5 — 28 = 184.5 ft. from B.

The limiting values of D_2 will be on the one hand $\frac{4}{3} D_3$, and on the other a value which will make L_2 one half of the length of the original curve.

In the field work there will be slight variations in length between the old and new lines, but these differences may easily be divided.

DEGREE OF CURVE.

By Wm. D. Pence, Assistant Professor of Civil Engineering.

Degree of curve may be defined as the angle at the center subtended by 100 ft. at the circumference. Established usage in this country recognizes two conceptions of this definition, viz: (1) the single-chord definition which assumes the 100-ft. unit, called the station, to be measured always on a single chord; and (2) the short-chord definition which assumes the station to be measured on one or more chords, depending on the sharpness of the curvature. To these may be added (3) the arc definition which assumes the distance to be taken on the actual arc, but which for practical reasons has not been applied in its strict sense to railroad curves.

The single-chord definition was evolved from usage which dates from the inauguration of railroad construction in the United States. It is applied by different authorities with varying degrees of strictness according to the importance attached, on the one hand, to accuracy and consistency, and on the other, to simplicity and facility in the several steps of laying out the curve. Those authorities who adopt the more precise interpretation employ corrected sub-chords in establishing fractional stations on sharp curves. The others assume the arc and its chord to be equal, and thus introduce an inconsistency which occasions a discrepancy in the closure of the curve that is distasteful to the careful field engineer.

The natural remedy for this conflict between consistency and economy was first perceived and applied in Western mountain railroad location, where the very sharp curvature required the adoption of simple and rapid methods. This remedy consists in the restriction of the 100-ft. chord to flat curves, and in the use of 50-ft., 25-ft. and 10-ft. chords as the curvature sharpens. The short-chord definition which is derived from this practice by the assignment of limits for the use of the several chord lengths, may be stated as follows:* Degree of curve is the angle at the center subtended by 100 ft. at the circumference measured on a single chord for curves up to 7°, on two 50-ft. chords thence to 14°, on four 25-ft. chords thence to 28°, and on ten 10-ft. chords thence; or in any case on shorter chords without sensible difference.

These definitions will be discussed with reference to (*a*) the radius, (*b*) the excess of arc over chord, and (*c*) sub-chord corrections.

NOMENCLATURE.

Let D = degree of curve, i. e. the angle subtended by a 100-ft. station,

n = ratio of length of assumed unit chord to 100 ft.,

" " its subtended angle to angle D,

m = " angle subtended by any sub-chord c, to angle D,

r_1 = radius of curve due to the use of 100-ft. chords, i. e. $n = 1$,

$r_{.5}$ = " " " " 50- " " " $n = 0.5$,

$r_{.25}$ = " " " " 25- " " " $n = 0.25$,

$r_{.1}$ = " " " " 10- " " " $n = 0.1$,

r_n = " " " " 100n- " "

r_a = " " by the arc definition, i. e. when $n = 0$,

r (approx.) = radius by approximate formula,

d_1 = difference between radius by arc definition and that due to the use of 100-ft. chords,

$d_{.5}$, $d_{.25}$, etc. = differences corresponding to the respective radii,

d (approx.) = difference between radii due to the arc definition and to the approximate formula,

c = any sub-chord subtending the angle $m\,D$,

e = excess of any actual arc over its chord c,

E = excess, per station, of the actual arc over the combined lengths of the unit chords,

s = correction to be applied to the length of any sub-chord c, to preserve the true curvature.

*The first authority to assign definite values to these limits was Wellington, "Economic Theory of Railway Location," New York, 1887, p. 258; also "Manual of Railway Field Work," Engineering News, Vol. XXII., p. 451, (Nov. 9, 1889), and Vol. XXIII., p. 321, (Apr. 5, 1890). The values above adopted are somewhat lower than those proposed by him. They were first suggested by Talbot, "Railway Transition Curves," The Technograph, No. 5, p. 79, (1890-91), and have since been accepted by Carhart, "Field-Book for Civil Engineers," Boston, 1893, p. 32.

THE RADIUS. The circumference of a one-degree curve by the arc definition is exactly 36 000 ft. in length, and the radius is 5 729.58 ft. Since the circumference varies inversely as the degree of curve, and the radius as the circumference, radius and degree of curve are exactly inversely proportional by the arc definition. Hence

$$r_a = \frac{5\ 729.58}{D} \qquad (1)$$

An approximate formula commonly used for the determination of radii is

$$r\ (\text{approx.}) = \frac{5\ 730}{D} \qquad (2)$$

The radii corresponding to the chord definitions are determined by the following expressions, the second forms being particularly advantageous for simple computation:—

$$r_{.1} = \frac{50}{\sin \frac{1}{2} D} = \tfrac{1}{2} \times 100 \times \operatorname{cosec} \tfrac{1}{2} D \qquad (3)$$

$$r_{.5} = \frac{25}{\sin \frac{1}{4} D} = \tfrac{1}{4} \times 100 \times \operatorname{cosec} \tfrac{1}{4} D \qquad (4)$$

$$r_{.25} = \frac{12.5}{\sin \frac{1}{8} D} = \tfrac{1}{8} \times 100 \times \operatorname{cosec} \tfrac{1}{8} D \qquad (5)$$

$$r_{.1} = \frac{5}{\sin \frac{1}{20} D} = \tfrac{1}{20} \times 100 \times \operatorname{cosec} \tfrac{1}{20} D \qquad (6)$$

$$r_{n} = \frac{100\,n}{2 \sin \frac{1}{2} n D} = \tfrac{1}{2} n \times 100 \times \operatorname{cosec} \tfrac{1}{2} n D \qquad (7)$$

Table I. gives a comparison of radii determined by equations (1) and (3). The differences between respective radii are shown numerically in the fourth column of Table I. and graphically in Fig. 1. It is of interest to observe that the excess of r_1 over r_a increases practically in direct ratio with the degree of curve for usual values of the degree. This relation and others of like practical value may be expressed algebraically in the following manner:—

In the sine series, $\sin x = x - \frac{x^3}{6} + \text{etc.}$, placing

TABLE I.—A COMPARISON OF THE LENGTHS OF RADII AND OF ACTUAL ARCS BY THE SINGLE-CHORD AND ARC DEFINITIONS OF DEGREE OF CURVE.

Degree of Curve.	Radius by the Single-Chord Definition.	Radius by the Arc Definition.	Difference between Respective Radii.	Excess of Actual Arc over a 100-ft. Chord.
	Ft.	Ft.	Ft.	Ft.
1	5 729.65	5 729.58	0.07	0.001
2	2 864.93	2 864.79	.14	.005
3	1 910.08	1 909.86	.22	.011
4	1 432.69	1 432.40	.29	.020
5	1 146.28	1 145.92	.36	.032
6	955.366	954.930	.436	.046
7	819.020	818.511	.509	.062
8	716.779	716.197	.582	.081
9	637.275	636.620	.655	.103
10	573.686	572.958	.728	.127
12	478.339	477.465	.874	.183
14	410.275	409.256	1.019	.249
16	359.265	358.099	1.166	.326
18	319.623	318.310	1.313	.412
20	287.939	286.479	1.460	.510
22	262.042	260.435	1.607	.617
24	240.487	238.732	1.755	.735
26	222.271	220.368	1.903	.863
28	206.678	204.628	2.050	1.002
30	193.185	190.986	2.199	1.152
35	166.275	163.702	2.573	1.572
40	146.190	143.240	2.950	2.060
45	130.656	127.324	3.332	2.617
50	118.310	114.592	3.718	3.245
55	108.284	104.174	4.110	3.945
60	100.000	95.493	4.507	4.720
65	93.057	88.147	4.910	5.570
70	87.172	81.851	5.321	6.501
75	82.134	76.394	5.740	7.513
80	77.786	71.620	6.166	8.610
85	74.009	67.407	6.602	9.795
90	70.711	63.662	7.049	11.072
95	67.817	60.311	7.506	12.445
100	65.270	57.296	7.974	13.918
120	57.735	47.746	9.989	20.920
140	53.209	40.926	12.283	30.014
160	50.771	35.810	14.961	41.779
180	50.000	31.831	18.169	57.080

$$x = \frac{\frac{1}{2}\, n\, D}{57.2958},$$

substituting in equation (7), and reducing,

$$r_n = \frac{2\,400\,(57.2958)^3}{24\,(57.2958)^2\, D - n^2\, D^3}$$

and $$d_n = r_n - r_a$$

$$= \frac{5\,729.58\, n^2\, D}{24\,(57.2958)^2 - n^2\, D^2}$$

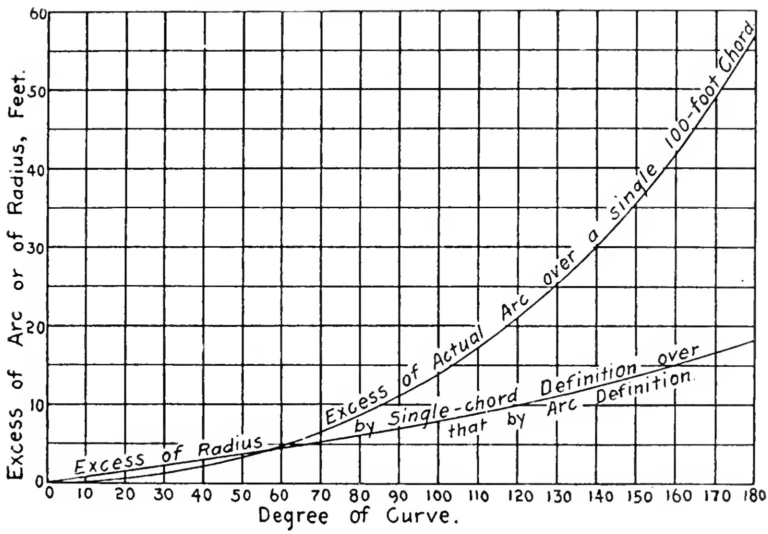


FIG. 1.

Dropping from the denominator the term $n^2\, D^2$, which is relatively small for usual values of D by the single-chord definition, and for all values by the short-chord definition,

$$d_n = 0.0727\, n^2\, D = 0.073\, n^2\, D \text{ (nearly)} \qquad (8)$$

and $$r_n = \frac{5\,729.58}{D} + 0.073\, n^2\, D \qquad (9)$$

Fig. 2 is a graphical representation of equation (8). The curved line, designated "approximate formula," represents the difference between the radius by the arc definition and that by the approximate formula (2). Subtracting equation (1) from (2),

$$d\,(\text{approx.}) = \frac{0.422}{D} \qquad (10)$$

Combining equations (8) and (10), the approximate formula is found to give exact values when $D = \frac{2.41}{n}$. The simultaneous values, shown by the respective intersections in Fig. 2, are 2.41, 4.82, 9.64, and 24.1 degrees for $n = 1$, 0.5, 0.25, and 0.1, respectively.

The limits above adopted for the use of the several unit chords in the short-chord definition are indicated in Fig. 2 by

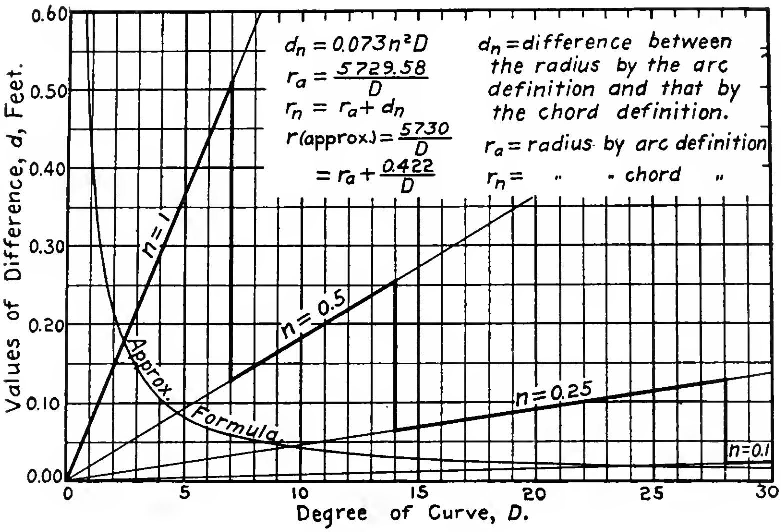


FIG. 2

bold lines. Radii may be determined readily by equation (9), the corrective term being taken from Fig. 2. Results obtained by this method agree very closely with those obtained by trigonometrical means, i. e. by equations (3) to (7) inclusive.

THE EXCESS OF ARC OVER CHORD. Again assuming the arc definition as a basis of comparison, it is evident that if the measurement of the 100-ft. unit be shifted from the actual arc to unit chords, the increase in the length of the actual arc subtending a fixed central angle is merely that due to the increment of the radius. Hence, the excess for any unit arc $n\ D$, subtended by the unit chord $100\ n$ is by equation (8)

$$e = 0.0727\ n^2\ D \times 0.01745\ n\ D$$
$$= 0.00127\ n^3\ D^2 \qquad (11)$$

Equation (11) has a very wide range if n be assumed to represent the number of stations in either the chord or the subtended arc. The coefficient is readily applied by noting that it is practically equal to 1/8 of one per cent. Applying equation (11) to the short-chord definition of degree of curve, the excess of actual arc over the unit chords in one station is

$$E = 0.00127\ n^2\ D^2 \qquad (12)$$

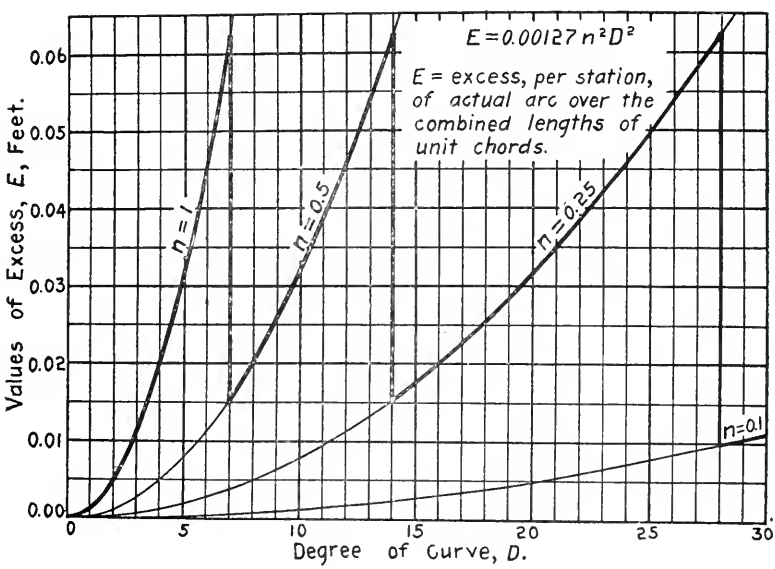


FIG. 3

The excess per station of the actual arc over chord by the single-chord definition, given in Table I. and Fig. 1, was determined trigonometrically. That for the short-chord definition, shown in Fig. 3 by the bold lines, was computed from equation (12) by substituting the several values of n. As seen in the diagram, the values of the ratio are so adjusted with relation to each other that the excess per station does not increase beyond a value slightly more than .06 ft.

SUB-CHORD CORRECTIONS. The length of the actual arc corresponding to the angle mD subtended by the sub-chord c, and having a radius r_n is

$$\text{actual arc } mD = 0.01745\, m\, D\, r_n$$

$$= 0.01745 \left(\frac{5\,729.58}{D} + 0.073\, n^2\, D \right) mD$$

$$= 100\, m + 0.00127\, m\, n^2\, D^2$$

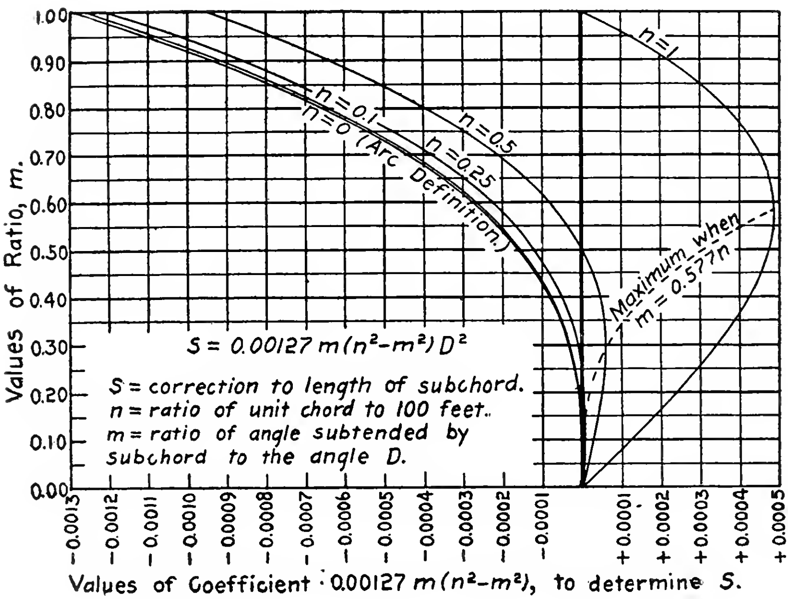


FIG. 4.

Subtracting the excess e of this arc over its chord, as determined by placing $n = m$ in equation (11), the length of the sub-chord subtending the angle $m\,D$ becomes

$$c = 100\, m + 0.00127\, m\, (n^2 - m^2)\, D^2 \tag{13}$$

But 100 m is the value obtained by assuming the chord to be proportional to the angle, so that the sub-chord correction is

$$s = 0.00127\, m(n^2 - m^2)\, D_2 \tag{14}$$

which is a maximum when $m = 0.578\,n$, and becomes negative when $m > n$. When the two ratios are equal, i. e. when $m = n$, $s = 0$. Fig. 4 gives values of the coefficient of D^2 in equation (14). The limiting value, $n = 0$, corresponding to the arc definition of degree of curve, when substituted in equation (14), reduces it to the form of (11) with reversed sign.

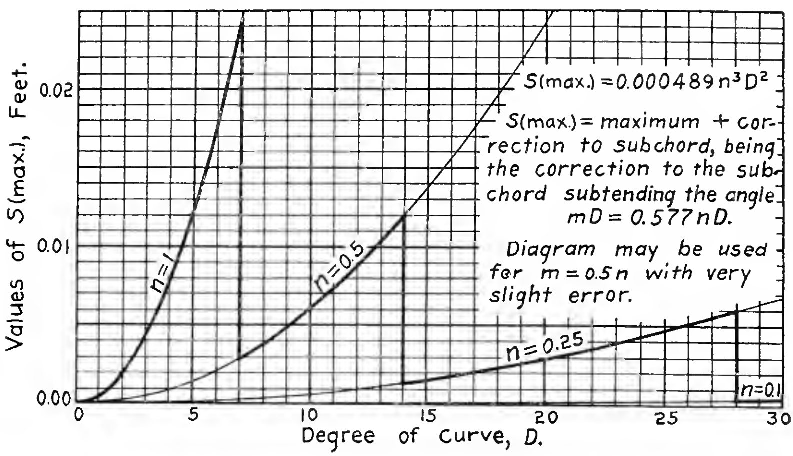


FIG. 5.

Fig. 5 represents the maximum positive value of the sub-chord correction,

$$s\,(\text{max.}) = 0.000489\, n^3\, D^2 \qquad (15)$$

which corresponds very closely to the correction to be applied when $m = 0.5\,n$. However, it may be seen in Fig. 5 that the maximum correction on any sub-chord is within the limits of accuracy usually assumed for laying out curves, so that, as a general rule, sub-chord corrections need not be applied when the short-chord definition is employed.

RELATIVE ECONOMY OF DIFFERENT HEIGHTS AND STYLES OF FREE-HAND LETTERS.

By R. C. Vial, '93, Assistant in General Engineering Drawing.

It is well known by anyone who has done free-hand lettering that different heights and styles of letters require different lengths of time for execution. The writer, not having seen any data on this subject, made a series of experiments to determine the relative time required to form letters of different styles and sizes. These experiments comprised the formation of 1 200 alphabets or over 31 000 free-hand letters. The work is the outgrowth of a paper on free-hand letters read before the Civil Engineers' Club of the University of Illinois. The experiments were undertaken for the writer's personal benefit and satisfaction, and were not originally intended for publication. It is unfortunate that the samples presented herewith were made upon paragon paper, since the waviness of the lines in the reproduction is due to the roughness of the surface of the paper.

The object of the work was to determine the relative economy of letters of different heights and styles. Two styles of letters were used, viz:—inclined small capitals (single stroke Gothic letters) and inclined lower-case letters of "Engineering News" style. In the execution of the work it was desired simply to do fair work combining quantity and quality. In each experiment greater quantity could have been obtained by sacrificing quality, or better quality of less quantity might have been shown. The rate of work was somewhat faster than ordinary office work of similar character. Nothing was permitted to interrupt the work during an experiment. In each case the length of an experiment was one hour, i. e., 60 consecutive minutes, the pen not being laid down between the time of the beginning and the end of each experiment. For uniformity throughout the tests, the letters of each experiment were made in alphabetical order. The number of alphabets per hour, as well as the number for each quarter hour, are tabulated on the next page. Guide lines for

TABLE SHOWING THE NUMBER OF ALPHABETS MADE PER HOUR.

HEIGHT OF LETTERS.			INCLINED, "ENGINEERING NEWS," LOWER CASE.					INCLINED SMALL CAPITALS.				
50ths of an Inch.	16ths of an Inch.	m. m.	First 15 Minutes.	Second 15 Minutes.	Third 15 Minutes.	Fourth 15 Minutes.	Total for 1 Hour.	First 15 Minutes.	Second 15 Minutes.	Third 15 Minutes.	Fourth 15 Minutes.	Total for 1 Hour.
2	......	1	......	......	......	......	93	18	17	18	17	70
3	1	......	......	......	......	......	104	17	18	18	19	72
4	......	2	......	......	......	......	104	16	17	17	18	68
5	2	......	21	24	22	26	93	13	13	13	13	52
6	......	3	20	21	22	26	89*	8	9	8	8	33†
7	......	......	16	18	16	18	68	9	8	9	9	35
8	......	4	14	16	16—	16+	62	8	8	8	8	32
9	3	......	10	12	14	16	53	8	8	8	8	32
10	......	5	12	14	14—	13	53	7	7—	7+	7	28
12½	4	......	......	......	......	......	......	6	6	6+	6+	25

* Work of poor quality.
† Talked during experiment.

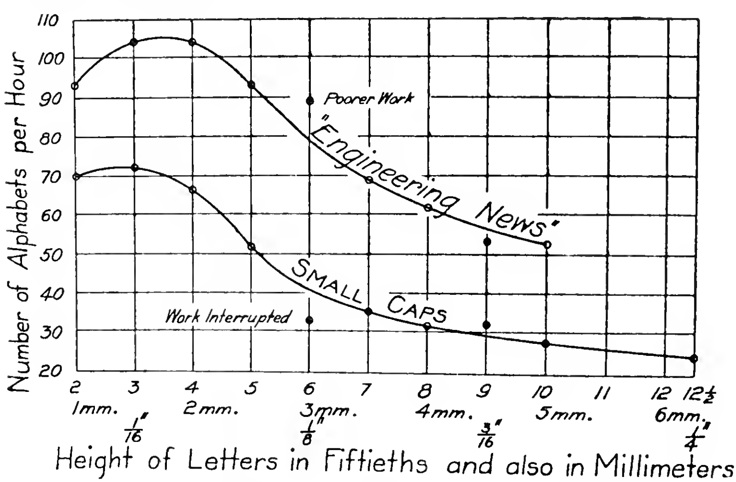
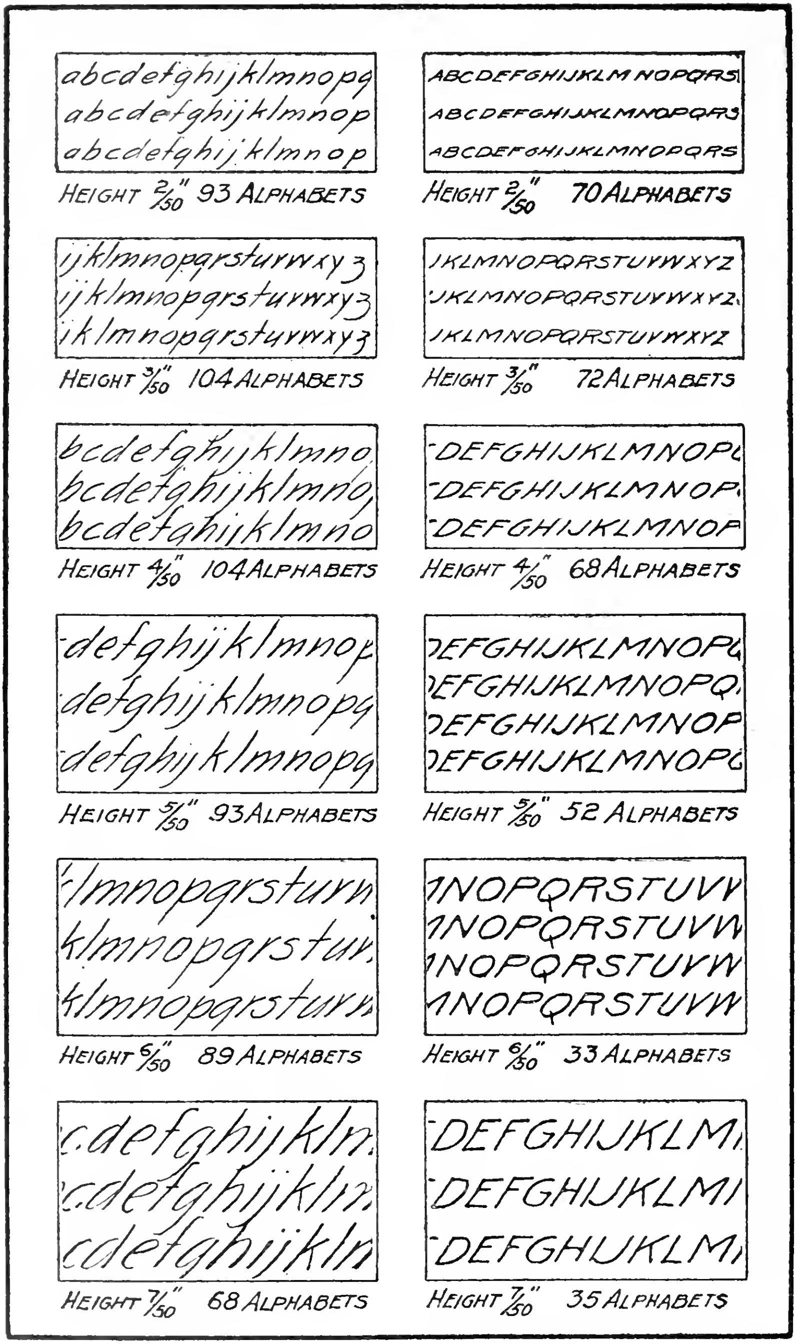


FIG. 1. RELATIVE SPEED OF FORMING DIFFERENT ALPHABETS.

top and bottom of letters were penciled previous to the beginning of an experiment but none of the letters were penciled. With each alphabet the work began with letters $\frac{2}{50}$ in. high, the height being increased $\frac{1}{50}$ in. for each succeeding experiment. A Keuffel and Esser lettering pen was used on the smallest letters. The remainder of the work was done with a Spencerian No. 1. The quality of work was kept as nearly uniform as possible.

The samples on pp. 156 and 157 are reproduced full size, from the original paragon sheets upon which the work was done. The letters have not been retouched nor cleaned but are exactly


HEIGHT 2/50" 93 ALPHABETS
HEIGHT 2/50" 70 ALPHABETS
HEIGHT 3/50" 104 ALPHABETS
HEIGHT 3/50" 72 ALPHABETS
HEIGHT 4/50" 104 ALPHABETS
HEIGHT 4/50" 68 ALPHABETS
HEIGHT 5/50" 93 ALPHABETS
HEIGHT 5/50" 52 ALPHABETS
HEIGHT 6/50" 89 ALPHABETS
HEIGHT 6/50" 33 ALPHABETS
HEIGHT 7/50" 68 ALPHABETS
HEIGHT 7/50" 35 ALPHABETS

fghijklmnop
HEIGHT 8/50" 62 ALPHABETS
GHIJKLMNO
HEIGHT 8/50" 32 ALPHABETS
abcdefghi
HEIGHT 9/50" 53 ALPHABETS
BCDEFGHIJKL
HEIGHT 9/50" 32 ALPHABETS
rstuvwxyz
HEIGHT 10/50" 53 ALPHABETS
RSTUVWXYZ
HEIGHT 10/50" 28 ALPHABETS
ABCDEFGHIJKLMNOP
HEIGHT 1/4" 25 ALPHABETS

as left at the end of the experiments, with the exception of the sample $\frac{7}{50}$ in. high of the "Engineering News" style. This experiment was made with ink not suitable for reproduction and the lines of the sample have been retraced with India ink.

In Fig. 1 the results of the tests are graphically shown. The heights of letters, in fiftieths of an inch with equivalents in sixteenths and in millimeters, are platted as abscissas, and the number of alphabets formed per hour as ordinates. The curves passing through the points thus located show that of the two alphabets used the "Engineering News" style is much the faster; and that in each case the most economical letter for the writer is one about $\frac{3}{50}$ in. high. The difference in speed for the two styles is accounted for by the different number of strokes in each alphabet. In an alphabet of the small capital letters there are about 60 strokes, and in the "Engineering News" alphabet less than 35. In other words it takes about half as many strokes of the pen to form an alphabet of "Engineering News" style as it does to form one of small capitals. In forming a letter the most care is required at the beginning and at the end of each stroke.

Probably no other person would, in a similar set of experiments, get the same results as those here given, nor is it certain that the writer himself could produce exactly the same data a second time. The actual results given apply to him only, but it is believed that the comparative results are farther reaching. It is with the latter point in mind that this paper has been presented.

HEATING AND VENTILATION BY THE HOT BLAST SYSTEM.

By F. H. Green, '96, and T. Weinshenk, '96, School of Mechanical Engineering.

In these days when our public buildings are crowded to their utmost capacity, when the size of our school buildings and the perfection of the workmanship render natural ventilation impossible, artificial ventilation is essential. We find as much attention paid to artificial ventilation and to the general comfort of the occupants of such buildings as is bestowed upon their external appearance.

Air and heat are two necessities of life. How to secure the first in a pure condition and the second most economically, constitutes the problem of heating and ventilation. The problem is complicated by the fact that it is not only necessary to secure pure air in a proper quantity, but that it is equally important to dispose of the foul air.

The various methods of heating and ventilating may be divided into two classes, viz: by gravity, i. e. by the difference between the weight of a column of warm and of cold air; and by mechanical devices. In the first class are: (*a*) the hot air furnace, (*b*) indirect steam or hot water, and (*c*) direct-indirect steam or hot water heating apparatus. The hot air furnace consists substantially of a large stove located usually in the basement and surrounded by an air chamber, with flues leading to the different rooms; a supply of fresh air being furnished to the chamber from the exterior. They are quite expensive in fuel, need frequent repairs, and it is difficult and often impossible to secure a uniform distribution of heat throughout the building.

The distant rooms and those most exposed to winds are the ones to suffer.

In the indirect steam or hot water system, the radiating surface for the different rooms is all located in the basement. The fresh air from outside passes over the coils and is distributed throughout the building in the same manner as from the hot air furnace. It is to some degree open to the same objection as furnaces regarding the distribution of heat.

The steam or hot water direct-indirect system consists of a radiator for each room provided with an independent cold air supply. It is to some extent dependent for its best efficiency on the direction and velocity of the wind. It furnishes good ventilation when the wind is not too strong, otherwise the air supply must be shut off to prevent cold air from entering the room.

The second method, the hot blast system of heating and ventilation, which is now extensively used, represents, perhaps, the most efficient plan yet devised. In large buildings containing large numbers of people, it is undoubtedly superior to all others.

Recognizing the fact that very little data is to be found relating to this system a series of tests were undertaken on a plant erected by the B. F. Sturtevant Co. in the High School building

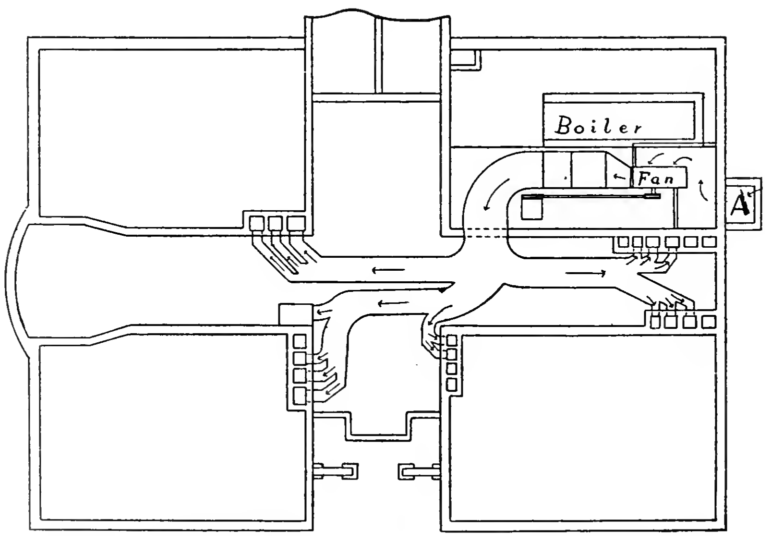


FIG. 1. PLAN SHOWING ARRANGEMENT OF HEATING APPARATUS.

of Champaign, Ill. Fig. 1 gives the basement plan with the arrangement of distributing ducts. The heating plant is located in the southwest corner of the basement and consists of a $4\frac{1}{2} \times 16$ ft. horizontal tubular boiler rated at 55 H. P.; of a 13×7 in. B. F. Sturtevant vertical throttling engine; of a 66×30 in. steel plate fan; of a corrugated sectional base, steel pipe heater, containing 3723 lineal feet of one inch pipe, and of an automatic Standard duplex pump. The steam is carried from the boiler through a 2½ in. pipe to the different sections of the heater. Each section is provided with a valve so that one, or more, can be cut out. The section nearest to the fan is supplied with steam from the exhaust of the engine. The condensation of the heater is carried through a 1½ in. pipe to the receiver from which it is returned to the boiler by means of the pump, while the condensation from the exhaust coil flows to the sewer.

By reference to Fig. 1, the relative positions of the boiler, engine, fan, heater and distributing ducts may be seen. The arrows indicate the direction in which the air is moving. The air is taken from out of doors through the opening A shown on the plan, and is forced by the fan, partly over the heater, and partly through the cold air duct. The latter is located above the hot air duct, and a damper placed in each, These ducts lead to vertical flues in the walls, through which the air is delivered to the rooms. At the bottom of the flue where the ducts enter, a mixing damper is placed which is regulated by a chain in each room. The air enters the room through a register located about eight feet above the floor in an inside wall. The foul air is removed through a register at the floor line on the same side of the room as the hot air register.

Several trials were made, during each of which, a regular boiler and engine test was conducted, and readings of air velocity, and temperature of each room taken at different levels. Table I gives the average results of forty readings for each room on the dates indicated.

TABLE I.—AVERAGE TEMPERATURE OF DIFFERENT ROOMS IN HIGH SCHOOL BUILDING ON CERTAIN DAYS.

ROOM.	Contents in cu. ft.	Exposed Wall in sq. ft.	Glass Surface in sq. ft.	AVERAGE TEMPERATURE ON					
				December 13. 1895.	January 28, '96.	January 29, '96.	January 30, '96.	February 20, '96.	February 21, '96.
1 A	9750	598	187.5	73.1	70	71.2	67.7	73.3	71.1
8 A	9750	507	150	73.7	69.2	72.5	72.	72.2	70.8
8 C	9750	715	295	70.5	68.7	67.2	72	71.2	73.3
Halls.	23424	412	224.6	67.5	67.7	67	67.6	67.4	68.2
Chem. Lab	9750	715	150	69.6	72	73	69.2	67.7	67.7
Nat. H's.	8375	712.5	111.9	71.0	70.0	70.0	72.0	71.6	71.3
Latin.	6562	637.5	149.2	69.3	70.9	67.7	71.2	68.6	71.3
Mathematics.	6562	367.5	111.9	67.3	71.0	70.0	69.9	69	67.4
High School—N.	34688	2216	482	67.2	66.5	67.2	69.9	65.8	71.6
" " —S.	......	......	......	66.2	66.2	67.0	69.0	71.2	71.1

The water actually evaporated, corrected for quality of steam, on December 13th, 1895, the day of our first test, was 6 400.4 lbs. This is equivalent to 6 400.4 (H—h), B. T. U., H and h being respectively the total heat-units in steam of the average observed pressure and in water of the average observed temperature of feed, as obtained from tables of the properties of steam and water. This gives the total number of heat-units delivered by the boiler equal to 6 400.4 × (1 166.6—129) = 6 641 055 B. T. U. Comparing the number of B. T. U. delivered to the heater with the number taken up by the air, we are enabled to determine the efficiency of the heater. The total number of cu. ft. of air delivered by the fan in eight hours was 2 830 464 cu. ft. as measured by a carefully calibrated anemometer. This amount gives 1572 cu. ft. per pupil per hour for 225 pupils, which was the total number of children in school.

In order to determine the number of units of heat given up by the heater to the air, it will be necessary to know the weight of air in pounds passing through the heater during the test: the specific heat of air under constant pressure, and the rise of temperature of the air in passing through the heater. The weight of air passing through the heater during the test may be found from the following formula, deduced from Gay Lussac's Law:—

$$G = \frac{.080744\,V}{1 + .002038\,(t - 32)}$$

In this formula V = volume of air in cu. ft. passing through the heater and t = the temperature of this air.

Substituting the values of V and t obtained from the experiment, in the above formula, we get

$$G = 189\ 641 \text{ lbs.}$$

The rise of temperature of the air in passing through the heater was found to be 100.5° F. From the definition of specific heat, it requires .2375 heat-units to raise one pound of air one degree, then for a rise of 100.5° it will take .2375 × 100.5 for one pound, and for 189 641 lbs. it will require 4 526 733 B. T. U.. The amount of heat lost in wasting the exhaust from the engine and pump was estimated in the following manner: A cold water meter was used to measure the amount of water required to replace the loss from these sources. On the first day it took 28.8 cu. ft of cold water at 60°, to replace the amount wasted at a temperature of 160°. Therefore the loss in B. T. U. is:

$$28.8 \times 62.5 \times (160 - 60) = 180\ 000 \text{ B. T. U.}$$

TABLE II.—DATA SHOWING DISTRIBUTION OF HEAT AND EFFICIENCY OF HEATER.

DATE.	Total coal burned, lbs.	Water evaporated corrected for quality of steam.	Total air delivered in 8 hrs., cu. ft.	Total weight of air passing through heater, lbs.	Cu. ft. of air per hour per pupil.	Temperature of external air. Fahr.	Temperature of hot air. Fahr.	Rise of temperature from external air. Fahr.	BRITISH THERMAL UNITS. Obtained from fuel.	BRITISH THERMAL UNITS. Imparted to air.	BRITISH THERMAL UNITS. Lost in exhaust.	Efficiency of heater.	Lbs. of steam condensed per sq. ft. of heating surface per hour.
December 13	967	6400.4	2 830 464	189 641	1572	22.6°	123.1	100.5	6 640 415.	4 526 733.	180 000.	70.0	0.78
January 28	700	5065	1 913 707	124 390	1701	30.0°	149.0	119.	5 297 990.	3 517 776.	230 100.	70.7	1.00
January 29	800	6326	3 021 481	207 274	1678	39.0°	117.8	78.8	6 755 168.	3 878 089.	368 160.	62.8	0.77
January 30	715	5724	3 526 234	250 362	1959	43.8°	99.3	55.5	6 239 160.	3 289 779.	438 016.	60.	0.70
February 20	1766	12189	3 517 440	221 599	1953	3.5°	169.0	165.5	12 833 798.	8 708 829.	461 760.	70.6	1.40
February 21	1420	10099	3 148 109	210 293	1749	16.2°	134.4	118.2	10 533 257.	5 902 944.	494 208.	60.7	1.20

This loss subtracted from the total number of B. T. U. delivered by the boiler will give very approximately the number of B. T. U. delivered to the heater. The efficiency of the heater will be the ratio of the heat imparted to the air, to that delivered to the heater, which gives

$$\frac{4\,526\,733}{6\,641\,055 - 180\,000} = 70\%$$

The results for the other days were obtained in the same manner and are given in Table II.

The high efficiency of the hot blast system of heating, comes undoubtedly from the bringing of cold air with great rapidity into such intimate contact with the heating surface as is done in the one-inch pipe coils, usually used, and the corresponding rapid conveyance of the absorbed heat by the air to the spaces to be heated. The velocities of air passing over the surface in such heaters vary from 600 to 1800 ft. per min. We thus see that the natural law does not determine the velocity at which air can absorb heat. The ability of this system to heat a building thoroughly and efficiently even in the coldest weather, together with the attention it has received from eminent engineers, places it undoubtedly, in the front rank as a means of heating and ventilating for large buildings.

THE KAMPSVILLE DAM.

BY S. T. MORSE, '96, SCHOOL OF CIVIL ENGINEERING.

Some years ago the United States government undertook the work of constructing a waterway from the Gulf of Mexico to Lake Michigan, such that the largest steamboats might go directly from the Gulf to Chicago. The project involves a large amount of dredging in the Mississippi river, the canalization of the Illinois river and the construction of a ship canal from the Illinois river to Lake Michigan.

In the construction of the canal, the government has been directly aided by the Chicago Sanitary District. The drainage canal is primarily intended to answer the sanitary requirements of Chicago, but all possible measures have been taken in its construction to render it a suitable channel for navigation, on the assumption that the government will eventually construct the necessary link from Lockport to La Salle. It has been estimated that the cost of constructing this canal constitutes nearly two thirds of the cost of the entire improvement.

At times of low water, the shallowness of the Illinois river has prevented navigation. To raise the low water stage, several dams have been constructed; but a large amount of dredging is yet required. From La Salle to the Mississippi, a distance of 225 miles, there is a fall in the river of but 29.6 ft., which gives a slope of 0.132 ft. per mile. Thus a navigable channel could be obtained by the construction of a reasonable number of dams and locks.

Before the government engaged in the work, the State of Illinois had constructed a dam across the river at Henry, and another about midway between Pekin and Havana, at the mouth of Copperas creek. It was found necessary to construct two more dams farther down the river. One was placed at La Grange, 75 miles from the river's mouth, and one at Kampsville, 30 miles from the mouth. The dams greatly decrease the amount of dredging necessary to produce the required depth. In this way the river has been canalized for two thirds of its entire course. Much dredging has been done so that at present there is a channel about four feet in depth up to LaSalle.

LOCATION OF THE KAMPSVILLE DAM. The most favorable site for the location of the dam was found to be one third of a mile below Kampsville, at a point just beyond the beginning of an easy curve in the channel of the river. At this point the river flows nearly south. The lock was placed against the inner or western bank, as shown at *b* in Fig. 1, and the L shaped abutment was put at the eastern bank as shown at *a*. By this arrangement the lock gates are protected from the current carrying drift materials, thus insuring that logs or other large bodies will not lodge against the gates at night and cause delay in their operation. At the same time care was taken not to place the dam so far below the beginning of the curve that the current would be thrown against the abutment and the revetment at the east end of the dam, and so render it difficult to prevent scouring. The dam thus situated backs up the water to the La Grange lock.

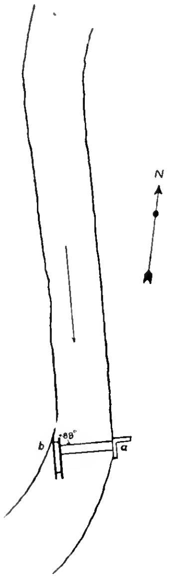


FIG. 1.

DESIGN OF THE DAM. The dams at Kampsville and La Grange are much alike in general appearance; but as the one at Kampsville was built last, it has several minor improvements.

The Kampsville Dam is 1 200 ft. long, and its crest is 7.4 ft. above low water. It is built of sheet piling which is supported by pile bents. On the up stream side of the piling, earth is filled in to the width of 44 feet. This filling is sloped back to the river bed and paved for a width of 20 ft. back from the crest of the dam, as shown in Fig. 2. Stone riprap is filled in between the piles. Two plank aprons are built on the caps of the pile bents. The one next to the crest is 24 ft. in width and has a slope of 11°, which brings its lower edge two feet above low water. The second apron, which is a horizontal one 10 ft. in width, begins here. The sheet piling and the aprons are nailed and driftbolted to a system of horizontal and sloping wales, the arrangement of which is fully shown in Fig. 2. The wales are drift bolted to five rows of 28 ft. piles. The piles are spaced 6 ft. apart in the rows. The first four rows are 7.5 ft. apart, and the fourth and fifth are 9.5 ft. apart.

PLAN OF

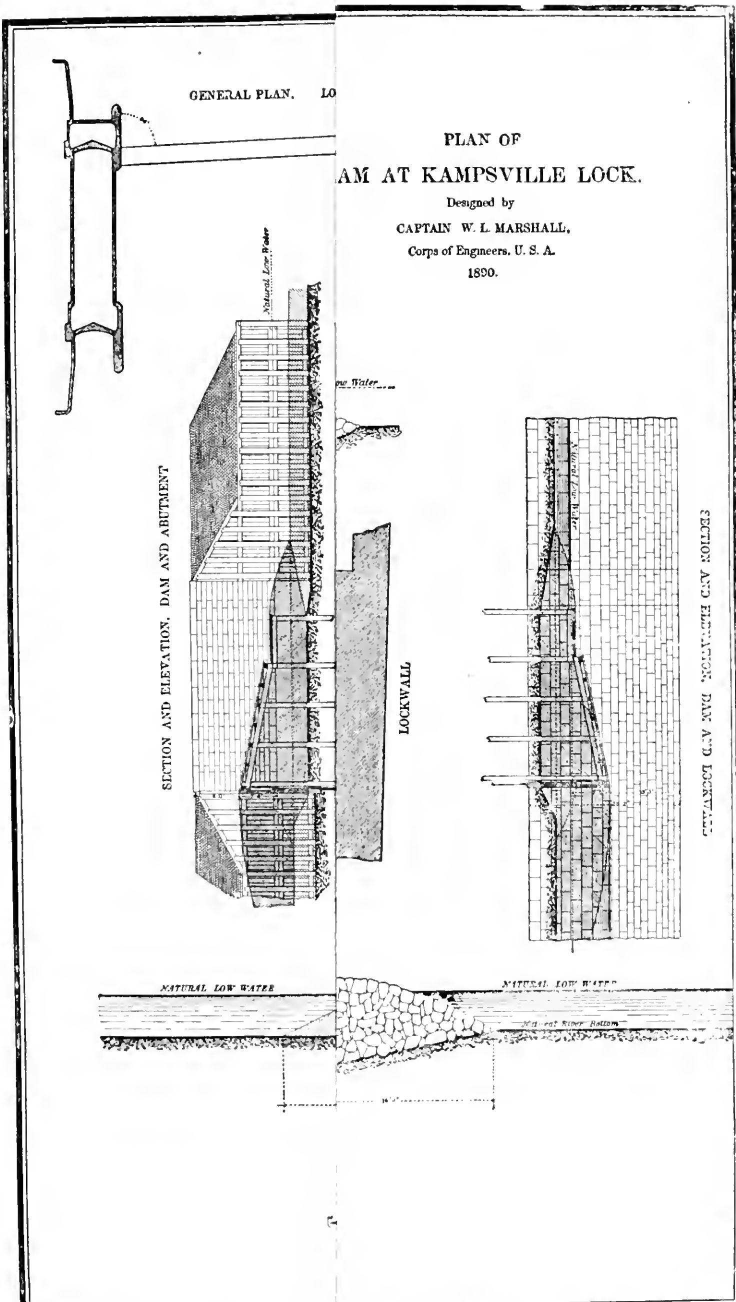
AM AT KAMPSVILLE LOCK.

Designed by

CAPTAIN W. L. MARSHALL,

Corps of Engineers, U. S. A.

1890.



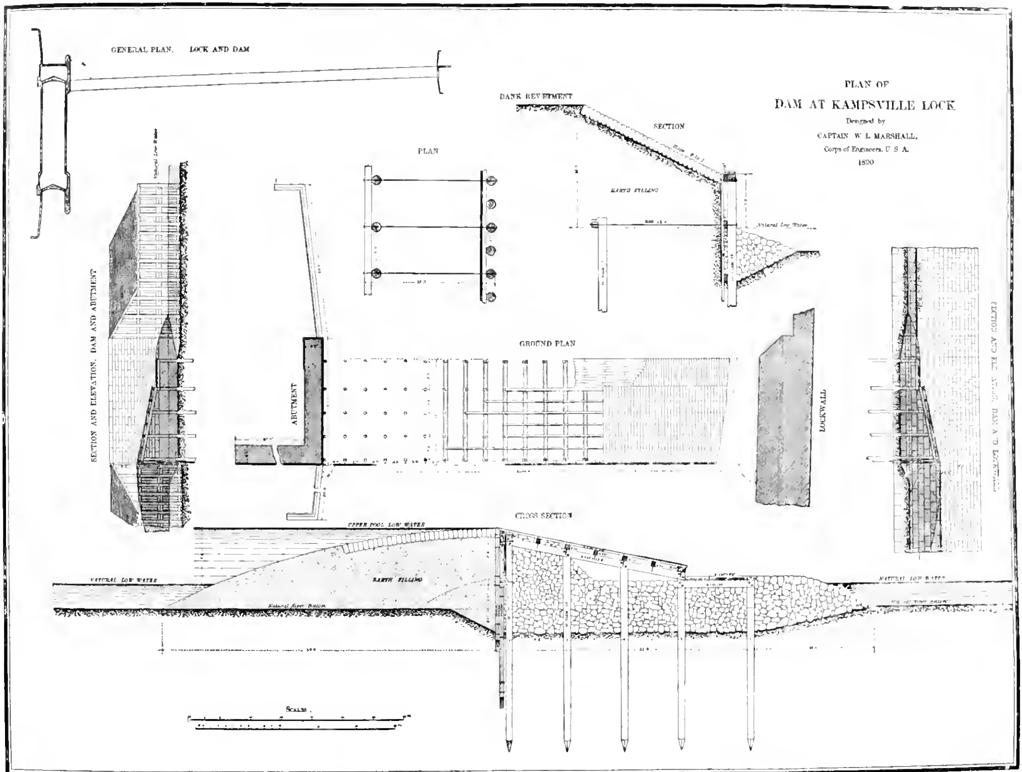


FIG. 2. THE KAMPSVILLE DAM.

From United States Public Works, by Capt. W. M. Black

Reprint by permission of Wiley and Sons.

The abutment at the east end of the dam is 17 ft. high, 6 ft. wide at the top, and 40 ft. long. At the upper end it has a wing which extends back 40 ft. at right angles to the bank.

The chamber of the lock, which is built in connection with the dam, is 350 ft. long and 75 ft. wide. The walls are constructed of ashlar masonry; they are 24 ft. high, 7 ft. wide at the top, and 12 ft. wide at the bottom.

METHOD OF CONSTRUCTION. The site of the dam was dredged to a depth of 3 feet in order to obtain a firm foundation. Round oak piles 28 ft. long were driven from 14 to 18 ft. into the bed of the river. Three drivers were kept constantly at work, and 160 piles were driven in a single day. At first the piles were driven with 3000-pound steam-hammers, but owing to the difficulty of procuring sufficient steam, these were abandoned and 3500-pound drop-hammers substituted. In all, 1 104 piles were driven.

The drivers were placed on barges which, as the work progressed, were secured to the piles already driven. The rows of piles were alined as fast as they were driven and slanting wales bolted to them. Horizontal wales were also bolted on a little below low water mark.

The sheet piling used was the Wakefield triple lap, made of 2 × 12 in. oak planks, 16 ft. long, spiked together so as to give a tongue and groove 2½ in. in depth. It was put together on the ground. This sheeting could be driven to any desired position by properly shaping the points. The driving was done by a 3 500 lb. drop hammer, which gave the best results with a fall of from three to four feet.

In the LaGrange dam, a single row of sheet piling was driven, but as might have been anticipated, the last of it was driven with great difficulty, owing to the increased velocity due to the increase in the head and the contraction of the waterway by the sheeting previously driven. This increased velocity also caused serious scouring of the bed of the dam. In order to avoid this difficulty at Kampsville, two rows of sheeting were driven. The first one was driven to a height of 7.4 ft. below the proposed top of the dam, and spiked to the wales previously placed at this height. The second row was then driven to the full height of the dam, and spiked to two 10 × 10 in. stringers, which were drift-bolted to the top of the first row of piles. As fast as the sheeting was driven, rubble was placed in the crib thus formed, in order to prevent scouring of the bed by the water which flowed over the crest of the dam.

Upon each side of the four rows of piles beneath the upper apron, was drift-bolted an 8 × 8 in. pine stringer 18 ft. long, and in each of the three intervals between the rows, a 6 × 8 in. stringer, 18 ft. long, was drift-bolted to the wales. These timbers were all arranged to break joints, thus giving maximum stiffness. The apron which is made of 4×12 in. planks, 25 ft. long. was placed on these stringers. Oregon fir being comparatively easy to obtain, and having been found very strong and durable, was used for the aprons. In constructing the lower apron, 4 × 12 in. wales extending from the fourth to the fifth rows of piles were drift-bolted to the piles as shown in the cross-section of the dam in Fig. 2. To these wales, 8 × 8 in. stringers 18 ft. long, were drift-bolted, the joints being broken. The 2 × 12 in. apron was spiked to the stringers.

The entire space around the piling was filled with stone which was closely backed around the piles and stringers. In all there were 9 144 cu. yds. of stone thus placed. The bed of the river below the top of the dam was filled with stone to a width of 16 ft. This required 1 404 cu. yds. of stone. It was thought that this filling would not only strengthen the dam, but that it would also aid in preventing the formation of channels beneath the sheet piling. The dam was completed by placing the earth filling in front of the sheet piling. The earth used was dredged from the bed of the river.

Time Required for Construction. Dredging and pile-driving began in October, 1892. This work was continued until January, 1893, during which time the piles for 60 bents were driven, and the waling put on. Owing to the high water, work was suspended until July 30, 1893, when pile driving was resumed. The work was then pushed, and being favored by an extremely low stage of water, was finished in 60 days. The first boat passed through the lock on September 30, 1893.

Cost. A statement of the amount of labor employed, the materials used, and the cost of the structure is given in the following table. The material for the table was taken from the report of Mr. C. V. Brainard, class of '83, University of Illinois, engineer in charge of construction.

COST OF LABOR AND MATERIALS FOR THE KAMPSVILLE DAM.

ITEM.	UNIT.	QUANTITY.	PRICE.	COST.
ABUTMENT.				
LABOR				$2 262.16
MATERIALS, including stones, piles, etc				3 237.26
Total				$5 499.42
DAM.				
LABOR, including subsistence, dredging.				$3 144.66
Earth filling	cu. yd.	3 332	$ 0.17	566.44
Ballasting with rock	"	11 795	0.404	4 761.30
Framing lumber	1 000 ft. B. M.	313 212	13.22	4 040.96
Driving piles—round		1 104	1.54	1 704.62
" " —sheet.		2 600	0.482	1 253.58
Making piles—sheet.	1 000 ft. B. M.	235 463 2 600	1.83 0.166	432.00
Transferring coal and ice				81.25
Care and repair of plant				203.74
Care of buildings and grounds				105.58
Total				$16 395.53
MATERIAL.				
Coal				1 276.72
Oil				127.64
Piles		1 391	3.05	4 128.47
Lumber				
Oak for sheet piles	1 000 ft. B. M.	302 136		9 482.93
Pine for stringers, etc	" "	74 891		1 408.14
Oregon fir for decking	" "	171 648		4 377.02
For bakery				53.06
Rubble	cu. yd.	11 795		10 615.50
Iron, bolts, etc				1 050.82
10 dump cars		10		810.00
Total.				$34 178.11
Total cost per round pile			4.59	
Total cost per sheet pile			3.66	
Total cost of abutment and dam				$56 071.06

DURABILITY. Although wood enters prominently into the construction of the dam, it can never decay, as it is constantly submerged. The greatest, and almost the only, danger lies in the fact that the water may undermine the structure. The possibility of this was shown during the summer of 1895, when the water passed beneath the sheet piling near the east abutment and washed out a considerable amount of rock filling. A portion of the decking was removed and several car loads of rubble were dumped into the cavity. No further trouble has been experienced. With the exception of this breach, the dam has stood perfectly for two years. The design of the dam is to be recommended for its comparative cheapness and ease of construction, and its probable durability under conditions similar to those at Kampville.

During the removal of the apron for repairing the leak above mentioned, an interesting fact was developed. It was expected that considerable difficulty would be found in starting the first plank, on account of swelled wood, but it was found that the plank had not swelled, and on sawing and cutting the wood, (Oregon fir) it was observed to be as dry as when placed in the work, although it had been in the water for two years.

ACCURATE CHAINING IN CITY SURVEYING.

By L. E. Fischer, '98, School of Civil Engineering.

The lines of work most generally met with in city surveying are street and property improvement, lot surveying, and subdividing. In all of these, chaining is a very important factor, much of the accuracy of the survey depending upon it. In locating the boundary lines of a lot valued at several hundred dollars per front foot, it would be inconsistant to use a Gunter's chain.

Rigid short rods, resting horizontally upon supports, have often been used with good results in determining the lengths of base lines, but these could not be used in cities unless the surveyor had the privilege of closing the streets while measuring across them. Another method of chaining, frequently used on base lines, is that of measuring with a steel tape of from one hundred to three hundred or more feet in length. Good results will be obtained by using a spring balance to regulate the tension, applying the ends of the tape to stakes set directly on the line, finding the elevation of these stakes, taking the temperature reading, then applying the necessary corrections. It is very evident, however, that no such laborious method could be used in the midst of the traffic, and in the slush, of large cities. A method of chaining that is precise and rapid, and avoids the slush is essential. Chaining with a fifty-foot etched steel tape, held horizontally, the ends being transferred to the ground by means of plumb-bobs, is undoubtedly the best method.

In this method of chaining, the rear chainman holds the string of his plumb-bob on the fifty-foot mark, then steadying the tape as much as possible by resting or drawing his forearm tightly against some portion of his body, he allows the point of his plumb-bob to hang precisely over the point previously fixed by the front chainman, or over the starting point. When in this position and the tape is steady, he calls out "right." The front chainman, after having taken the line given him by the rear chainman, clears away any obstruction at the point to be marked, determines the horizontal position of the tape, and then holds the string of his bob tightly against the end of it. He must also brace himself in some way, for by the unequal pulling of the chainman the tape is very apt to sway. At the signal of the rear chainman, the fore chainman lowers his plumb-bob quickly so as to make a slight indentation in the ground or a mark on the pavement, the case may be. If it can be done a pin is stuck at this point, making an angle of about forty-five degrees with the surface of the ground, and at right angles to the line of measurement. The pin is thus stuck to allow the rear chainman to hold the point of his plumb-bob over the exact point. The tape can be accurately leveled by a third man standing opposite the middle point of it.

When there are no obstructions and the slope is sufficiently great to allow one end of the tape to be held on the ground while plumbing at the other, it should be so held, since the tape is then more steady.

The sag of the tape requires careful attention. There are formulas for the correction of errors due to sag, but owing to the difficulty of applying them they are not extensively used. If a tape be compared with the standard by the chainmen who work together, with the same tension and consequently the same sag used in their regular chaining, sag will not materially affect the result. Unless a spring balance is used the same tension can not be had at each application, but two chainmen will soon find that there is a certain pull at which the tape is easily steadied and will therefore tend toward a constant tension. However when the sag is suddenly eliminated, as by holding both ends of the tape down on a plane surface, an error will be introduced. Wind will of course tend to increase the sag, but as the tension or pull required to steady a tape on a windy day is greater, this tendency will be overcome. On very windy days it is useless to try to obtain good results as the plumb-bobs will not hang still. When the curb stone is free from obstructions, it is well to measure alongside of it, as the error due to alignment will then be slight. However it is not deemed advisable to measure directly on the curb stone when it is level, for then the sag will be eliminated, thus introducing an error.

The usual correction for expansion and contraction due to temperature, is necessary in this as in all other methods of accurate chaining.

To have skilled field hands or chainmen is of the utmost importance. "Common every day chain stretchers" will not answer. Men who have been trained to the quick and accurate use of the plumb-bob are required. Three or four weeks may easily be spent in becoming proficient in this work. The advantages of this method over that of measuring directly on the ground and applying a correction for the slope is very evident when the difficulty of accurately determining the rise and fall of the ground is considered. With a tape of standard length, two good chainmen, and fair conditions of temperature, the degree of accuracy attainable in this way is very high. The only just causes for error are: the effects of temperature which may easily be eliminated by a correction for the expansion of steel, and the error due to sag which is difficult to eliminate but easily reduced to a minimum by good chainmen. The accuracy of this method of chaining thus depends wholly on the chainmen. In work on which the writer has been engaged, two measurements of a line one thousand feet long were made in this manner, with an error of a quarter of an inch, which is an error of 1 in 48 000.

A DESCRIPTIVE INDEX OF SOME TYPICAL ELECTRIC LIGHT AND POWER CENTRAL STATIONS, AND ISOLATED PLANTS.

By Wm. Esty, Assistant Professor of Electrical Engineering.

Some wise man once said that the next best thing to knowledge is the ability to find it. The object of the writer in preparing this index was primarily to aid his senior electrical engineering students in finding descriptions of typical electric plants. to be used as guides in the design of similar plants. A full course in the design and installation of light and power plants forms an important feature of the work in electrical engineering at the University of Illinois. To carry out this instruction in an ideal way, would require a number of visits by students and teacher to various plants where careful study could be made of local conditious, and of the good and bad features of the installations. When however, frequent trips are not possible, the next best thing is the critical study and examination of the plans and equipment of various types of stations as published in the journals. This information, unfortunately, is widely scattered, how widely, the writer never fully realized until the task of hunting it up and running it down, confronted him. Some help, to be sure, was obtained from existing indexes, but the greater part of the articles had to be painfully searched for, one by one, among the indexes of the individual volumes of the journals consulted. If more care was given to the compilation of the indexes of this latter class, a great deal of time and annoyance could be saved those who consult them.

It may not, perhaps, be out of place to give below a list of published indexes, which are of great value to the engineer.

A Descriptive Index of Current Engineering Literature, Vol. I, '84-'91, published by the Association of Engineering Societies, J. C. Trautwine, Jr., Secy., 419 Locust St., Philadelphia, Pa., 475 pp., of which 40-50 pp. are devoted to electrical topics. $2.50.

Vol. II, '92 to '96, of the above Index, published by the Engineering Magazine, Times Building, New York City, contains the Index material which has appeared in the monthly numbers of the Journal of the Association of Engineering Societies during the past four years, 400 pp. $4.00.

The Engineering Index with descriptive notes published monthly in the Engineering Magazine. Price of the Magazine, $3.00 per year.

Synopsis of Current Electrical Literature for 1895, Max Osterberg. Published by D. Van Nostrand Co., 23 Murray St., New York City, 143 pp. $1.00. Contains the synopses which appeared monthly during 1895 in Electric Power.

Digest of Current Technical Electrical Literature by Carl Hering. Appears weekly in the Electrical World, 253 Broadway, New York City. Electrical World $3.00 per annum.

Index to Engineering Periodicals, F. E. Galloupe, published by Engineering News Pub. Co., New York City. Vol. I, 1883-87, 599 pp., Vol II, 1888-92, 396 pp.

No attempt has been made to make the Index which follows exhaustive, as it dates back only to 1889 and only such journals as were readily accessible have been consulted. The list of stations chosen is not intended to include only the best or the most important examples of design, but is rather a collection of stations representing American and foreign practice, good, bad, and indifferent.

ABBREVIATIONS USED.

E. E.—Electrical Engineer, N. Y.

L. E. E.—Electrical Engineer, London.

E. R.—Electrical Review, N Y.

L. E. R.—Electrical Review, London.

St. Ry. Jour.—Street Railway Journal, N. Y.

E. T. Z. — Electrotechnische Zeitschrift, Berlin.

E. W.—Electrical World, N. Y.

W. E.—Western Electrician, Chicago.

L. E.—Electrician, London.

St. Ry. Gaz.—Street Railway Gazette.

St. Ry. Rev.—Street Railway Review.

CENTRAL STATIONS.

*WEST END RAILWAY POWER PLANT IN BOSTON. 2pp. Description of the temporary station and the one then building. The largest units then available were 1000-H. P. triple engines (Allis-Corliss) belted to 4 T-H 200 KW. 4-pole generators. 13 of these units were installed in their new station taking the place of 300 H. P. McIntosh and Seymour 300 H. P. engines driving 3 T-H "D" 62 K.W. machines. Details. E. W. 15:44,114, Jan. 18, Feb. 15, '90.

*WEYMOUTH, MASS., ELECTRIC LIGHT STATION. ⅔ pp. Cut of interior and brief description of equipment, circuits, etc. Station is 75 × 40 ft. and two stories high. 1 Ide compound, condensing 13 × 22 × 18 in., 1 Ide single 10 × 14 in. engines. 3 LD T-H 50-1200 c. p. arc light dynamos. 2 T-H 650 light alternators. Plant supplies 52 arc lamps, 169 series incandescent 32 c. p. lamps. E. W. 13:177, Mar. 8, '90.

*NEW STATION OF THE SALEM, MASS., ELECTRIC LIGHTING CO. 2 pp. Sectional elevation, plan, and views of two floors. Engines: Two 350 H. P. double tandem compound condensing McIntosh and Seymour; one 150 H. P. Fitchburg. These engines drive by countershafting, clutches, etc., 4-30-light T-H 2000 c. p. arc dynamos, 2-400 light incandescent dynamos, 2-650 light T-H alternators, and 1-1300 light T-H alternator. E. W. 15:191, Mar. 15, '90.

*STATION OF MUNICIPAL ELECTRIC LIGHT CO., BROOKLYN, N. Y. 1 p. Building 75 × 80 ft., two stories. 1st floor, engines, boilers, coal; 2d floor, dynamos, which are driven from an overhead main shaft, to which the belts pass from the engines below through the floor. E. W. 15:221, Mar. 29, '90.

*NATICK, MASS., ELECTRIC LIGHT STATION. 2 pp. Some novel features are described and illustrated. E. E. 10:127, Aug. 6, '90.

*NEW UPTOWN STATIONS OF THE EDISON ILLUMINATING CO., New York. Gives details of building and arrangement of steam and electrical apparatus. E. W. Jan. 19, '89.

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*Illustrated.

*THE LARGEST ARC LIGHTING STATION IN THE WORLD. A full description of the central station of the Municipal Elec. L. and P. Co., of St. Louis, together with details of the organization and method of conducting the business. Contains many features of interest. 5 pp. E. W. 17:4, Jan. 3,' 91.

*NEW ELECTRIC LIGHT AND POWER STATION AT LOWELL, MASS. A. C. Shaw. 3 pp. Arc and incandescent lighting and railway service. T-H apparatus. Total output 3000 H. P. Gives section of engine and dynamo room and plan of whole station with dimensions from plans of the designer, H. C. Patterson of the Thomson-Houston Co. E. E. 11:39, Jan. 14, '91.

*NEW STATION OF THE CLINTON, MASS., GAS LIGHT CO. A. C. Shaw. 2pp. Employs the Evans friction system of driving. Gives plan and sectional elevation of station with dimensions, and cut of switchboard from plans of the designers, the Wright Elec. Eng. Co. of Boston. Both arc and incandescent lighting is furnished, the dynamos being T-H and Schuyler. E. E. 11:568, May 20, '91.

*THE BUFFALO ELECTRIC RAILWAY. LARGEST DEVELOPED TYPE OF ELECTRIC ST. RY. PRACTICE. C. J. Field. 6pp. Gives map of route, plans, elevations, etc., with full dimensions. Equipment includes 6 units. Ball engines 250 H. P. each, direct belted to Edison 225 H. P. dynamos. Underground conduit system described. Contains many valuable hints. E. E. 11:99, Jan. 28, '91.

*ELECTRIC LIGHTING IN COLUMBUS, O. 1p. Brief description of plant of Columbus Electric Light and Power Co. The Company supplies 800 arc (T-H) lamps for street, and 400 for commercial lighting, and 1160 incandescent lamps. T-H dynamos are used, and are direct belted in pairs to 100 H. P. engines. E. W. 17:70, Jan. 31, '91.

*NEW HAMPSHIRE LIGHT AND POWER STATION. 2pp. A description of the combined water and steam power plant of the Dover (N. H.) Electric Light and Power Co. Power is supplied by a 500 H. P. turbine, and two McIntosh and Seymour 250 H. P. engines, the latter being used when the water

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*Illustrated.

supply falls off, or on account of repairs. A cut and end elevation of the power house are shown. The installation presents several interesting features. E. W. 17:90, Feb. 7, '91.

*A MODEL PLANT. 2pp. NARRAGANSETT ELECTRIC LIGHTING CO., PROVIDENCE, R. I. A description of the large station and its equipment. Output 1450 arc lamps, and 10500 incandescents. Allis engines, 500, 1500 H. P., 35 T-H arc dynamos, and 5 Westinghouse alternators. E. W. 17:126, Feb. 21, '91.

*THE ELECTRIC LIGHTING OF ST. BRIEUX, FRANCE, 1p. A description of the installation taken from the London Elec. Rev. Power is developed at a waterfall at Ponts Neufs, 13 km. away, by two 150 H. P. turbines running at 250 r. p. m. These drive 2 T-H 70 KW. alternators giving an E. M. F. of 2100-2600 volts, in order that the voltage shall be 2100 at St. Brieux. Gives diagram of connections at the St. Brieux station, and details of method of connecting alternators in parallel by the use of reactive coils. E. W. 17:359, Mar. 16, '91.

*ELECTRIC LIGHTING PLANT AT GARDNER, MASS. ⅔ p. Gives brief description of station, its arrangement and equipment, including a cut of dynamo room, showing belting, switchboard, etc. Dynamos include 2 T-H 50 light 1200 c. p. arc machines, and 2 T-H 650-light alternators. E. W. 17:303, Apr. 25, '91.

*LARGEST ELECTRIC POWER STATION IN THE WORLD. 4pp. Description of work on West End Ry. Station, Boston. E. E. Oct. 15, '90. (See next reference).

*CENTRAL POWER STATION OF THE WEST END STREET RY. CO. OF BOSTON. 19 pp. A. C. Shaw. Very complete. Detailed dimensional drawings of plant and machinery. E. E. 12:443, Oct. 23, '91.

*CENTRAL STATIONS OPERATED BY WATER POWER. 1 pp. G. A. Redman. A paper read before the Nat. Elec. Light Assoc. at Montreal, Sept. 10, '91. Describes plant at Rochester, N. Y. Gives valuable information and suggestions. E. E. 12:300, Sept. 16, '91.

*Illustrated.

*NEW STATION OF THE BROOKLINE GAS LIGHT CO. 2 pp. Robert Amory. Abstract of a paper read before the New England Ass'n. of Gas Eng's., Feb. 38, '92. Plan and sectional views. E. E. 13:284, Mar. 16, '92.

*ELECTRIC LIGHTING AT TOPEKA, KANSAS. A description of this plant, which is owned by the city. Gives cost of operating. Trans. A. S. C. E., Vol. XXVI., Apr. '92, pp. 427-32. Discussion, pp. 430-8. Abstract in Eng. News, June 16, '92.

*EAST CLEVELAND ELECTRIC RAILWAY. Descrip- of plant. St. Ry. Jour., Apr. 92, pp. 200-4.

*THE SPRINGFIELD, ILL., ELECTRIC LIGHT AND STEAM DISTRIBUTION PLANT. 5 pp. L. W. Collins. Gives full description of station and equipment. Details of Holly system of steam heating by exhaust steam from engines, with full page plan (dimensioned) of steam distribution connections. E. E. 15:327, Apr. 5, '93. (See also brief description (2 pp.) of same plant by W. F. Collins in E. E. 13:545, June 1,'92).

*POWER HOUSE OF THE NEVERSINK MOUNTAIN ELECTRIC ROAD. 2 pp. H. S. Hering and W. S. Aldrich. Forms Part II. of a long serial on a test of the above road. Detailed description of the turbine and dynamo plant, with plan and elevation, dimensioned. E. W. 19:379, June 4, '92.

*ELECTRIC RAILWAYS OF MILWAUKEE, WIS. Description of the electric railway system of Milwaukee, the power plant, etc. St. Ry. Rev., July '92, pp. 351-6.

*NEW STATION OF THE EDISON ELECTRIC ILLUMINATING CO. OF BOSTON. 16 pp. A. C. Shaw. Very full and detailed description of the entire plant. Gives detailed dimensioned drawings of sections, elevation, plans, etc.; also details of steam fitting, switchboard, etc. E. E. 14:119, Aug. 10,'92.

*THE ELECTRIC STREET RAILWAY SYSTEM OF LITTLE ROCK, ARK. 5 pp. Full and detailed description, giving plans, elevations, cuts, etc. The station was designed by B. J. Arnold of Chicago, and admirably illustrates the adapti-

*Illustrated.

bility of engineering skill to peculiar local conditions. W. E. 11:97, Aug. 20, '92; also E. E. 14:203, Aug. 31, '92.

*CENTRAL STATION OF THE CONCORD GAS LIGHT CO., AT CONCORD, N. H. 1½ pp. A. C. Shaw. A Reynolds Corliss 18 × 42 in. engine drives, by countershaft, the following dynamos: 3-50 light T-H arc machines for public lighting, 3 ditto for commercial lighting, and 1–1350 light T-H alternator. The use of L. P. and D. transmitters reduce the floor space occupied very greatly. E. E. 14:169, Aug. 24, '92.

*NEW STATION OF THE LOWELL AND SUBURBAN ST. RAILWAY CO., LOWELL, MASS. 4 pp. A. C. Shaw. 3–500 H. P. units installed. Each unit consists of 1 Cooper-Corliss 500 H. P. engine driving by direct belting 2-200 KW. T-H 4-pole ry. generators. Gives plans, elevations, etc. E. E. 14:345, Oct. 12, '92.

*NEW POWER HOUSE OF THE CENTRAL ELECTRIC RY. CO., BALTIMORE, MD. 1 p. H. K. McCay. Gives plan and elevation of station (dimensioned). 3 compound McIntosh and Seymour 240 H. P. engines each direct belted to 3 T-H multipolar ry. generators. E. E. 14:432, Nov. 2, '92.

*NEW PLANT OF BIDDEFORD AND SACO, ME., RY. CO. 4 pp. A. C. Shaw. Designed by W. L. Church. 2 Westinghouse comp. non-condensing 130 H. P. engines, each direct belted to 1 T-H 4-pole 90 KW. ry. generator, thus giving two units; these are placed obliquely to the walls of the station to save floor space. Plan and section of station given, also results of tests made by the Mass. Elec. Eng. Co. of Boston. Total rated capacity of plant is: boilers, 200 H. P. at 100 lbs. steam pressure; engines 260 H. P.; generators, 240 H. P., thus giving ratios of 80:104:96. Full description. St. Ry. Jour. Dec. '92, p. 760. E. E. 14:494, Nov. 23, '92.

*THE LIGHTING OF WASHINGTON PARK, CHICAGO, ILL. 3 pp. F. A. Scheffler. Description of plant, wiring, details of lamp post switches, man-holes, etc. Plant consists of 3-110 H. P. Frazer and Chalmers Corliss non-cond. comp. engines belted direct from 6-10 in. pulleys to 6 Brush 50 arc light (2000 c. p.) dynamos. There are 29 miles cable (No. 5) lead

*Illustrated.

covered, and laid in underground conduits. E. E. 14: 513, Nov. 30, '92.

*ELEVATED RAILWAY, THE LAKE ROLAND, BALTIMORE, MD. 5 pp. A. V. Abbott. Full description of station, line, etc., with section, elevation, plans, etc. 2 Corliss tandem comp. $20 \times 36 \times 60$ in. engines drive by countershaft and clutches 4 T-H 4-pole 400 KW. ry. generators. 2-150 H. P. Ball engines drive by direct belting Edison No. 32 dynamos. E. E. 14:549. Dec. 7, '92.

*CHICAGO CITY RY. CO. Description of entire plant. Use Mohr tubular boilers and Wheelock engines. Boilers provided with mechanical stokers. Ropes will be used instead of belts. St. Ry. Jour. Dec. '92, p. 723.

*POWER STATION OF THE NEW HAVEN AND WEST HAVEN ST. RY., NEW HAVEN, CT. 6 pp. A. C. Shaw. Full description, with section, plan, and view. This is the first power station in the U. S. to use direct coupled slow speed dynamos throughout. Ultimate capacity is 1000 H. P. Present equipment:—3 Manning 150 H. P. boilers furnished with mechanical draft by blower run by a 5 H. P. Westinghouse engine. 3 Westinghouse comp. 160 H. P. engines direct coupled to 160 H. P. Westinghouse multipolar ry. generators. Each unit called a "Kodak" occupies a floor space of only $6' \times 16'\ 4''$. Entire plant area is less than 5 sq. ft. per electrical H. P. E. E. 15:111, Feb. 1, '93.

*THE ELECTRICAL SIDE OF ST. LOUIS, MO. A description of the stations of the following Cos. St. Louis and Suburban Ry., Lindell Electric Ry., Benton and Bellefontaine Ry., Southern Ry., Missouri Electric Ry., Union Depot Ry., Cass Av. and Fair Ground Ry., Mo. Electric Light and Power Co., Municipal Arc Light and Power Co. Numerous illustrations of exteriors and interiors. E. W. 21:99,119,135, 151. Feb. 11, 18, 25, Mar. 4, 1893.

LIVERPOOL, ENG., ELEVATED ELECTRIC RY. 4 pp. H. Scholey. Details of construction and full description. 4 horizontal comp. engines each of 400 H. P. drive by ropes 4 El-

*Illustrated.

well-Parker shunt-wound 238 KW. 500 volt bipolar dynamos. Total cost including equipment about $425 000 per mile. E. E. 15:165, Feb. 15, '93.

*ELECTRIC TRACTION IN THE CITY OF PHILADELPHIA. 2 pp. R. L. Warner. Gives description of station and equipment with plan, section, etc. 3 Corliss engines 250 H. P. each belted direct to 250 H. P. Westinghouse 4-pole generators. 36 in. idlers set beneath belts near dynamos to prevent flapping of belts. E.E. 15: 286, Mar. 22, '93.

*MUNICIPAL ELECTRIC PLANT IN BERNE, SWITZERLAND. 1 p. 3 Turbines, (120 H. P.), 3 Oerlikon 6-pole 84 KW. 120-volt dynamos, belt driven. 144 Tudor accumulators (690 amp. hours). Gives diagram battery connections. Capacity of plant 3000 16 c. p. lamps. E. W. 21: 275. Apr. 15, '93.

*THE FIRST ELECTRIC RY. IN NEW ORLEANS. 5 pp. A. L. Johnston. Gives map of route, details of track, car barn, work-shops, cars, etc. Describes equipment fully. 3 Corliss comp. tandem cond. engines each of 300 H. P. belted by 34 in. double belts to 5½ in. line shaft, with clutches, etc. 3 G. E. 4-pole 200 KW. dynamos at 425 r. p. m. belted by 22 in. belts to line shaft. E. E. 15:381,406, Apr. 19, 26, '93.

*THE COLOGNE, GERMANY, MUNICIPAL LIGHTING STATION. 4 pp. C. P. Feldmann. Full description of station and equipment. Diagrams of mains, current distribution in mains, and scale of rebates to consumers. Detailed description of the switches used for connecting the alternators in parallel. In August '92 there were 13000-16 c. p. lamps connected. Total cost plant $465 000. E. W. 21:5,30, Jan. 7, 14, '93.

*ELECTRIC PORTAGE BETWEEN LAKES ONTARIO AND ERIE. 8 pp. T. C. Martin. Full description of the combination water and steam power plant. Gives profile of road, plan of power house, (100 × 62 ft). E. E. 16:121, Aug. 9, '93.

*INTRAMURAL ELECTRIC ELEVATED RY. AT THE WORLD'S FAIR, CHICAGO. 3 pp. Description of power house and equipment, with details of the G. E. big 1500 KW. gen-

*Illustrated.

erator. E. E. 16:221, Sept. 6, '93. Eng. News, Sept. 7, '93, pp. 190-1. See also another article in St. Ry. Jour., Sept. '93.

*CITIZENS' ST. RY. OF MUNCIE, IND., WITH NATURAL GAS AS FUEL. 2 pp. L. W. Collins. Station 62½′ × 125′, 2 stories high. 2-150 H. P. Ideal engines each belted direct to a 100 KW. T-H ry. generator. Additional room for 2-200 H. P. dynamos, and 2-300 H. P. engines, and 2 more boilers. Gives plan of pumping plant with description. E. E. 15:623, June 28, '93.

*ECONOMY IN SMALL CENTRAL STATION LIGHTING. TRANSFORMERS ON A 3-WIRE SYSTEM. 1 p. Describes the equipment of the station at Petersboro, N. H. using transformers on a 3 wire system, giving connections. A Rodney-Hunt turbine 4 miles from centre of distribution runs a G. E. 2000 volt alternator. Secondaries of transformers have 104 volts each side. Valuable hints given. E. E. 16: 424, Nov. 15, '93.

EASTERN POWER STATION OF THE BROOKLYN CITY R. R. Description of the plant designed by F. S. Pearsontaken from the St. Ry. Jour. 6 Allis-Corliss cross comp. engine s each of 2000 H. P. direct connected to 6-1500 KW. G. E. multipolar ry. generators, the same type as was used in the Intramural power station at Chicago. Condensed description of equipment. E. E. 16: 490, Dec. 6, '93. St. Ry. Jour. Dec. '93.

*ELECTRIC RAILWAYS OF SAN FRANCISCO AND NEIGHBORING TOWNS. Short description of plants of different roads. St. Ry. Jour. June '93, et seq.

*POWER STATION OF ATLANTIC AVE., BROOKLYN, ELECTRIC RAILWAY. Use Babcock and Wilcox boiler, and comp. cond. Corliss engine. Condenser worked by small Corliss engine. St. Ry. Jour., May '93, p. 275.

*THE JERSEY CITY AND BERGEN ELECTRIC RAILWAY. Description of the plant. Uses water-tube boilers and cross comp. high speed engines. St. Ry. Jour., Dec. '92, p. 720.

*THE NEW ORLEANS AND CARROLLTON ELECTRIC RAILWAY, NEW ORLEANS, LA. Description of entire line

*Illustrated.

and power plant with plan of car house and buildings. St. Ry. Jour., May '93. p. 283.

*THE ROCK CREEK RAILWAY, WASHINGTON, D. C. 2½ pp. P. A. Draper. A concise description of the entire plant. Uses 2 Babcock and Wilcox boilers each 184 H. P., 1 McIntosh and Seymour tandem comp. cond. 250 H. P. engine; 1 Ball and Wood cross comp. cond. engine of 250 H. P. There are 4-90 KW. T-H 4-pole ry. generators belted direct in pairs to the flywheels of the two engines above mentioned. E. E. 15:264; Mar. 15, '93.

*THE CALUMET ELECTRIC RAILWAY. A good description, showing the method of wiring and road bed construction. St. RY. Gaz., Feb. 27, '93.

*AN AMPHIBIOUS RAILWAY, THE CAMDEN GLOUCESTER AND WOODBURY. 3 pp. The railway is called "amphibious" because so much of its route is over trestles erected in the swamps and creeks near the sea-coast. Gives a good description of the track construction, and of the station which furnishes current for both light and power, including plan of station, cuts of engines, etc. Equipment includes 3 Babcock and Wilcox 400 H. P. boilers, 3 Westinghouse comp. 250 H. P. engines direct coupled to 3 Westinghouse 250 H. P. generators. E. E. 17:6. Jan. 3, '94.

*HUDDERSFIELD (ENG.) CORPORATION WORKS. 6 p.p. A full description of a modern English lighting station. Equipment includes 1-50 KW. 2-100 KW. and 1-250 KW. Mordey alternators (2000 volts) driven by cotton ropes direct from Brush engines. Interesting details are given with cuts, of system of low pressure (100 volts) distribution from secondary mains, the synchonizers for coupling the alternators in parallel, high pressure mains (concentric cables) and Brush dry joint boxes. The station is especially designed to facilitate future extension. Section of station given, and numerous illustrations. Lon. E. R. 34:87, Jan. 26, '94.

*BURNLEY CORPORATION SUPPLY STATION (ENG.) 2 pp. Brief description of a station possessing many interesting features. System is the low-tension 3-wire, distrib-

*Illustrated.

uted from a point in the centre of the town a quarter of a mile away. 2 Elwell-Parker 90 KW. 230-volt dynamos are driven direct by ropes (8-1¼ in.) from horizontal comp. cond. Corliss engines. Each dynamo connected across the two mains of the 3-wire system, while it is left to compensators and 120 E. P. S. accumulators (80 amps. for 9 hrs., or 125 amps. for 4 hrs.) to maintain the balancing of the circuits. Sketch of connections given. Only three men required to run plant, as the batteries furnish the light all but 7 hrs. each week day. Lond. E. R. 34:146, Feb. 9, '94.

*SCARBOROUGH (ENG.) ELECTRIC SUPPLY CO.'S WORKS. 2 pp. Description of an interesting station with some unique features. System is high pressure (2000 volts) alternating one with street and house transformers, 2 Parsons' cond. steam turbines, each of 250 H. P. direct coupled to 2-pole 150 KW. 2000-v alternators giving 80 p. p. s. at 4800 r. p. m. Cuts showing section of junction boxes, transformers in substation, are given. Total number of lamps connected about 5000. The entire cost of plant is about $100 000. Lond. E. R. 34:303, Mar. 16, '94.

*NEW WESTINGHOUSE COMBINED DIRECT AND ALTERNATING CURRENT GENERATOR AT ROCHESTOR, N. Y. 2 pp. J. Dennis. Jr. Description and cut of combined generator which gives direct current at 550 volts, or 2-phase alternating current at 385 volts. Plant can be run by steam or water power. E. E. 17:245, Mar. 21, '94.

*NEW 5000 HORSE POWER WATER POWER PLANT OF CONCORD (N. H.) LAND AND WATER POWER CO. 4 pp. A. C. Shaw. Detailed description of station and equipment, giving plans, elevation, section, etc. Rodney Hunt 39 in. horizontal turbines of 209 H. P. each belted through shaft to 7 T-H 50-light arc dynamos, and 6-250 KW. G. E. tri-phase generators. Voltage of transmission is 2500. Line is No. 4 silicon bronze triple braided wire. E. E. 17:270, Mar. 28, '94.

*ELECTRIC STATION OF THE CITIZENS' LIGHT AND POWER CO. OF ROCHESTER, N. Y. R. Cartwright. A paper read before the Am. Soc. Civ. Engs., Mar, 7, '94. An

*Illustrated.

elaborate description of the development and utilization of the water power, with numerous details of construction. The plant can be run by both water and steam. The paper is written from the standpoint of a civil, rather than an electrical engineer, almost no mention being made of the electrical equipment. Trans. A. S. C. E. Vol. XXXI, Mar, '94; Eng. News, Mar, 8, '94; Cond. E. R. 34: 627, 692, June 1, 8, 15, '94.

*ELECTRIC LIGHTING, HEATING AND POWER PLANT NEW BOSTON AND MAINE AND FITCHBURG R. R. UNION STATION, BOSTON. 4 pp: A. C. Shaw. Full description, with plan of station, engravings. etc. 4 Westinghouse "Kodak" comp. cond. engines 14 × 24 × 14 in. direct connected to 125 KW. generators. 2 of 125 volts; 2 of 500 volts. Another similar engine is belted to a 2200 light Westinghouse alternator, and a 11 × 19 × 11 in. engine is belted to a 1100 light alternator. T-H 62 KW. bipolar generator giving 220 volts runs the elevators. E. E. 17:485, June 6, '94, Eng. Dec. June 2, '94.

*PORTSMOUTH CORPORATION WORKS. 13 pp. A full and detailed description of a station which is said to have departed more than any other in England from the recognized engineering practice. Uses Ferranti combined engines and alternators. 212 KW. at 2100 volts at 50 p. p. s. Ferranti the first to use commutated currents for arc lighting in commercial work. The rectifyers are described and illustrated. Parsons' cond. steam turbine, 150 KW. alternators, 2-pole giving 2000 volts at a speed of 300 revs., frequency is 50. Lond. E. R. 34:662, June 8, '94; Lond. E. E. June 8, '94; Lond. Elec., June 8, '94.

*DERBY (ENG.) MUNICIPAL SUPPLY WORKS. 3 pp. Description of station and equipment. 3 units of the following: Siemens' 40 light constant current arc dynamo direct coupled to 35 H. P. vertical engine. 3 units of 50 H. P., Siemens' alternator (2000 volts) direct coupled to vertical comp. engine; 3 similar units of 100 H. P. Substations contain 8-21 KW. and 6-10.5 KW. transformers. L. E. R. 35:67, July 20, '94.

*MANCHESTER CORPORATION WORKS (ENG). 4 pp. Full description of plant, wiring, etc. Uses the 5-wire system, diagrams of wiring being shown. 4 Elwell-Parker 240 KW.

*Illustrated.

and 2 Mather-Platt bipolar 240 KW. dynamos belted to vertical comp. engines. L. E. R. 35:69, July 20, '94.

BURTON (ENG.) CORPORATION WORKS. 3 pp. Description of station and equipment. The alternating current at 2000 volts is used with a street transformer system distributing at 100 volts. 3-125 H. P. Fowler horizontal comp., non-cond., engines drive direct by ropes 3-66-KW. Hall alternators. L. E. R. 35:76, July 20, '94.

*ELECTRIC RAILWAY AT ASHLAND, WIS. Short description of the power house and line equipment. St. Ry. Jour., Feb. '94.

*ELECTRIC RAILWAY OF EVERETT, WASH. Short description of power plant and line equipment. Ball cross comp. engines and return tubular boilers are used. St. Ry Jour., Feb. '94.

*ELECTRIC RAILWAY PLANT OF THE MILWAUKEE ST. RY. CO. Description of the power plant for the electric railway and the illuminating plant. E. E. 17: Mar. 14, '94.

*A WESTERN TWO PHASE PLANT. Brief description of the plant of the Twin City Gas and Electric Light Co. of La Salle, Ill. 2 Ide engines, one drives 2 T-H 30 light arc dynamos, the other a 60 KW. Stanley two phase generator, W. E. 15; 231, '94.

THE ELECTRIC LIGHT PLANT OF HAMDSTEAD, ENG. 2 pp. Description of station and equipment. Willams' comp. engines direct coupled to Siemens' alternators of the following outputs: 1 of 200 KW. 2 of 100 KW. and 1 of 20 KW. L E R 35:410, Oct. 9, '84

ELECTRIC LIGHTING AT WORCESTER, ENG Victor turbines drive by ropes Mordey alternators of 125 KW. Description of station and machinery. L. E. R. 35:441, Oct. 12, 94.

* ELECTRIC SYSTEM OF PHILADELPHIA TRACTION CO. H. S Hering. Very complete and detailed description of the entire system. Gives map of route, tables of data, plans, etc. Westinghouse engines direct connected to Westinghouse generators 4 power stations included. E. W. 24:383, 421,-453,491; Oct. 20, '94, et seq. St. Ry Jour., Jan. '94.

*Illustrated.

*POUGHKEEPSIE CITY AND WAPPINGERS FALLS, N. Y. ELECTRIC RY. 2 pp. Description of station and system. Gives map of route. The feeding point is 8 miles from the station, and the spur line to New Hamburg is 10 miles. 2 G. E. 200 KW. generators are direct coupled to 300 H. P. Ball and Wood engines, (comp. cond.) Grades are numerous and heavy. An interesting feature of this system is the application of the "booster" method of feeding, enabling 2-0000 wires to supply the motor cars at the end of a track 8 miles away, where the grades are unusually heavy, E. E. 18:360, Oct. 31, '94; E. W. 24:479, Nov. 3, '94.

*ELECTRIC RAILWAY SYSTEM OF TORONTO, CAN. 3 pp. Description of system. E. E. 18:409, Nov. 21, '94.

*THE CASS AVENUE AND FAIR GROUNDS RY. ST. LOUIS. A description of the power plant. Has an Allis-Corliss engine, 18 × 36 in. making 150 r. p. m. Gen. Elec. system. Down-draft boilers. Has 31.5 miles track (4′ 10″ gauge) 78 and 80 lb. girder rails, and 140 cars, 70 being motor, and 70 trailer cars. St. Ry. Jour., Dec. '93.

*THE DOUGLAS AND LAXEY ELECTRIC RAILWAY. Description of this English tramway of about 7 miles in length, with maximum grade of per cent, and of the electrical equipment, including accumulators. St. Ry. Gaz., Sept. 8, '94, E. R. Aug. 24, '94.

*ELECTRIC RAILWAY AT ITHICA, N. Y., with 10½ per cent. grades. By J. C. Trautwine, 3d. St. Ry. Rev., Nov. '94.

Description of the system of Ithica, N. Y., with special mention of the power station and its use of water power. St. Ry. Gaz. Dec. 1, '94.

*POWER PLANT OF THE LYNN AND BOSTON R. R. CO. An article describing the building and power equipment of this road. Corliss engines and 4000 H. P. of Babcock and Wilcox boilers. Gen. Elec. system. 153 miles of track, 11 of which are operated by horses, 142 by electricity. 60-90 lb. rails, tram, T, and girder. 475 cars, 112 being horse. St. Ry. Jour., Jan. '94.

*Illustrated.

*POWER PLANT OF THE WORCESTER (MASS.) TRACTION CO. Short addition to description published in St. Ry. Jour., of July '93. St. Ry. Jour., Jan. '94.

*NEW POWER STATION OF THE LINDELL RY. CO., SL. LOUIS. 2 pp. Description of plant. 3 units, each consisting of a Soutwark tandem com. 22 × 26 in. engine, direct belted to 750 H. P. Westinghouse generators. W. E. 16:1, Jan. 5, '95.

*THE ELECTRICAL STATION OF ARGUES-LA-BATAILLE. J. A. Montpellier. A municipal lighting plant fully described and illustrated, the principal feature being a turbine. L'Electricien, Jan. 5, '95.

*THE FRANKFORT, GERMANY, MUNICIPAL ELECTRIC LIGHT STATION. 3 pp. R. Haas. A description of the mechanical and electrical features of the plant, with details and illustrations of the transformer pits, underground work and oil insulated transformers. 3 units consisting of 750 H. P. horizontal comp. engines, and 500 KW. alternators (3 000 volts) from Brown, Boveri & Co., direct coupled. E. E. 19:23, Jan. 9, '95.

*THE HESTONVILLE, MANTUA AND FAIRMOUNT PASSENGER R. R. CO., OF PHILADELPHIA. 4 pp. Description of the station and system. The power house has an ideal location. A map of the route, plain view, switchboard, etc. are shown. 4-750 H. P Greene tandem com. engines are direct coupled to G. E. 400 KW. ry. Generators. E. E. 19:34, Jan. 9, '95. Also St. Ry. Jour. Nov. '94.

*THE ELECTRICAL EQUIPMENT OF THE ORLEANS R. R., NEW ORLEANS, LA. 4 pp. Fine example of modern engineering. Allis-Corliss comp. cond. tandem engines, 2 of 300 H. P. and 1 of 600 H. P. 1 G. E. 200 KW. generator direct connected to each of the smaller engines now installed, and each one, owing to the absence of grades is expected to run 25 single motor cars, an average of only 8 KW. per car. E. E. 21:329, Apr. 1, '96.

*SYSTEM AND POWER HOUSE OF THE FAIRHAVEN AND WESTVILLE R. R., NEW HAVEN, CT. 3 pp. Gives

*Illustrated.

photograph, plan and section of station. A fine example of a modern plant. Westinghouse 300 KW. generators direct connected to Allis-Corliss comp. engines. 36 motor cars. Total capacity of plant 2 000 H. P. E. E. 19:48, Jan. 16, '95.

*THE CHICAGO EDISON COMPANY. Its history and work. 19 pp. T. C. Martin. A very complete detcription of this immense incandescent lighting plant with illlustrations, plans, sectional views, etc., of every essential part of the plant. E. E. 19:63, Jan. 23, '95.

*THE FRANKFORT ON THE MAIN MUNICIPAL LIGHT AND POWER PLANT. 6 pp. G. J. Melins. Full description of plant, and distribution system. Gives plan, sectional view, map of feeders, mains, etc., and other important details. E. W. 25:97, Jan 26, '95.

*THE MUNICIPAL LIGHTING PLANT OF SOUTH NORWALK, CT. 1 p. Description and statistics of plant. During '94, the average cost per lamp per year, including interest and depreciation, $59.29. The station supplies 120-2000 c. p. arc lamps. Equipment: 1-125 horizontal tubular boiler; 2 Western Electric 60 light arc dynamos direct belted to a 100 H. P. Ideal engine. E. E. 19:97, Jan. 30, '95.

*THE ELECTRICITY WORKS AT YARMOUTH, (ENG.) A municipal electric lighting plant, high pressure alternating current generator with transformer stations for incandescent lighting and direct current series machines for supplying street arc lamps. A very full account with a number of diagrams. Lond. E. E. 19:97, Jan. 11, '95; abstract in E. E. Jan. 30, '95.

*DIRECT CONNECTED ARC LIGHTING STATION. ½ p. Brief description of the first direct connected arc plant in the U. S. installed by the Mutual Elec. Lt. and Power Co., at 89th at Loomis Sts. Chicago. 3-125 light Brush arc dynamos direct connected to 3 Bullock-Williams high speed engines. 2-3000 H. P. Water tube boilers. E. W. 25:164, Feb. 9, '95.

Description with numerous illustrations. Elec. Industries, Feb. '95.

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*Illustrated

*THREE CENTRAL ELECTRIC LIGHT WORKS. A full description with good illustrations, of three new municipal plants at Halifax, Nottingham and Drewsbury. Lond. E. R. Feb. 1, '95.

*THE EDDY STREET POWER STATION AT PROVIDENCE, R. I. 2 pp. G. T. Hanchett. 8 Babcock and Wilcox 500 H. P. boilers, 2 Stirling 500 H. P. boilers. 3 Greene tandem comp. engines are direct belted to 3 G. E. 500 KW. generators (500 volts), 2 Greene cross, comp. engines direct coupled to 2 G. E. 750 KW. generators. Units are so chosen that outputs from 500 up to 3000 KW. by steps of 250 can be obtained. E.W. 25:133, Feb. 2, '95.

*THE MUNICIPAL LIGHT AND POWER PLANT AT BREMEN, GERMANY. F. Jordan. The works are laid out on the three wire system, comprises four stations, one principal station with boiler and machinery, and three accumulator, booster and regulating apparatus, sub-stations. One of the characteristics of the plant is that the two wire system is used between main and sub-stations, and the three wire distribution only starts at the the sub-stations. A number of good illustrations are given. E. T. Z. Feb. 7, '95.

*NEW PLANT OF THE CLEVELAND ELECTRIC ILLUMINATING CO. 4 pp. A complete description of a large arc and incandescent lighting plant with plan and cross-section (dimensioned.) E. E. 19:167, Feb. 20, 95.

*BUFFALO (N. Y.) ELECTRIC LIGHTING PLANTS. 2 pp. F. C. Perkins. Describes station and equipment of the plants at Elk and Court Sts. The Elk St. station and the Black Rock station supply the street arcs, while the other station furnishes commercial arcs and incandescents. Machinery at Elk St. includes 2 Allis-Corliss comp. cond. engines, 1 of 1 500 H. P., and 1 of 1 000 H. P., both belted to a long line of shafting. 39-50 light, and 5-125 light Brush arc dynamos. At Court St. there are 8 comp. cond. engines from 100 to 400 H. P. 11 T-H 50 lght arc dynamos belted in tandem to Noye high speed engines. 2-300 KW., 3-70 KW. and 2-60 KW. alternators; 1 G. E. 200 KW. 500 volt generator for power. A number of Small photo-

*Illustrated.

graphs showing interiors and exteriors are given. E. W. 25:229, Feb. 23, '95.

*NEW POWER STATION OF THE CONSOLIDATED TRACTION CO., OF NEW JERSEY. The station will have a capacity of 8000 H. P. Each engine will be direct coupled to a Westinghouse multipolar generator. The plan of station and track, general plan of piping, plan and elevation of engine piping shown and described. St. Ry. Jour., Jan. '95.

*THE SYSTEM OF THE PEOPLE'S TRACTION CO., PHILADELPHIA. 14 pp. A full description, with views and diagrams, the principal ones being a coal elevating plant, the Delaware Ave., power station, with sections, engine room, plans of boilers and engines, car houses, sections of track, Sperry motor, plan and section of man-hole, etc. St. Ry. Jour., Jan. '95.

*THE SYSTEM OF THE BINGHAMPTON R. R. CO. (N. Y.) This company now owns all the street railway lines in Binghampton. A complete description of this plant, with various views, is of especial interest, as this city installed the first electric railway in New York State. St. Ry. Jour., Feb. '95.

*ELECTRIC STORAGE BATTERY CO'S. PLANT FOR LIGHT AND RAILWAY, AT MERRILL, WIS. 2 pp. Description of a small plant divided into two, one operated by water power, the other by steam. Growth of business made enlargement necessary and a storage battery was installed. Curve and data given. Railway built for 2 cars. Length road, 1¾ miles. E. E. 19:247, Mar. 13, '95.

*BUFFALO STREET RY. POWER PLANT. 2 pp. F. C. Perkins. The latest additions to the equipment comprise 2-1250 H. P. vertical, comp. cond., Lake Erie engines direct connected to 2 G. E. 800 KW. ry. generators. W. E. 17:141, Mar. 23, '95.

*A MODERN ELECTRIC LIGHT STATION. 2 pp. Description of the First District station of the Edison Elec. Ill. Co., at Pearl St., Brooklyn. 2-150 H. P. vertical, com. Willians engines, each direct connected to 2-400 KW. G. E. generators, and 2-750 H. P. comp. Lake Erie, each direct coupled to similar

*Illustrated.

dynamos. 3-wire system used. Two sets of "boosters" illustrated and described. E. W. 25:445, Apr. 13, '95.

*A COMBINATION ALTERNATING AND DIRECT CURRENT PLANT. BUDAPEST, HUN. 4 pp. 3 vertical, triple, Schichau engines direct connected to 3 Schuckert 2-phase 1800 volt generators. At a sub-station continuous current dynamos direct driven by two phase motors, deliver current directly to the distributing net-work, and also charge a battery of accumulators (Tudor type) in this station. The alternators are rated at 300 KW. at 51 p. p. s. Several cuts are given including dynamo room at primary station, and at sub-station, accumulator room, and ground plan of primary station. Detailed account. E. W. 25:653, June 8, 95.

*COMBINATION OF LIGHTING PLANT AND WATER WORKS, AT MUNROE, LA. 1½ pp. Description of plant and equipment with special mention of the pumping machinery. E. E. 19: 544, June 12, 95.

*MUNICIPAL WATER WORKS AND ELECTRIC LIGHT PLANT OF NORTH ATTLEBORO, MASS. 4 pp. This plant uses the same building for its water works and lighting plant, and furnishes incandescent instead of arc lamps for lighting the streets. C. O. Milloux of New York was the designer and engineer. The plant cost $49 000. Fitchburg tandem comp. cond. 175 H. P. and 100 H. P. engines are belted to countershaft. 1 G. E. 60 KW. and 1-120 KW. alternator furnish current for the lights. 1-250 H. P. boiler. Detailed description. E. E. 19:579, June 26, '95.

*NOTES ON THE RECONSTRTCTION OF A SMALL CENTRAL STATION, F. L. Pope. Paper read before the Am. Inst. of Elec. Engineers, June 27, '95.

The plant described is located at Great Barrington, Mass. Various changes, described in detail, were introduced, such as the substitution of 126-32 c. p. incandescent lamps for 35-1500 c. p. arcs for street lighting. A turbine located 5 miles away replaced the old steam plant, and Westinghouse 2-phase generators (2100 volts) took the place of a 3-wire direct current system, etc. These changes with others put the plant on a paying basis.

*Illustrated.

The paper, full of valuable ideas and suggestions, will repay careful study by electrical engineers. Trans. A. I. E. E. Vol. XII, June '95; Electricity, July 3, '95; E. W. 26: 41, July 13; E. R. July 10; E. E. July 17; W. E. Aug. 24, '95.

*POWER PLANT OF THE BALTIMORE AND OHIO R. R. AT BALTIMORE, AND ELECTRIC LOCOMOTIVES. 5 pp. Detailed description with plan of station, and numerous views. Equipment of station given in detail. E. E. 20:40, July 10, '95.

WILKESBARRE, PA., ELECTRIC LIGHT CO'S. NEW STATION. 6 pp. J. H. Vail. Full details, plan, elevation, sections, etc. This plant well illustrates the use of the "booster," in practice, as it causes the saving of 50 per cent in copper. E. E. 20:293, Sept. 25, '95.

*NEW STATION OF THE BRUSH ELECTRIC CO., BALTIMORE, MD. 1 p. Equipment of station is of the most modern type. 4 Westinghouse 2-phase A. C. dynamos (each of 15000-16 c. p. lamps capacity) directly coupled to Westinghouse vertical comp. engines. 18-65 light Brush arc dynmos, and 5-80 light Westinghouse arc dynamos and belted to simlar engines. E. E. 19:365, Apr. 24, '95.

*NEW METHODS IN CENTRAL STATIONS AT BELFAST AND LEICESTER. In Belfast gas engines have been adopted, being the largest installation of gas engines in the world. A 200 volt system is used and distributed on the 3-wire plan, in conjunction with a set of accumulators. Lond. E. R., Apr. 26, '95.

*A 300 KW. TWO PHASE INSTALLATION AT FITCHBURG, MASS. 1 p. H. M. Floy. 1 Westinghouse 2-phase 300 KW. generator (2250 volts) direct connected to 6 Pelton water wheels. Current carried 2 miles over 4 stranded conductors, and reduced from 2150 to 220 volts by 2-100 KW. transformers, and then supplies a number of Tesla motors. E. E. 19:386, May 1, '95.

*THE CHICAGO METROPOLITAN ELEVATED ELECTRIC R. R. 2 pp. Description of station equipment, etc. 4

*Illustrated.

Allis-Corliss 1000 H. P. engines direct connected to 4-800 KW. G. E. 12-pole KW. generators, and Allis 2000 H. P. vertical engines direct coupled to 2-1500 KW. G. E. generators. Mechanical stokers, ash removers, etc. E. E. 25:525, May 4, '95.

For a well illustrated and most careful description, see St. Ry. Rev. May 15, '95.

*TYPICAL CHICAGO RAILWAY POWER HOUSES. 2 pp. A description of the plant of the Chicago Elec. Transit Co., at California Ave. Fireproof construction. 4 Fraser and Chalmers cross, comp. cond. 800 H. P. engines direct coupled to 4 Siemens and Halske 620 KW. dynamos. W. E. 16:213, May 4, '95.

*LOCK HAVEN, PA., ELECTRIC RY. CO. 2 pp. Description of a small country road. 2-125 H. P. boilers, 2-100 H. P. Phœnix engines, 2 Westinghouse 60 KW. generators. Track (6 miles single) runs on one side of highway. The combined station and car-barn is of fire-proof construction. Describes track and line construction, and a home-made snow-plough. E. E. 19:415, May 8, '95.

*THREE PHASE PLANT OF THE VERMONT ELECTRIC CO., AT WINOOSKI, VT. 1 p. Brief description of equipment and line, illustrated by photographs of dynamo room and exterior. 1 Westinghouse three-phase generator, rated at 46 amperes at 2500 volts, running at 450 r. p. m. and a frequency of 60, can be either belted direct from turbine, or from a counter-shaft driven by turbine or engine. E. E. 19:431, May 15, '95.

*PORTLAND, ORE., LIGHT AND POWER DISTRIBUTION FROM THE WILLAMETTE FALLS. 5 pp. Transmission line is 14.3 miles long. A full and detailed description of the station, line and equipment. 3-450 KW. G. E. 3-phase 6000 volt generators are connected to Victor turbines. The current is transmitted to Portland and reduced to a voltage of 400. For power purposes, rotary converters transform to 500 volts direct. E. E. 20:341, Oct. 9, '95.

For a six-page article with map, sections, etc., see E. W. 23:457, Apr. 7, '94.

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*Illustrated.

*THREE PHASE RAILWAY SYSTEM, AT LOWELL, MASS. 2 pp. Full description of a very interesting installation. E. E. 20:375, Oct. 16, '95.

*MUNICIPAL LIGHT AND POWER PLANT AT READING, MASS. ½ p. Brief description of plant and equipment. Plant cost $62 000. E. E. 20:448. Nov. 6, '95.

NEW ELECTRIC LIGHTING PLANT AT INDEPENDENCE, IA. 1 p. Brief description. 1 Corliss cross comp. 325 H. P. engine drives by ropes a 180 KW. Standard alternator furnishing 32 c. p. incandescent lamps for street lighting, as well as commercial lights in conjunction with transformers. E. E. 20:449, Nov. 6, 95.

*ELECTRIC LIGHTING OF EDINBURGH. 4½ pp. H. R. J. Burstall. Abstract of paper read before the Inst. of Mech. Engs., giving details in condensed form. E. E. 20:493,521, 543, Nov. 20, '95 et seq.

*EDISON ELECTRIC ILLUMINATING CO. OF NEW YORK CITY. 25 pp. J. Wetzler. A most complete and elaborate description with detailed drawings, and numerous good illustrations of the several huge stations of this company. E. E. 21:25, Jan. 8, '96.

ISOLATED PLANTS.

*LIGHTING PLANT FOR NEW HOTEL WALDORF, (New York City). 8, 6-pole 50 KW. Gen. Elec. Co.'s generators coupled direct in pairs to 150 H. P. straight-line engines. 22 H. P. of Crocker-Wheeler motors besides fan-motors are intsalled. Wiring on both 2- and 3-wire systems; interior conduit. 6200-16 c. p. lamps actually installed. 2 pps. E. W. 21:259, Apr. 8, '93.

*AN IDEAL ISOLATED ELECTRIC LIGHT PLANT (Society of Savings Bldg. Cleveland.) One story building 50×50×20 ft. high. 2-25 KW. G. E. generators direct connected to Lake Erie engines; 1-50 KW. coupled direct to Lake Erie engine; 1-45 KW. to Case engine. 1 p. Brief description. E. E. 16:43, July 12, '93.

*ROPE DBIVEN ELECTRIC PLANT OF THE RACQUET CLUB (New York City). Brief description of a novel

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*Illustrated.

and interesting plant. Output is 1000-16 c. p. incandescent lamps. Available floor space, 9×38. ft. 1 p. E. E. 14:594, Dec. 21, '93.

*ELECTRIC LIGHTING COMBINATION FOR THE SOUTHERN HOTEL (St. Louis). Brief description of the electric equipment consisting of 3 direct coupled units. Each unit comprises an "Ideal" 125 H. P. engine direct connected to a G. E. Co. 6-pole dynamo, and drives by belt from governor pulley other dynamos. ¼ p. E. E. 17:20, Jan. 3, '94.

*STORAGE BATTERIES FOR PRIVATE HOUSE LIGHTING. A description of the private plant of B. L. Smith at Lake Forest, Ill. W. E. 15:169, Oct. 13, '94.

*LIGHTING PLANT AT COOK COUNTY HOSPITAL. (ILL.) Equipment includes 2 "Ideal" 125 H. P. engines and 4 National incandescent dynamos each of 600 lights capacity. Each engine is belted direct to a pair of machines thus giving a duplicate set. W- E. 15:219, Nov. 10, '94.

*STORAGE BATTERY FOR LIGHTING APARTMENT HOUSES IN CHICAGO. Equipment includes 2 Ideal engines of 80 and 50 H. P., 2 Waddell-Entz dynamos of 60 and 30 KW., and a battery of 56-400 ampere-hour Pumpelly-Sorley cells. W. E. 15:49, Aug. 4, '94.

*ELECTRICAL PLANT OF THE NEW STATE HOUSE OF MASSACHUSETTS. By W. S. Keys. 3 pps. Description of the lighting, heating and ventilating plants. Former consists of 3 tandem compound non-condensing McIntosh and Seymour 13x19x15-in. 10 H. P. engines direct connected each to 2 G. E. 50 KW. 6-pole dynamos. Total output about 8000-16 C. P. incandescent lamps. E. E. 20:27, July 10, '95. Elec. Rev. Dec. 12, '94.

*BOSTON NEW PUBLIC LIBRARY. W. S. Key. 3 pp. Various interesting devices are described, such as the ventilation fans driven by G. E. Motors of 50 H. P., the book carrier service, switchboard, wiring and fixtures, the steam and electric plants, etc. Engines are 2 tandem compound non-condensing 150 H. P. Leavitt machines direct connected to 2 Siemens and

*Illustrated.

Halske 5-pole 220 volt 92 KW. dynamos. E. E. 19:503, June 5, '95.

ELECTRIC PLANT IN THE NEW PLANTERS' HOTEL, St. Louis, Mo. One 160 H. P. Southwark engine coupled direct to one 8-pole G. E. 100 KW. generator, at 275 r. p. m. Two 135 H. P. Fitchburg engines direct connected to G. E. 75 KW. generators; and one 45 H. P. Fitchburg engine direct connected to G. E. 25 KW. generator to carry the day load. Hotel is wired for 4000-110 volt incandescent lamps. W. E. 16:165, Apr. 6, '95.

LOUISVILLE AUDITORIUM PLANT. 1½ pp. 3 engines; 2 Ball and Wood, 75 and 100 H. P.; 1 Bass Foundry 100 H. P.; 6 dynamos; 2 Wood arc machines supplying a total of 65 arc lamps; 4 Ft. Wayne incandescent machines supplying a total of 1800-16 c. p. lamps. Plant is installed in duplicate. W. E. 16:224, May 11, '95.

*ELECTRICAL EQUIPMENT OF A. M. ROTHSCHILD AND CO'S. STORE. (Chicago, State and Van Buren Sts.) 2 McEwen 15 × 16 in. engines direct coupled to 2 Thompson-Ryan 100- KW. 10-pole, 110-volt dynamos. The dynamos are furnished with the Ryan compensating field series windings, and are absolutely sparkless from no load to a large overload, and maintain a perfectly constant potential at all loads. An especially interesting installation. W. E. 16:249, May 25, '95.

*STORAGE BATTERIES IN MAYWOOD, ILL. 1 p. Description of the private plant of E. Norton, who lights his house from batteries in the basement, charging them from dynamos located at his factory. W. E. 16:165, Apr. 6. '95.

*ELECTRIC LIGHTING PLANT OF THE AMERICAN TRACT SOCIETY'S BUILDING, (New York City). 1 p. 2-125 H. P. water tube Root boilers, banked into a battery, and 1 Root 250 H. P. boiler worked singly. McIntosh and Seymour engines direct coupled to multipolar G. E. generators. Three units, one of 100, one of 50, and one of 25 KW. are installed. Switchboard adapted to 3-wire system. E. W. 26:617, Dec. 7, '95.

*LIGHTING PLANT IN N. Y. METROPOLITAN MUSEUM. 1 p. 4 Rutzler and Blake boilers., 2-135 H. P. straight-

*Illustrated.

line engines each driving, by belting, 2 Edison No. 16 compound dynamos. Switchboard adapted for either 2 or 3-wire system. E. W. 25:384, June 7, '95.

*AN OFFICE BUILDING LIGHTING PLANT. 1½ pp. Fidelity and Casualty Co., New York City. 2-50 H. P. Ames simple non-condensing engines direct coupled to 2 G. E. 25 KW. 110 volt generators. 3-wire iron armored conduit. Switchboard details, etc. Fine plant. E. W. 25:477, Apr: 20, '95.

BOOK REVIEW.

MECHANICAL ENGINEER'S POCKET-BOOK. A reference book of rates, data and formulas, for the use of engineers, mechanics and students. By William Kent, A. M., M. E., 1087 pages. Price $5.00.

In this age of rapid progress so much is expected of an engineer that he finds it absolutely necessary to have convenient and reliable reference books which contain not only the standard tables but also a well classified and indexed collection of the latest and best data. In every respect this book fills this want for mechanical engineers in a far more satisfactory way than any work of its kind. The portion devoted to electrical engineering contains much valuable matter. It is, however, principally a compilation and makes no pretense of covering this branch.

In summing up, we may say, that this book is undoubtedly invaluable to the mechanical engineer even though he may already have others on the same subject. The same also applies to many electrical engineers whose occupation requires some knowledge of mechanical engineering.

WATER SUPPLY FOR CITIES. Mr. John W. Hill, C. E., of Cincinnati, O., delivered a lecture on the above subject at the University of Illinois, January 21, 1896. The problems involved in securing wholesome water supplies for cities were carefully considered. Especial attention was given to the consideration of harmful bacteri known to exist in polluted water. Typhoid fever, being the best known and the most fatal of the water carried diseases, was discussed in detail. Comparisons were made of the typhoid death rates in 66 cities, and attention was called to the sources of water supply of these cities. The methods of purifying polluted waters were compared by showing their efficiency in removing bacteria.

Perhaps the most striking feature of the lecture was the discussion of the economic advantages of good health. By assuming a value of $10,000 for a human life and allowing for medical attendance, it was shown that the annual loss from typhoid fever in the United States is greater than would be the cost of establishing purification works for every city in the country.

The address has been published by the University in pamphlet form for distribution, and will be sent to the graduates of the University of Illinois or to others interested, upon application to A. N. Talbot, Professor of Municipal and Sanitary Engineering.

"The Animal as a Machine and as a Prime Motor, and the Laws of Energetics." By R. A. Thurston, Director Sibley College, Cornell University. Published by John Wiley & Sons, 53 East Tenth St., N. Y.

This is a little book of 100 pages, but it contains as much information as many books of double the number of pages. The concise and clear manner in which the relation between matter and force, and energy is brought out is gratifying. The discussion on the efficiency of the animal system and its comparison with motors of human invention should be read with pleasure and profit by all.

The tables of "Energy Values of Foods" and their relative values as muscle, brain and "heat givers" are in convenient form for reference, and could be used to advantage by persons interested in athletics, either in our college or elsewhere. After reading the chapter on "Final Deductions," we are disheartened at the past success of human inventions and again inspired by the perfection of the transformation of energy as illustrated by the animal organism.

ANNOUNCEMENT.

THE WISCONSIN ENGINEER. The engineering students of the University of Wisconsin are about to begin the publication of a semi-annual magazine. One of its special features will be an index of the engineering literature published in the technical periodicals for the preceding six months. The magazine will contain about 140 pages of technical matter. The first number will be issued June 1. The subscription price is 50 cents per number, or $1.00 per year. W. H. Williams, Madison, Wisconsin, is Business Manager.

The Technograph is indebted to the following publications for exchanges:

GENERAL EXCHANGES.

The Technic of the University of Michigan; Year Book of the University of Minnesota; Annual Report of the Illinois Society of Civil Engineers and Surveyors' Society; Transactions of the Ohio Society of Surveyors and Civil Engineers; The Michigan Engineers Annual of the Michigan Engineering Society.

SINGLE EXCHANGES.

Transactions of the American Institute of Electrical Engineers; Technology Quarterly; Proceedings of the Electrical Society of Cornell; Journal of Association of Engineering Societies; Journal of the Elisha Mitchell Scientific Society; Bulletin of the University of Wisconsin; The I. A. C. Engineer of Iowa State College; Fifth Annual Publication of the Colorado College Scientific Society.

IN MEMORIAM.

AMOS GABLE CLARK was born September 17, 1871, at Petonica, Ill., and died at his home in Urbana on January 20, 1896, of typhoid fever. He removed with his parents to Urbana, and entered the Urbana High School, but did not graduate. He entered the University in 1890 and graduated with the class of '94. The following year he took post-graduate work in his chosen subject—architecture. He then went to Chicago and entered the employ of the Chicago Architect, Henry Ives Cobb, in whose service he was at the time of his death.

Of his remarkable athletic achievements we need say but little. He took up athletics, as all other matters, seriously, and allotted a portion of each day to his gymnasium work. But it was not Amos Clark the athlete who was so endeared to the whole student body, but Amos Clark the man. His sterling individual worth drew forth an admiration that is lasting and enduring. He was modest, never discussing his own deeds nor mentioning his achievements. Somewhat slow in choosing his friends, but having once chosen he was true and unswerving in his loyalty to them. His innate modesty and unassuming honesty completely disarmed any incipient jealousy, and it could truly be said of him that he had among the whole student body no enemy, nor one who harbored for him an unkind thought.

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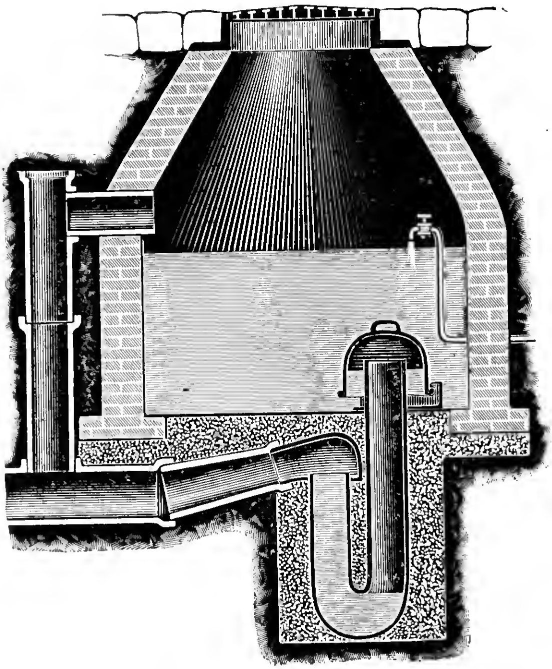

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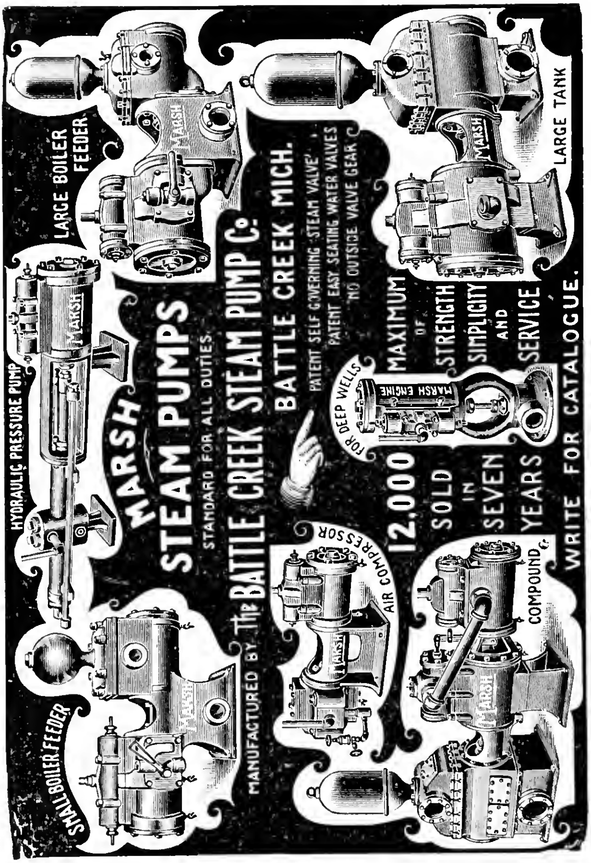
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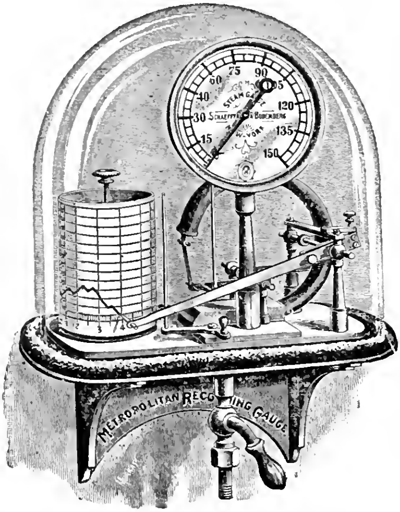

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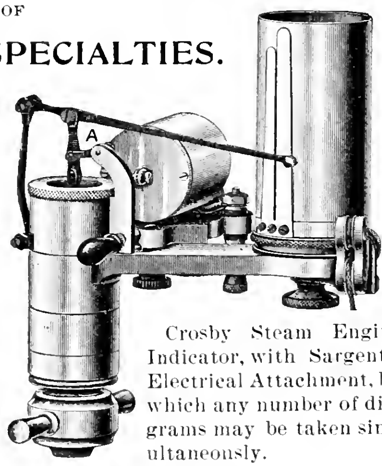

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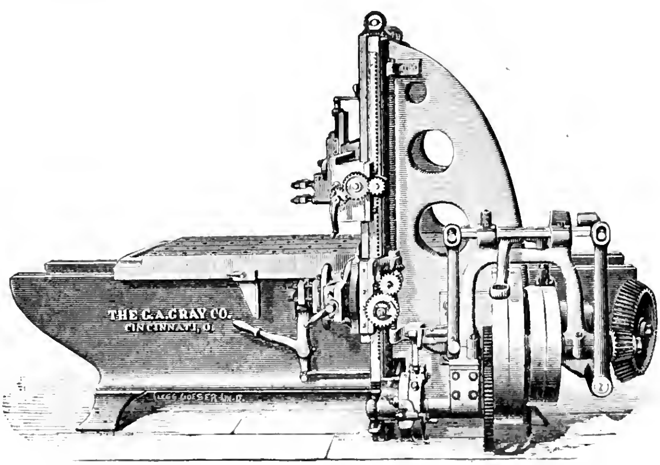

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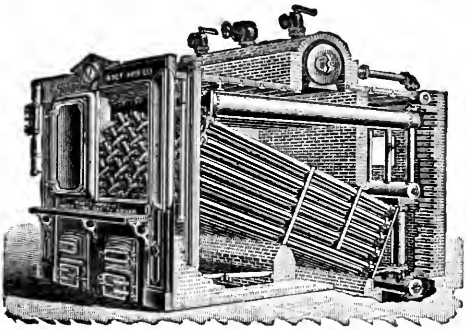

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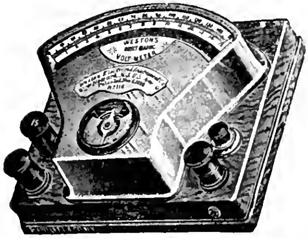

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