No. 5.

THE TECHNOGRAPH

UNIVERSITY OF ILLINOIS.

1890-91.

CONTENTS.

PRICE 50 CENTS

ADDRESS, TECHNOGRAPH, UNIVERSITY OF ILLINOIS,
CHAMPAIGN, ILL

No. 5.

THE TECHNOGRAPH.

Published by the Civil Engineers' Club and the Mechanical Engineers' Society of the

UNIVERSITY OF ILLINOIS.

CHAMPAIGN, ILLINOIS,

1890-91.

BLOOMINGTON, ILL.:
Pantagraph Printing and Stationery Company.
1891.

THE TECHNOGRAPH.

No. 5. UNIVERSITY OF ILLINOIS. 1890–91.

THE SCHOOLS OF MECHANICAL AND CIVIL ENGINEERING IN THE UNIVERSITY OF ILLINOIS.

By Selim H. Peabody, LL.D., Regent.

The first movements toward the establishment of schools of Civil Engineering in America sprang from the demand for competent engineers of railways consequent upon the rapid development of that system of transportation in the third decade of this century. A second and larger impulse came about thirty years later, when Congress made its first subsidy for scientific training in the Land Grant Act of 1862.

The state of Illinois was among the first to move in the founding, under the provisions of this act, of a school of practical and experimental science, chartered in 1867 and opened to students in March, 1868. In those days the differentiation between the subjects of civil and mechanical engineering began to be more fully appreciated, and the institution here begun was one of the earliest to provide a distinct course of study, with separate equipment in each of these lines of engineering work. The workshops here erected were the first distinctively educational shops opened in America, those at Worcester following soon after. But the Worcester shops were manufacturing shops, with educational tendencies, rather than shops purely and simply for instruction. The primary object of the shops at Champaign has been instruction, with very little consideration of manufacturing results. Dr. Runkle, of the Institute at Boston, has been called the father of shop-training in America, a distinction which he surely never claimed for himself. The shops at Champaign were built, equipped, and opened to students seven years before the first shop-work was done at the Massachusetts Institute of Technology. A full exhibit from our shops, including a line of work analogous to the so-called "Russian" system, a kind of work practiced here for at least four years previous, was placed in the Centennial Exposition in Philadelphia in 1876, and a diploma was awarded to this University therefor. Dr. Runkle's school-shop in 1877, was no more an innovation or a discovery than is Dr. Elliot's proposition of to-day that college students of larger capacity may graduate with a bachelor's degree after three years' study. The University of Illinois graduates a student when he has completed his course, and does not ask whether he has occupied three, four, or five years in so doing.

The shops at Champaign have sent out full lines of its courses of shop instruction, including blue-print copies of its drawings, and finished specimens of work, to various institutions scattered from the Atlantic to the Pacific coasts. It was more complimentary than ingenuous for the distinguished president of an Eastern College, to publish a complete series of fac-similes of our shop-drawings, reduced copies of blue-prints obtained from us, dimensions and all completely figured, with the statement that the series was perhaps the most complete extant, but without any credit to the institution where they originated, or any recognition of indebtedness thereto. The University of Illinois has never sought to protect for herself such products, but has freely distributed them to all inquirers, but she believes that she may modestly reclaim her own. She farther confidently claims, that in America there was no earlier practice in "Manual Training" than hers, and that nowhere else has that practice been more consistent or more successful. But this has been restricted to its proper sphere as an incident and adjunct to other earnest and scholarly culture, and never has been put forward unduly as a hobby, or a fad.

All our engineering courses begin substantially at the same point. The entering student is expected to show evidences of fair previous training, covering the branches taught in primary and grammar schools, and most of those taught in the High schools. In particular, he should be well versed in Elementary Algebra, and in Geometry, both plane and solid. He should have had some practical contact with elementary science; and because his opportunities will probably have been better in these subjects, Physics, Physiology, and Botany are named. The desire is that he shall have thus acquired some training, some discipline, while the mere knowledge of facts is deemed of less consequence. It must be admitted that the ideals are not realized as often as could be wished.

A good knowledge of the English language is deemed indispensable. The applicant must not be less than fifteen years of age, and ordinarily should have reached eighteen. If to these qualifications could be added a good practice in drawing, both free-hand and with instruments, and some careful linguistic culture, the results would be very advantageous. It is to be hoped that these may be required at a day not far distant.

The new student is entered at once upon a course of higher mathematical work, for the double purpose of its exact discipline, and of its needful facility for solving the multitudinous problems which occur in the higher departments of his engineering study. It is meant that he shall acquire the power of sifting matters to their fundamental principles, and for this purpose the mathematical training is absolutely indispensable. Parallel with this opens careful training in the exact power of expression in drawing, in its mathematical rather than its artistic phase. Parallel, also, comes the concrete applications of these subjects, in the treatment of materials, wood, iron, sand, etc., in the shop. In each of these lines of work, the prime excellence to be sought and inculcated is precision, exactness, accuracy. Without these, effort is wasted, and habits worse than useless are inculcated. In the shop, particularly, is this noticeable. A few enter the shop showing a native inaptitude for shop methods; but for one such, there are many who show that for the want of proper training in their preceding work, stimulated only by that which fond parents suppose to be the coruscation of mechanical genius, or by training inefficiently given in the early years, before the lad has any real appreciation of earnest purpöses, that which they have learned as to "the use of tools" is a delusion and a snare; that much pains must be taken to unlearn bad methods and to erase bad ideas, before good ones can be inculcated.

These three, the shop, the drawing room, and the mathematical class room, lie so at the foundations that they can not be avoided. To furnish some element of broader culture, at the same time, work is added in some modern language. So ends the first year's work.

In the second year, the mathematical work proceeds. Physics comes in as an important theoretical and experimental study. The differentiation of the departments begins. The civils enter in their work of surveying in its various phases, including an intimate acquaintance with the most refined instruments of measurement. The mechanicals pass from instruction to construction; terms which indicate tendencies rather than differences, since every piece of work involves both elements. Finished machines begin to show themselves in the shop, as the results of work that begins in the designing room, and follows through all the practical departments.

In the third year the schools unite in the investigation of the problems of mechanics, resistance of materials, hydraulics, etc.; problems exhaustively discussed by the aid of the mathematical processes previously mastered. But each school becomes yet more specialized. The mechanicals discuss the elements of mechanism; the quality of materials; the combination of machinery. The civils are busy with the intricacies of construction of railways, and of municipal improvements.

In the fourth year are reached the higher specialties in each department. The civil's surveying has developed into the discussion of geodetic problems; their investigation of the material elements and of mechanical problems, culminates in the designing of masonry constructions, and in the theoretical and practical investigation of devices for transit over the land, through the air, and over and under the waters, and the everlasting hills. In like manner the mechanicals are burrowing into the vital constitutions of motors and appliers of force, and the methods of harnessing the powers of heat, flowing water, and electric currents, to the service of men.

In all this, it is hoped that one mistake, a serious one, may be avoided. These students, ardent, earnest, industrious, successful, must not come to their graduation with the supposition that they have mastered the whole of the sciences that pervade their specialties. These subjects are broad as the world, and as long as eternity. Only those principles that are fundamental can be grasped as the product of study for four brief years, if, indeed, there should be time and strength for so much as that. The engineer, the mechanician, must be content to be a student during all the years of the longest life that may be granted for his efforts.

Too many students wish to restrict themselves to those specialties in their respective courses which they imagine are of direct and particular "use." The reason is, that they have a limited, an inadequate interpretation of the word "use." Had they the opportunity to reconstruct man, they would make him only senses, fingers, and stomach. The University courses have endeavored in some measure, quite too small, to supplement these vigorous, technical studies, with others, which may tend toward the humanities, which may broaden vision, stimulate aspirations, enlarge conceptions of life, and capacities for enjoyment. The engineer should not be a mere machine, typified by his own steam engine, or dynamo, or theodolite; he should strive to grow into a large-hearted, acute, brainy, and efficient man. He must not only have great capacities, but fair means of showing to the world such capacities. He should be able to write clearly and accurately; to speak forcibly and effectively; to be a power in the sphere of his action. He has an account to give, as well for the talents which he may acquire, as for those which were given him to possess and to enjoy.

In this brief account of the schools of civil and mechanical engineering, most has been said of the present, the actual. The possible, in the future, is yet larger and more worthy. The ideals are not yet realized; there is much to do before they can be realized, requiring combined and persistent effort. The progress made is but earnest of that which is sought, and for which the aid of students, instructors, the public, and the state, is invoked.

THE TOPOGRAPHICAL SURVEY OF THE CITY OF ST. LOUIS, MISSOURI.

By Oliver W. Connet.*

No city contemplating any extensive improvements can afford to be without a careful topographical survey and an accurate contour map. The survey should cover the whole city, and the map should be on a large scale and show the streets, alleys, public grounds, water courses, contours, etc. The information necessary for the location, plans, and preliminary estimates for sewers, street improvement, and other public works, can not be obtained so quickly or at so little cost in any other way; and the study of their location can not be so general and comprehensive as may be made from such a map.

This has been recognized in St. Louis, and such a survey is in progress in this city. The survey was authorized by an ordinance approved March 21, 1889, and the field work was begun in June of that year. The purpose of the survey, as stated in the ordinance, is for the perfecting of plans for the drainage of the city, and for use in locating and opening streets and alleys, and in the establish-

*For three years a member of the class of '87, and at present assistant engineer on the topographical survey of St. Louis.

ing of grades for streets and public places. The survey is under the supervision of the Sewer Commissioner, Mr. Robert E. McMath, and in direct charge of Mr. B. H. Colby, first assistant engineer. The force authorized by the ordinance is as follows, viz.: one first assistant engineer in charge, one precise level man, one topographer, one draughtsman, three recorders, and as many field hands as are necessary. The ordinance directs that the survey shall be begun in that part of the city where least provision is made for drainage and where the increasing population makes plans for improvements necessary.

In compliance with this provision the survey was begun in the central portion of the city west of Grand avenue. Up to the date of this paper, February 1, 1891, the field work is nearly finished in the district bounded on the north by Florissant avenue, on the east by Grand avenue, on the south by Tyler avenue, and on the west by the City Limits.

The work of the survey may be divided into four heads: Triangulation, Precise Levels, Topography, and Office Work. The first two are in a sense preliminary to the topography, but of primary importance as regards the accuracy of the survey.

Triangulation.

The triangulation, which is the basis of the survey, has been carried forward as the work has progressed. The area covered by the triangulation is about 30 square miles.

About one half of the stations are marked by limestone monuments 6 x 6 x 36 inches, set in the ground. The remainder are on the roofs of buildings. The system has fifty-four stations, and sixty-five triangles. The stations are so distributed that they are on the average less than a mile apart, but the average length of the sides of the triangles is about one and one half miles. In most cases the three angles of the triangle have been read by the repetition method.

The system is based on a line in the trans-continental triangulation of the United States Coast Survey. The line is from a point on the old stand-pipe to the tip of the dome of the Insane Asylum. The latitude and longitude of these two points, with the length and azimuth of the line joining them, were taken from the Coast Survey reports.

In the report of the Sewer Commissioner for the year 1890, Mr. Colby gives the following: "The average closure of triangles has been a little over four seconds. The angles of each triangle were summed, and the deficiency or excess from 180° was divided equally among the three angles before computing the sides. No other adjustment has been made, or thought necessary. Several checks have been made upon length of sides, and discrepancies have been from 1 in 80,000 to 1 in 180,000."

It is expected that an ordinance will be passed requiring that all surveys of streets and subdivisions be connected with the triangulation, and that the true azimuth of all lines be recorded. Such a requirement is necessary because the present records do not furnish sufficient data to plot the streets on the maps, or retrace the lines on the ground. In anticipation of this a number of triangulation stations have been connected with, which were not necessary for the topographical survey.

Precise Levels.

Precise levels have been run on the principal streets west of Grand avenue. Benches have been established on an average four to a mile along the lines run. The lines have been so connected that no point in the district covered is more than one half mile from a precise bench. There have been 361 benches established, and the distance run in duplicate is about 92.5 miles. These benches are to be the standard for all of the departments and for all elevations in the city. For the convenience of the other departments and of engineers and surveyors in general, a list of the benches with their description and elevations is published. The greater part of the benches are on the stone foundations of bridges and buildings, but in parts of the city where such marks could not be had, a burnt tile slab, 4 x 18 x 18 inches, with a copper bolt leaded into the center, was buried to a depth of four feet. The point is accessible through a tile pipe specially made for the purpose.

The limit of error allowed is 0.0208 feet into the square root of the distance in miles. In the above mentioned report the following figures are given, showing the degree of accuracy with which the work has been done: "The average closure per mile has been 0.013 feet. The probable error in the determination of a single mile of the work is 0.001 feet. If the work lay in a continuous line, the elevation of the last bench, as determined from the first, would be known within a probable error of 0.066 feet."

Topography.

The value of the survey depends on the amount and reliability of the information given. To this end every precaution has been used to secure this result. The best instruments have been procured, experienced men employed, and the greatest care required. All possible checks are taken in the field to prevent errors from creeping into the work.

The stadia has been employed as the best and most rapid method of locating points and obtaining their elevation. By this method 300 points may be located in a day. The party is composed of the topographer, one recorder, three stadia-men, and one general-utility man. The instrument used is a complete Buff & Berger transit, reading horizontal angles to 10 seconds and vertical angles to 1 minute. The vertical circle has each quadrant graduated from 0° to 90° so that the angle of depression or elevation may be read with the telescope direct, or inverted, thus eliminating errors of adjustment of the vertical circle. The level is attached to the verniers in such a way that the zeros may be brought into a horizontal plane without disturbing the leveling screws.

The stadia boards used are 12 feet long, and represent a distance of 458 meters, or the value of 100 meters is 2.62 feet on the board. The figures used on the stadia are similar to those used on the United States Lake Survey. Distances are read in meters, and elevations are obtained in feet by means of Ockerson & Teeple's tables. Oak stakes 1 x 1 x 10 inches are used for stadia stations, and are driven nearly flush with the ground.

All lines of stadia courses begin and end on triangulation stations, or other stadia stations which are in connecting lines. Both verniers are read to 10 seconds on all stadia courses. In this way the azimuth is repeatedly checked in the field, and data obtained by which the location of the stations may be checked when the co-ordinates are computed. The error of closure after making the known corrections for inclination and graduation of rods, is about 1 in 800. The average error of closure of azimuth is about 1 minute 5 seconds for each line run, or 11 seconds per station. All azimuth readings are with reference to the true meridian.

Elevations are carried by means of distance and vertical angle. The height of instrument is carefully measured with a rod (graduated for the purpose), the middle wire is brought to the corresponding point on the board, and the level on the vertical circle is brought to the center of the tube before the angle is read. It is remarkable with what accuracy elevations may be carried when these precautions are taken and care is exercised to keep the instrument in adjustment. The average error of elevations is less than 0.2 of a foot per mile.

The notes are kept in well bound books, 5 x 8 inches in size, made especially for the survey. They contain 100 double pages, and have the heading of the columns printed on every page, as shown below:

LEFT-HAND PAGE.

Object.	Distance.	Vernier A.	Vernier B.	Vertical Angle.

RIGHT-HAND PAGE.

Difference of Elevation.	Elevation.	Remarks.

The last column is used for descriptions of bench marks, corner stones, stadia stations, etc., or for sketches.

The area covered (up to the present time) by the topography is 14,930 acres, or 23⅓ square miles. The elevations of 54,500 points have been determined, or an average of 3.65 points per acre.

The time occupied in field work is as follows: Triangulation, 62 days; precise levels, 114 days; topography, 248 days; total, 424 days.

OFFICE WORK.

The office work consists in reducing the field notes, and plotting. The latitude and longitude of all triangulation stations are determined to hundredths of a second, and also their linear distance from the two nearest minutes of latitude and longitude. The azimuth, and length of the sides of the triangles are computed.

The rectangular co-ordinates of all the stadia stations, with reference to the nearest 20 seconds of latitude and longitude, are computed, adjusted, and recorded in a book for that purpose. This is an important part of the work, as by this means the error of closure is systematically adjusted, and checks the location of the stations before the plotting is done. The plotting is done on heavy mounted egg-shell paper, cut into charts antiquarian size. The charts are projected by the polyconic method. The tables based on the development of the Clarke spheroid, published in the report of the Coast and Geodetic Survey for 1884, are employed. The scale is 1 in 2,400.

The charts have the parallels and meridians for every 20 seconds of latitude and longitude on them, and triangulation and stadia stations are plotted by rectangular co-ordinates from them. Other points are plotted by polar co-ordinates. The streets and alleys are plotted by means of connections made on the ground and from data obtained from the street department.

The precise level notes are reduced, and a list of benches, with elevations and descriptions, prepared for publication in the annual report of the Sewer Commissioner. The differences of elevation of the points located by stadia are found by means of Ockerson's stadia tables, and the elevations determined and recorded in a column of the field book. In finding the elevation of stakes, the mean of the differences found by the readings taken in both directions is used; and the error of closing between benches is divided equally on the stakes in the line.

All the points taken are plotted, and their elevations written in small figures on the charts and the contours drawn in. The contour planes are taken 3 feet apart. The charts are finished in ink. The elevations of the contours, names of streets, etc., are to be printed on them by means of a small hand press.

Cost.

The exact cost of the survey can not be given until it is completed, but some facts concerning the cost of the work, up to the present time, will be of interest. The total cost of the survey to February 1, 1891, is $18,827.68. This includes salaries, new instruments, office furniture, transportation, etc. Deducting $1,927.68, for the value of instruments, etc., on hand, leaves a balance of $16,900.00 as the actual cost of the survey. The cost of the different branches of the work has been as follows:

Triangulation	$1,812.00	or	11	per cent.
Precise levels	2,762.00	or	16	"
Topography	6,060.00	or	36	"
Office work	6,266.06	or	37	"
Total	$16,900.00		100	"

The cost of running precise levels has been $30.00 per mile, run in duplicate. The average cost of the parties, per day, including transportation, instruments, etc., is as follows:

Triangulation	$29.25
Precise levels	24.25
Topography	24.50

The average total cost per square mile is $724.50, or a little over $1.13 per acre.

GRIP FACES FOR CABLE ROADS.

By F. W. Richart, '91.

One of the heaviest expenses of the cable system of street car propulsion, is that of renewing cables. Another item of considerable expense, is the necessary frequent renewal of grip faces or *dies*, as they are usually called. The effect of various materials used for dies, on the life of the cable, and the relative life of dies made of these different materials, is a subject which is of considerable importance to Cable Companies, but has not received much attention in technical publications.

Very little information could be obtained concerning the earlier forms of grips. Some of the earlier cable roads in San Francisco used the Paine grip, which had solid dies, with a pair of carrying pulleys at each end, forced out beyond the dies by springs, and which carried the cable, preventing it from rubbing the dies when they were released. The carrying pulleys are not usually used in more modern practice. Another form of grip designed to prevent wear of the cable, consisted of two rectangular steel bars having rounded ends, each having a dove-tail groove the entire circumference in the long direction. In these grooves short brass blocks were placed, so that when the grip was slackened the brass blocks slid round, taking the wear instead of the cable.

This was once used on the Brooklyn bridge, but was unsatisfactory. The grip used on that bridge at present consists of small sheaves with grooves facing, which turn when the grip is slack, but on increasing the pressure the friction becomes sufficient to stop their turning and move the car. This grip has been used on cable roads with unsatisfactory results. The tendency is to lengthen the cable and diminish the diameter. All Kansas City lines use dies made of the Worrell alloy, which is made of cast-iron and another metal supposed to be copper. The endurance of the dies is two weeks on two lines, and is given by two authorities as two weeks and seven weeks on the third. The one who gives two weeks is probably the best authority. The Locust Street Line, of St. Louis, use a phosphor bronze die, which gives satisfactory results, lasts as long as six weeks, and wears the cable less than soft (presumably cast) iron. The Chicago City Railway Co. use a grip die which lasts one month. The composition is copper 60 lbs., tin 10 lbs., zinc 13 oz., lead 18 oz.

Quite a number of roads have tried cast-iron with unsatisfactory results. It can be used but a short time before renewal is nec-

—2

essary. A silicated iron has been used on one of the Chicago roads, lasting about five times as long as ordinary cast-iron.

Cast-steel is being used to a considerable extent at present, and with very satisfactory results. It lasts several times longer than any of the alloys or cast iron, and, according to Mr. Van Vleck, wears the cable but a trifle more. The Vogel Cable Construction Co. state that gripping dies are made of the hardest material possible, and when the expense is not too great of tool steel.

The conclusions to be drawn from the tables below are not numerous. We can see that cast-iron does not last any considerable length of time. Some grades of cast-steel are poor, but good grades give greater wear than any other material cited. Of alloys, phosphor bronze wears longest. The alloy used by the Chicago City Railway Co. seems to give very good wear, but is evidently expensive. As to the life of cables as effected by different materials used in the dies, the average life of Kansas City cables from the table is 10.84 months with dies made of the Worrell alloy, while the Washington and Georgetown cable has not yet been renewed after eleven months use, with cast-steel dies. The only difference in the two cables is in the number of wires, the diameter being the same. The former has 96 and the latter 114 wires in six strands, with hemp core.

LIFE OF GRIP DIES OF VARIOUS MATERIALS.

Road.	Material.	Len'th	Life.	Remarks.
Chicago..........	....	19"	144 miles....	
N. Chicago........	Cast iron	20"	225 miles....	
"	Silicated iron (special mixture)...	19"	700 miles....	
"	Cast-steel..........	19"	368 miles...	Not Chi'go C. S. Co.'s make.
"	"	19"	2009 miles...	Chicago Cru. S. Co.'s make.
"	"	20"	2250 miles...	
Chicago City Ry....	Composition	......	One month..	
Washington and Georgetown Ry.	Cast-steel........	$15\frac{1}{2}$"	....	Have not been removed after $4\frac{1}{2}$ months' use.
Kansas City	....	......	....	Dies, two pieces each 7" long.
Metropolitan.......	Worrell alloy.......	14"	Two weeks..	
Grand Avenue	"	16"	Two weeks / 40 to 50 das	Two authorities.
K. C. Cable.	"	......		
St. Louis	....	.....	15 days......	
Locust St. Line ..	Phosphor bronze ...	......	6 weeks	Made by Congden Brake Shoe Co., Chicago.
Broadway Line....	....	......	1 to 3 weeks.	
Vogel Cable Con.Co.	Hardest possible ..	$11\frac{1}{2}$ 12	....	L'gth me'd from scale drawing.

Life of Cables.

Street.	Lgth. cable, feet.	Life cable.	Speed.	Character road.	Remarks.
Kansas City.....			7 to 9 miles per hour.	Very	
E. 5th........	....	6 months..		crooked	Met'p'li'an Line
W. 5th........	....	7 months..		... .	
E. 12th.......	....	12 months.		13 per cent	
W. 12th.......	....	7 months..		grade	
W. 18th.......	32300..	7 months..		....	
E. 18th.......	....	18 months.		....	
Westport......	30500..	14 months.	9 miles..		Grand Ave Line
Walnut	14200..	4 months..	8 miles..	Very	
15th	29500.....	15½ mo..	9 miles..	crooked	
Holmes.......	22000..	Has been in 22 mo..	9 miles..	10 per cent grades	
Main Line....	....	8 months..	8 miles..	18.53 per	K. C. Cable Line
Washington ...	....	9 months..	12 miles.	cent grade	
Troost Ave....	....	12 months.	9 miles..	....	
Washington....	....	....	....	....	
7th	33000..	On 11 mo.	....	Almost	Business very he'vy
Chicago..... ...	... .	....	....	straight	
Chi. Cy. Ry. Co	....	40000 mi..	....		

THE FOUR-MILE CRIB OF THE CHICAGO WATER-WORKS.

By Simeon C. Colton, '85.

Engineer for the Contractors.

This piece of work has received slight notice in engineering perio dicals, but not by any means such as its prominence warrants. When this massive steel and timber crib left the Chicago harbor, it carried a cargo one half larger than ever floated on the great lakes, and carried this with a draught of only 14 feet.

The construction of this structure was begun on January 7, 1889, by the FitzSimons & Connell Co., by placing the launching ways. These ways consisted of nine sets of 12 x 12-inch oak timbers placed at an incline of three fourths of an inch to a foot to the face of the dock, which was cut down to a foot above high water. The ways were covered with 4 x 12-inch oak, and on these slides was built the ti mber bottom. For lubricating the ways a mixture of tallow and graphite was used.

The shoe, 12 inches high, consisted of two parallel timbers 12 x 12-inch pine, and formed a polygon of 24 sides, the greatest diameter being 124 feet. See Fig. 1.

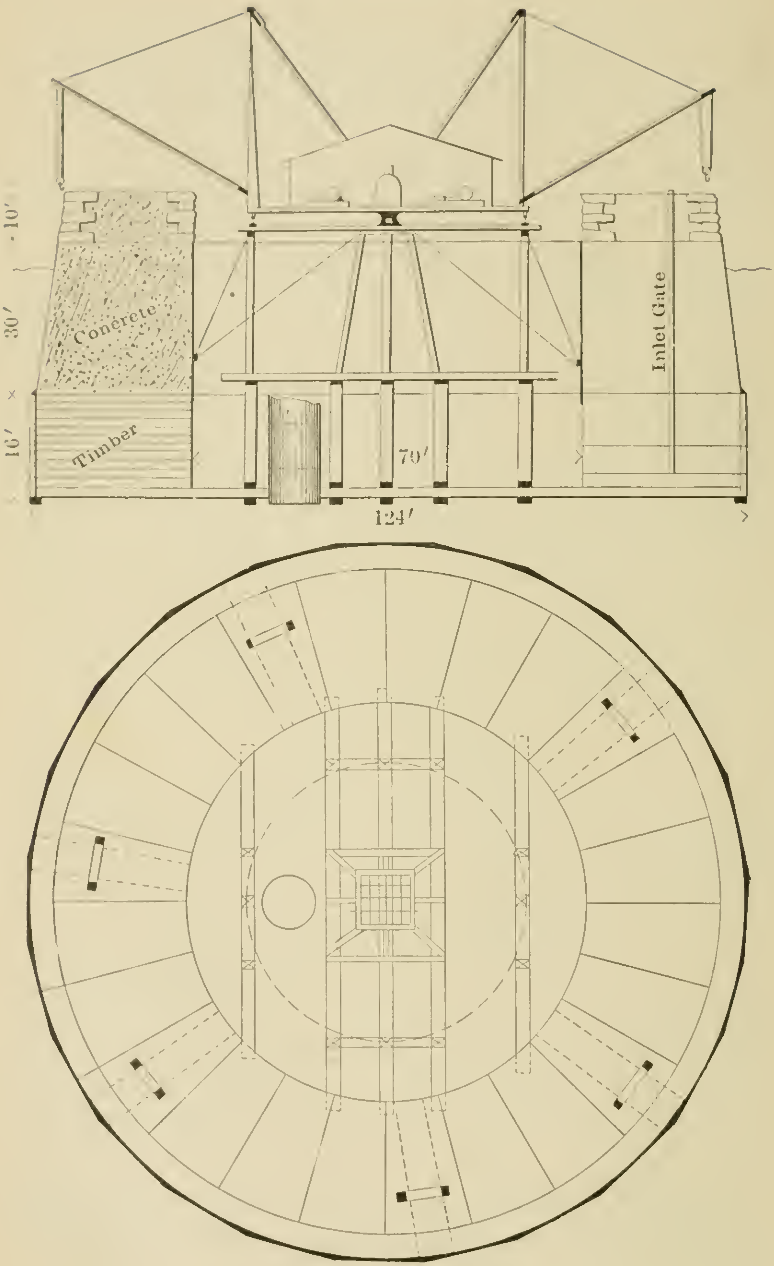


FIG. 1. FOUR-MILE CRIB.

Upon this shoe the timber was laid, upon blocking on the ways, and firmly bolted with 32-inch round drift bolts, forming a platform 2 feet thick and 125 feet in diameter. All timber in these two courses was surfaced on four sides to make more compact work and give a better caulking seam. Upon this bottom a 70-foot circle was struck, and between the circle and the sides of the polygon (26½ feet) the timber was carried up 13 feet higher. This ring was planked vertically both outside and inside with 6-inch oak securely drift-bolted to the pine and thoroughly caulked. The inlet ports to the center well were placed 5 feet up and were 5 feet square. These ports were closed by gates and stoppers before the launching of the structure.

With the planking and bottom well caulked, the structure was ready for the launch, except that the 2-foot bottom would stand neither the launching strains nor the pressure caused by the displacement. The plan which had been adopted at the outset of the work was to load the structure to draw 27 feet and keep the interior well dry, thus this clear space of 70 feet was expected to withstand a pressure of 1,600 lbs. per square foot, or a total pressure of 3,000 tons. In order to cope with this pressure we placed five Howe trusses 20 feet high within this well, and built the ends fast into the outside circle of timber. The lower chord, composed of four pieces 5 x 12, was securely bolted to another chord underneath the bottom of the crib. One truss was placed on the center line of the well, and two others each side, 10 and 22 feet distant. In order to further help the trusses, a central tower 30 feet high was built of 12 x 12 timbers in bents of three, and capped with 14 x 16 oak. Through the oak cap, twenty 1⅛-inch round rods were passed, leading down at an angle of 30° and securely fastened by pins and lugs to the inside steel cylinder. Notwithstanding these precautions, as well as the fact that the crib was sunk to a depth of only 25 feet before the water was allowed to enter the center well, the posts on the tower were crushed into the caps 1 to 2 inches, and the oak cap was badly bent.

Upon the fourteenth course of timber in the ring the steel cylinder was started. This cylinder was 124 feet in diameter at the bottom, and 118 feet at the top, and 30 feet high, and consisted of plates ⅜-inches thick, 4 feet wide, and 16 feet long. Each sheet butted in the ring, and lapped the rings above and below. Lead was used in the butted seams to secure a water-tight joint. The vertical sheets were joined by angles, these same angles receiving the ends of a bulkhead sheet, ⅜-inches thick, 4 feet wide, and 24 feet long. The inner cylinder was parallel to, and 27 feet away from the outside. Thus we have the metal structure, two cylinders 124 feet and 70 feet in diameter, joined by 24 solid bulkheads placed on radial lines, the whole weighing 430 tons. There were some 96,000 rivets in the work, which fitted so well that no holes required more than a drift to draw them into place. All seams were caulked, so that the steel work was absolutely tight.

The cylinder was filled with Portland cement concrete, consisting of 1 part cement, 3 parts sand, and 6 parts stone. The stone was broken to pass a 1½-inch ring. Rubble stone were imbedded in the concrete, each stone being carefully laid flat and surrounded with concrete well tamped. The concrete was mixed by a screw mixer (Caldwell's) mounted on a scow, and was able to turn out 250 cubic yards in 10 hours. All concrete and stone was handled by a double-ended derrick mounted on a movable platform over the center well; this derrick being able to reach every point in the circle of the crib, and was able to lift 15 tons.

When about 1,500 cubic yards of concrete had been placed aboard, the crib was towed into position a distance of about four miles. Two tugs towed her about three miles in two hours. Once started on her journey the water was let into the inner well by means of valves placed in the sides for that purpose, and after reaching the site some 200 cords of stone were placed on top of the iron to secure the structure against damage by storms during the night. The crib, when sunk, showed about 8 feet above the water, and up to date has settled about 30 inches into the clay bottom, leaving the top of the steel 5 feet 6 inches out of the water.

Work was stopped for the season November 5, 1889, with about one half the pockets filled with concrete. Upon resuming operations June 11, 1890, it was found that the winter's storms had caused a slight unevenness in the settlement, but had not damaged the structure a particle.

Stone setting was commenced July 21, and the masonry portion of the structure was completed September 25, 1890. In that time 5,000 cubic yards of concrete had been handled, and about 19,000 cubic feet of granite masonry had been set. This time includes, of course, all the stormy weather, during which we were unable to reach the crib, that is, during this period of 64 days we actually worked only 40 days. The granite masonry was but a facing on the outer and inner circles, the center being filled with concrete. The masonry as completed reached 16 feet above the water, but is to be carried higher after the completion of the tunnel. The stones in the outer circle were bound together by copper clamps 2 inches by 20 inches, weighing 50 pounds each.

The concrete and masonry being finished the derricks were run to one side over the outer wall, and were used as a hoist during the sinking of the inlet shaft. The two lower sections of the shaft had been put in place before the crib was launched, and hence required only to be cut loose in order to begin the sinking. This was accomplished with little difficulty, and we found that there was little or no leakage through the 3-inch space between the shaft and the bottom of the crib, the water having been shut off by the settlement of the crib. Heavy timber guides were placed about the shaft, thus securing its sinking in a plumb position.

The shaft consisted of thirteen sections of a cast-iron cylinder 10 feet internal diameter and 8 feet high, bolted together by internal flanges. The cast-iron shaft was underpinned at a depth of 92 feet below datum by a 12-inch brick shaft to a sump, making the total height or depth 111 feet 4 inches to top, and standing 11 feet 4 inches above city dature (about water's edge).

The material excavated was mostly loam and clay, no pump being required in the shaft, although we stopped 12 inches above a water-bearing strata. In fact, water was thrown down the shaft to wet the miners' spades. About 160 tons of pig-iron was piled upon the shaft to force it to the required depth, this being nearly 160 pounds per square foot of shaft in the ground.

The inlet gates were placed in the third section from the top, and are entirely submerged; they are operated from the top by means of screws. These gates would entirely shut off the water from the city, should the tunnels ever need repairs. All sliding parts of the gates are faced with brass in order to avoid rust.

I have mentioned no losses as being sustained by the Fitz-Simons & Connell Co., during this construction on account of storms, but they were not a few. We consider ourselves extremely fortunate in being able to say that only one life was lost during the continuance of the work, and that by drowning. Although the top of the structure is 16 feet above the water, on several occasions have the waves gone clear over this wall, throwing solid water into the inner well.

At the present date the 8-foot tunnel has progressed about 300 feet from the four-mile crib shaft in shore (under another contractor) and is making good progress daily.

NOTES FROM MECHANICAL ENGINEERING THESES.

The Heating Power of Illinois Coal.

In the accompanying table is given a summary of the results of analyses and tests of samples of Illinois coal made by Messrs. R. B. McConney, '89 (A), and F. H. Clark, '90 (B), together with the results obtained from samples of Youghiogheny coal which are inserted for comparison. The samples were, in nearly all cases, taken from the cars as received in Champaign, the object being to obtain a fair average sample of the commercial coal in every instance. The percentage of moisture, volatile matter, fixed carbon, and ash were determined by the usual laboratory methods. The heating power was determined by burning samples of the coal in a water calorimeter of the form described in the *American Engineer* for June 12, 1889. In this method 2 grams of pulverized coal are mixed with say 7.5 grams of potassium chlorate ($KClO_3$) and 2.5 grams of potassium nitrate (KNO_3). The mixture is placed in a deep crucible, a fuse is inserted and lighted, and the crucible is then covered with a cylindrical cup which is perforated near its edge with many small holes. The crucible and inverted cup are then placed in a known weight of water at a known temperature. The gases of combustion given off escape through the small holes and thence through the surrounding water, the temperature of which is therefore raised. This rise of temperature is the basis of the calculation of the heating power. In Mr. McConney's tests the proportions of coal, potassium chlorate, and potassium nitrate used were as already given. Mr. Clark found by a special series of tests that the highest results were obtained with the proportions 2 grams coal; 13.5 grams $KClO_3$; 4.5 grams KNO_3, and these proportions were used in his experiments. In both sets of tests the method followed was to burn three charges from the same sample; if the results agreed, the value so found was taken to be the heating power; if they did not agree, two more charges were burned and the average of all was taken in Mr. Clark's test as the heating power; but in Mr. McConney's tests, the results given are the mean between the value most frequently found in five tests and the maximum value. The average difference between the highest and lowest values for any one sample in Mr. Clark's tests is from .5 to .6 of one per cent of the tabulated values.

Heating Power of Illinois Coal.

Location of Mine.	Observer.	Heating Power B. T. U.	Volatile mat'r pr ct	Fixed carbon, per ct	Ash, per ct	Moisture, per cent.
LaSalle, LaSalle county	A	12,169	39.4	43.95	8.43	8.22
Peru, " "	A	11,829	37.19	47 2	6.61	9.00
Bloomington, McLean county	A	11,313	35.99	45.20	14 71	4 10
Oakwood, Vermillion county	B	12,528	37.55	46.0	8.65	7.8
Fairmount, " "	B	11,431	31.8	47.05	13.05	8.1
Danville, " "	B	12,285	32.35	53.0	3.65	11.0
" " "	A	12,506	43.70	45.37	6.15	4 78
" " "	A	11,655	37.07	46.43	10.88	5.62
Lincoln, Logan county	A	11,272	34.99	44.50	12.06	8.45
" " "	B	11,718	31.3	49 5	11.7	7.5
Mt. Pulaski, Logan county	A	11,360	35.82	46 53	9 97	7.68
Niantic, Macon county	A	11,529	36.25	47.4	8 47	7.88
" " "	B	11,529	34.15	45 5	8.5	11.85
Riverton, Sangamon county	A	11,633	35.39	48 45	9.78	6.38
" " "	B	12,096	38.45	44 3	6.15	11.1
Barclay, " "	A	11,205	35.67	46.25	10.71	7.37
Pana, Christian county	A	11,610	36.37	46.95	9.46	7.22
Assumption, Christian county	B	13,068	41.2	50.1	4 8	3.9
Mt. Olive, Macoupin county	A	11,441	35.43	44.49	11.11	7.97
" " "	B	11,772	35 0	51.5	8.2	5.3
Odin, Marion county	A	11,954	33.99	50.86	9.08	6 07
" " "	B	12,663	41.1	46.9	6.1	5 9
Kinmundy, Marion county	B	11,664	34.0	47.45	11.55	7.0
Sandoval, " "	A	11,959	35.07	50.86	6.88	7.19
Centralia, " "	A	11,781	38 18	45.50	8.04	8.28
DuQuoin, Perry county	A	12,170	32 03	53.69	7.44	6.84
" " "	B	12,393	30.35	54.08	8.9	6.67
Big Muddy, Franklin county	B	12,825	32.15	56.0	4.0	7.85
Carbondale, Jackson county	B	12,582	33.65	57.5	4.6	4.25
Youghiogheny, Pennsylvania	A	13,940	33.13	60.82	4 65	1.40
" "	B	14.256	35.8	58.1	5.4	7

Tests of a Smoke-Preventing Furnace.

During the winter of 1889–90 tests were made by Messrs. McKee and Gilliland ('90), of a steam jet smoke-preventing device as applied to two of the steam heating boilers at the University of Illinois. These boilers are of the Root type, each consisting of 100 4-inch tubes 9 feet long, and having 22.5 square feet of grate surface, and are used wholly for steam heating. The returns from the radiators and coils are connected to traps and thence to a tank from which the water is fed to the boilers by a steam pump. This pump is supplied with steam from a small vertical tubular boiler which also supplied steam to the jets of the smoke preventer at a gauge pressure at the boiler of from 35 to 40 pounds.

The arrangement for preventing smoke is as follows: Along each side of the furnace about 9 inches above the grate is a row of openings about ¾-inch in diameter and about 6½ inches from center to center. Each is formed by a cast-iron tube set in the brick work which may be compared to the outer tube of a Bunsen burner. Air is supplied to what corresponds to the side openings in a Bunsen burner from the ash pit by passages left in the brick work, one passage supplying two tubes. At the back end of each tube is a steam jet of which the opening is about one-sixteenth inch in diameter, corresponding in position to the gas jet in a Bunsen burner, which is supplied with steam by means of a ¾ inch steam pipe set in the brick work and connected to the small boiler previously mentioned. This pipe is doubled back and forth in the bridge wall, the object being to superheat the steam on its way to the jets.

Five pairs of tests were made in all, three with both main boilers in use, and two with single boilers. For each pair of tests, *i. e.*, one with jets in use and one without jets, the times were selected when the conditions were as nearly identical as possible. In all of the tests the evaporation in the main boilers was found to be slightly greater with the jets than without them, the average evaporation being increased from 5.16 pounds of water from and at 212° per pound of coal to 5.31, or about 2.9 per cent. But more coal was required for the small boiler when the jets were in use, so that taking the plant as a whole the efficiency with the jets in operation was found to be about 99 per cent. of that without the jets. After making allowance for the loss by radiation from the small boiler and for the steam used by the pump, both being determined by tests and calculation, it was found that 23.2 pounds of coal per hour were required to furnish steam to the jets.

As a smoke preventer the arrangement is fairly successful. The steam supply to the jets for each boiler is controlled by a ¾-inch globe valve. When these valves are opened about two turns, the smoke issuing from the chimney is reduced to a light cloud excepting at the time when the furnace doors are opened for firing. The rate of combustion is ordinarily about 13.5 pounds of coal per square foot of grate per hour.

A CLOCK FOR EVERYBODY.

Prof. Ira O. Baker.

Probably but few, if any, persons living to-day appreciate the inconvenience in matters involving the time of the day which existed before the invention, or even the wide distribution, of clocks and watches. In all countries until a comparatively late date, and in some even now, the diurnal revolution of the heavens, the rising, culmination, and setting of the sun and stars were the only means of telling the time of day. Owing to the cheapness of watches and clocks, and in no country are they as cheap or as good as in our own, the ability to tell time by the sun or stars is liable to become a lost art, if it is not already lost.

One object of this articie is to offer a few hints on the determination of time by simple observations of the heavens; and it will not have been written in vain if it shall incite even a few to observe the revolution of the heavens and contemplate the grandeur of the movements.

THE DAY CLOCK.

"The sun to rule by day." Remember, 1, That the meredian is a circle passing through the north point, the zenith, and the south point; 2, That the pole is on this meridian at an angle above the north horizon equal to the latitude of the observer (for a majority of the readers of this it is a little less than half way up from the north); 3, That the equator of the heavens is 90 degrees from the pole, *i. e.*, the equator passes through the east and west points and crosses the meridian at an angular distance south of the zenith equal to the latitude—a little more than half way up from the south.

When the sun is on the meridian it is 12 o'clock, noon. Imagine a line drawn from the east point of the horizon to the north pole, then when the sun is on this line it is 6 a. m. The straight edge of a card or pencil held very close to the eye will be of great assistance in tracing this line through the sky. Notice that in the summer the sun crosses this line long after sunrise, while in the winter it crosses the line before sunrise. Similarly a line drawn from the west point to the north pole is the 6 p. m. line. If the sun is half way between the 6 a. m. line and the meridian, it is 9 o'clock; if one-third of the way, 8 o'clock, etc., etc.

To those who have not tried it, this will seem like a rough way of determining the time, but it is astonishing how great accuracy can be attained by a little practice, particularly when the sun is near either 6 o'clock line. Experience seems to show that with a little practice any bright boy of fifteen can determine time by this method within fifteen minutes. The method is specially applicable in localities where the cardinal points are accurately marked as, for instance, in the West where the roads, fences, etc., run north and south, and east and west.

The time determined as above is apparent solar time, and differs from the time kept by a good clock. In the words of the household almanac, "the sun is fast" or "the sun is slow;" that is, time determined by the sun will be faster or slower than the true time according as the sun is "fast" or "slow." The common almanacs usually contain a column which shows for each day of the year how much the sun is fast or slow. An examination will show that about the first of November the sun time is 16 minutes *too fast*, and that the difference grows less for nearly two months either way from that date, when there is practically no difference between the two kinds of time. About the middle of February sun time is 14 minutes *too slow*, and the difference decreases each way from that date for about a month and a half, when the two practically agree again. For any other time of the year, the difference is inappreciable. Notice that sun time never differs more than about 15 minutes from the local time.

The time found and corrected as above is *local* time, and will differ from *railroad* time, which most clocks now keep, according as the observer is east or west of the meridian from which the railroads count their time. It is not necessary here to explain the method of making this correction.

THE NIGHT CLOCK.

"And the stars to rule by night." The ancients seem to have determined the time during the night by the rising, culmination, and setting of the various constellations. Euripides, who lived 480-407 B. C., makes the chorus in one of his plays ask the time in this form:

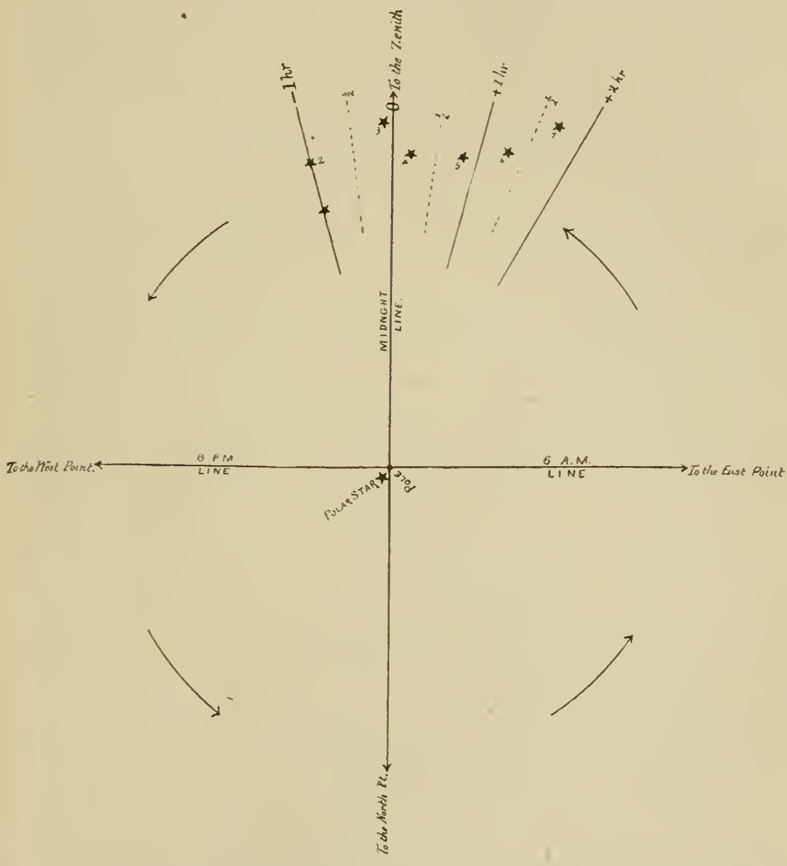
"What is the star now passing?"

And the answer is:

"The Pleiades show themselves in the East;
The eagle soars in the summit of heaven."

It must have required a prodigious memory to keep in mind the times of rising of the various constellations, particularly as they change from day to day.

It is not known that the method described below was used by the ancients, but it is probable that this and many somewhat similar devices were employed to tell the time. It would almost seem that the Creator, in his sympathy for those who are poor in the things of this world, has provided them with a clock of unapproachable magnitude, the dial plate of which is studded with jewels, and hung high in the northern heavens, where it has continued to mark off the hours with unerring certainty since the beginning of time itself. The Great Dipper, whose nightly revolutions about the pole has been observed by all, is the great night clock. An examination of the accompanying diagram will show how it marks off the hours.



At this time of the year (spring), the great dipper is to be found early in the evening high in the northeast; it moves west as the hours go by. The diagram represents this constellation when at its highest point. The dipper is composed of seven bright stars; the two marked 1 and 2 in the diagram are called the pointers, since they point nearly toward the north star. The stars of the dipper correspond to the figures on the clock face. In an ordinary clock the figures are fixed and the hands are movable; but in our great star clock the figures (stars) are movable, and the hand (the meridian) is stationary. The heavy lines shown in the diagram are one hour apart. Then, if the pointers are on the meridian, an hour thereafter afterwards, a point half-way between stars 3 and 4, will be on the meridian. The dotted lines indicate the half hours. Notice the method of numbering these lines. A little study will be required to fix in mind the positions of the several lines. Notice that there are two stars in each hour space. The + 2 line is as far beyond 7 as 7 is from 6. Notice that if lines were drawn through stars 4, 5, 6, and 7, they would indicate quarter hours, nearly.

On the 21st of March, when the line marked 0 coincides with the meridian, *i. e.*, when the line 0 points from the zenith to the north point of the horizon, it is 12 o'clock midnight. This is the time at which the diagram is set. When the line + 1 comes into the meridian, it is 1 o'clock; when + 2 is in the meridian, it is 2 o'clock; and when —1 is in the meridian it is 11 o'clock, etc. If the dotted line between stars 4 and 5 coincides with the meridian, it is half past 12 o'clock, etc.

When the line + 2 has passed by the meridian, the time can still be estimated by imagining a line +3 to be placed as far to the right of +2 as +1 is to the left; but before line +2 has passed very far by the meridian, the line —1 or the imaginary one —2 will have come into the 6 o'clock line on the west. If the line —1 coincides with the west 6 o'clock line, it is 5 a. m. Similarly, if the +2 line coincides with the 6 o'clock line on the *east*, it is 8 o'clock p. m. Thus between the two 6 o'clock lines and the meridians, it is possible to determine the time at almost any hour of the night. In the spring and summer, the 6 o'clock lines and the meridian above the pole will be used; and in the fall and winter, the 6 o'clock lines and the meridian below the pole must be employed.

Our great north clock is a sidereal clock; it keeps star time, of which 366¼ days make a year. As compared with common clocks, it gains a day in a year; hence, it gains nearly four minutes in a day, or, to be a little more accurate, it gains each day four minutes lacking four seconds, *i. e.*, 3 min. 56 sec. The two kinds of time agree on the 21st of March, but for any other time of the year the star clock is too fast. Suppose that on the 21st of April it is 12 o'clock midnight by the north clock, what is the true time? The 21st of April is 30 days after the 21st of March, and hence the star clock has gained 30 times 4 minutes, which equals 2 hours, or more exactly the gain is 2 hours lacking 2 minutes; therefore, on the given date, 12 o'clock by the north clock corresponds to 2 minutes before 10 o'clock p. m.

The computation necessary to correct the north clock is greatly simplified by noticing that the gain in 3 months is 6 hours. For example, if on the 21st of June the north clock indicates 12 midnight, we know immediately that the clock is 6 hours fast, and that therefore the true time is 6 p. m. If on the 21st of July the north clock indicates 6 a. m., we find the true time by remembering that the star clock was six hours fast on the 21st of June, and that it has gained 2 hours since, and hence is 8 hours fast; therefore the true time is 10 p. m. Similarly for other times of the year. With a little practice these explanations are readily comprehended and easily remembered. It is astonishing what degree of accuracy can be attained by a little practice.

To those studying astronomy, the north clock affords a simple and easy method of determining the right ascension of any particular star, and is, therefore, a great help in finding the objects described by the text-books. In times past, the writer's students in descriptive astronomy reported that this device was very useful to them for this purpose.

CURBS AND GUTTERS.

F. R. Williamson, '92.

The thickness and depth of curbs, and the form and size of gutters can not be computed from theoretical considerations, but must be determined by a careful study of practice. In this article will be briefly given some results of practice.

Curbs.

The minimum height above the gutter may be put at 3 inches, while the maximum will depend upon the height of the sidewalk above the gutter. The depth below the upper surface of the gutter varies in practice from 10 to 15 inches, but with a concrete foundation it may be less. In the ordinary form of curb, the thickness ranges from 3 to 6 inches, and the lengths most commonly used range from 2 to 6 feet. For foundation, sand and gravel are largely used. Concrete is now rapidly gaining favor, as it permits a curb of much less depth, and at the same time makes a firmer base. The curb is sometimes set vertically but more generally it is given a slight batter, in which case the top is usually dressed horizontal and flush with the sidewalk.

Gutters.

On many streets no special form of gutter is used other than that formed by the curb and the crown of the street, while on equally as many others some form of gutter is provided. In the latter case the surface of the gutter may be either flat or slightly concave. The gutters are generally constructed of the same material as the street pavement, but in the case of cobble stone pavements a flat stone 1 foot or more wide is placed in the middle of the gutter.

Examples.

In the report for 1889 of the Engineering Department of Washington, D. C., are given the following specifications. *For Standard Granite Curb:* Length to be not less than 6 feet, depth not less than 20 inches nor more than 24 inches, thickness 6 inches, base must average not less than 6 inches in width. The curb must

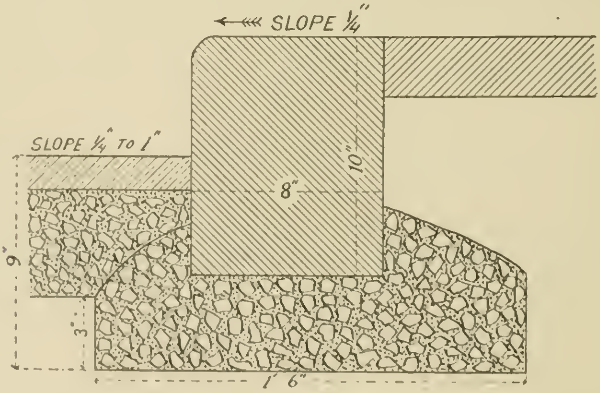


Fig. 1. Granite Curb.—Washington, D. C.

be dressed 12 inches on the face, 3 inches on the back, 6 inches deep at the joints, and the top beveled ¼ inch. *For Blue Stone*

Curb: The specifications are the same as above except that the length must not be less than 4 feet, nor the thickness less than 5 inches. *For Special Granite Curb* (Fig. 1): Length not less than 6 feet, thickness 8 inches, depth not less than 8 inches nor more than 10 inches, dressed on top the full depth of the face, and 3 inches on the back, and the top beveled ¼ inch.

In the very valuable series of papers on Municipal Engineering in *Engineering News*, Vol. 17, the standard curb and gutter of Philadelphia is described. See Fig. 2.

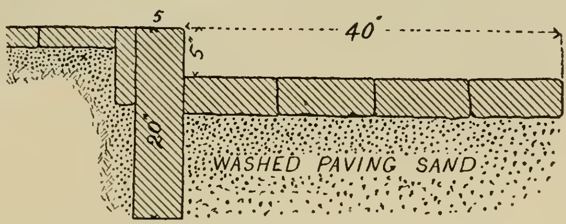


FIG. 2. CURB AND GUTTER.—PHILADELPHIA.

The thickness of the curb is 5 inches, depth 20 inches, and length 6 feet. The gutter is 5 inches deep, except at inlets where it varies from 7 to 10 inches. The bottom of the gutter consists of a flat stone about 10 inches wide, and 3 to 5 feet long, laid 5 to 8 inches below the top of the curb.

In Cincinnati, Ohio, one of the standard forms of curbs is 4 to 5 inches thick, not less than 21 inches deep, and 3 feet long; dressed 10 inches on the ends, 12 inches on the face, and 3 inches on the back; set on 2 inches of packed sand and gravel, with a batter of 1¼ inches, forming a right angle with the gutter flag. Stones are placed back of the bottom of each curb to help counteract the pressure of the sidewalk. The gutter flags are not less than 3 feet long, about 6 inches thick, and 16 inches wide; are cut on the side next to the curb, the top hammer dressed, the ends dressed and squared to make ¼ inch joints 3 inches deep; and are set upon a 6-inch bed of gravel. The ordinary depth of gutter is 7 inches.

Through the courtesy of William T. Rossell, Captain of Engineers, U. S. A., I am enabled to give a brief description of the combination curb and gutter used in Washington, D. C.

Fig. 3 shows the general section, and Fig. 4 shows a horizontal view and a vertical section at hand-hole.

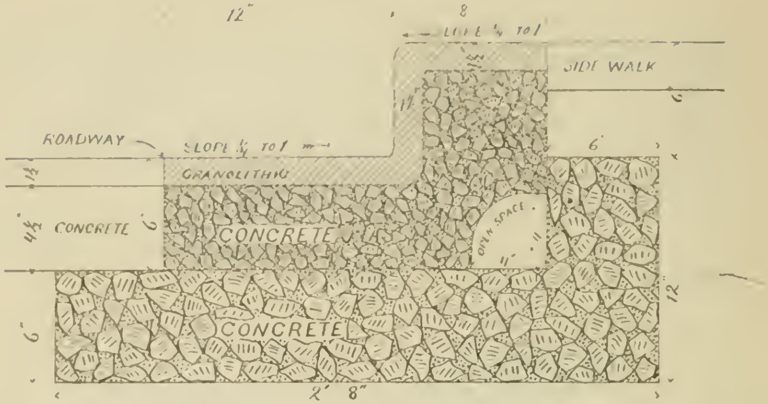


FIG. 3. COMBINATION CURB AND GUTTER.—WASHINGTON, D. C.

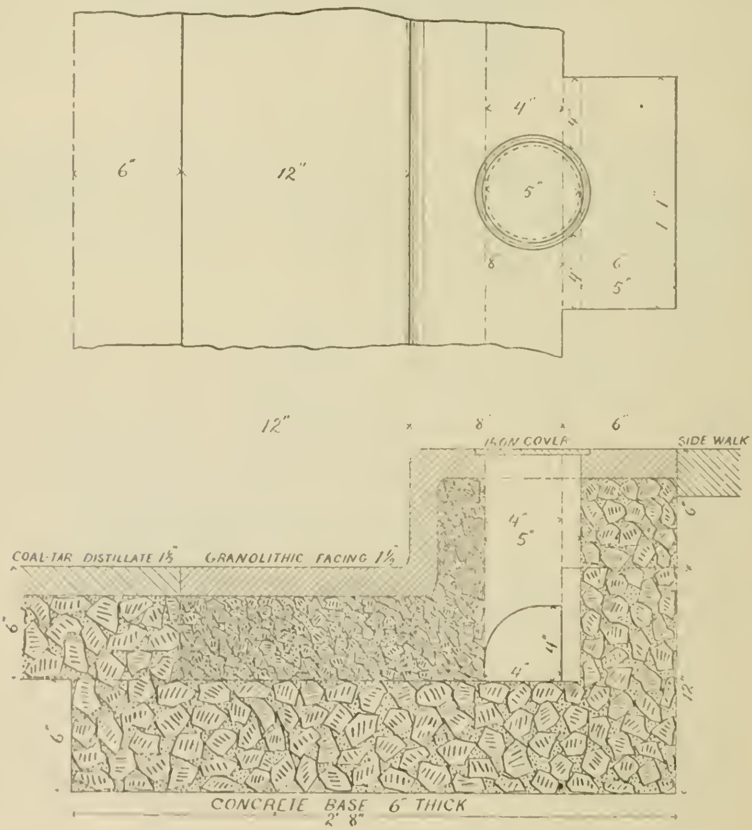


FIG. 4. HAND-HOLE IN COMBINATION CURB AND GUTTER.—
WASHINGTON, D. C.

The dimensions and general plan are as shown in the cuts. The combined curb and gutter consists of concrete composed of one part Portland cement, two parts clean sharp sand, and three parts clean stone broken to pass a 1-inch ring. The exposed surfaces of both gutter and curb are coated 1½ inches thick with a mortar composed of three parts granulated granite and two parts cement. The curb and gutter are sawed, at intervals of 8 or 10 feet, to allow for expansion and contraction and to give the appearance of cut stone. A conduit, 4 by 4 inches, for electrical conductors is left at the base of the curb if so ordered by the Engineer Commissioner. Hand-holes, to give access to this conduit, are left at intervals of about 50 feet.

A REMARKABLE SINK-HOLE.

By R. A. Mather, '92.

Sixteen miles west of Chicago on the Chicago, Burlington & Quincy Railway, there is a remarkable sink-hole. As the east-bound train passes from a 20-feet cut, a passenger may observe a small flat, some 15 or 16 feet below grade, 1,000 feet across and extending half a mile on either side the track. This flat is grown over with slough grass and cats'-tails, and is partly covered with water. When the grading for the first two tracks was done several years ago, trouble was caused by the sinking of the embankment. Piles were driven but to no avail. The roadbed was completed by filling in until the embankment stopped sinking.

Last summer when the embankment was being widened for a third track, it again began to sink, sometimes from 1 to 3 feet in a night and sinking altogether 40 feet. For two months a large construction gang worked steadily on the fill without gaining a foot. The earth under the embankment, instead of becoming more compact was pressed out and up, actually moving the telegraph poles 12 feet farther from the track and raising a ridge 10 feet high. As there is an end to all things, equilibrium was finally established and the track brought to grade.

About 95,000 cubic yards of gravel and dirt were required to fill the sink. The cost of labor and material for the 1,000 feet of embankment, including the new roadbed and the fill on the old one, was $10,000, or $10 a linear foot, about seven-tenths of which was owing to the sink-hole. Trains had to slow up to 4 miles an hour, which added much to the expense, particularly as some days more than a hundred trains passed over the road.

No borings were made to determine the strata, which perhaps was not wise, since a complete knowledge of the ground might have led to a plan which would have saved considerable expense.

The flat is underlaid by a stratum of Niagara limestone. Although underground caves are often found in strata of rock, yet this can not explain the sinking, for the roadbed would have sunk rapidly rather than gradually, had the dome of a cave which supported it suddenly given away. Besides, this would not explain why the earth was displaced along the sides of the embankment. Apparently the roadbed rests upon either a bed of quicksand or a bed of clay saturated with water. Either material, with bed-rock under it and a tough crust of earth over it, would have a tendency to transmit pressure to all confining surfaces. When a load great enough to exceed its ultimate strength was put upon the crust, it gave way thus transmitting the pressure to the quicksand or saturated clay below. The sand or clay in turn transmitted the force of the load, as upward pressure, against the under side of the surrounding crust. As the load of the embankment was increased, the upward pressure against the crust increased until finally the surface in the neighborhood of the telegraph poles was raised into a ridge. The quicksand or saturated clay followed the displacement of the crust, while the embankment followed the displacement of the quicksand or clay. As more dirt was added to fill the sink, the load was increased, at last producing such a strain on the ridge that it cracked open, leaving a gap 2 or 3 feet wide.

ROPE DRIVING.

By F. L. Bunton, '91.

The transmission of power by rope, cotton, hemp, rawhide, or manilla is fast taking the place of gearing and leather belting for large powers, and where the distance between the power and the work is comparatively great.

Cotton rope is the most generally used in England, where it is said to be the best, but as a greater part of the applications are in cotton factories its extensive use is readily understood. Hemp, rawhide and manilla are used extensively in the United States. The average duration of manilla rope is about six months. Rawhide is guaranteed for three years. One drive of ten coils of 1¼-inch manilla rope in an electric plant in Chicago was used twelve months before it broke. A transmission at the Rookery Building, Chicago; of twenty coils of ⅞-inch rawhide rope, transmitting 225 H. P., was used two years, and was spliced but once during that time.

Cotton is more extensible than the others; hemp and manilla are about the same in regard to extensibility and flexibility, while rawhide does not form to the pully quite so readily nor stretch so rapidly. When the latter becomes set to the pully it maintains its original cross-section more nearly than any of the other kinds. Care should be taken in splicing, long splices being better than short, as a more uniform cross-section is given to the rope and sudden enlargements cause abrupt changes in velocity, when passing over the pulley. The Chicago Link-Belt Machinery Co. make their splices from twelve to twenty-five feet in length.

Mr. C. W. Hunt* recommends a working-stress of $\frac{1}{36}$ of the breaking strength, while the Link-Belt Machinery Co., of Chicago, use $\frac{1}{33}$ of the breaking strength. Mr. W. H. Booth† says 5,000 feet per minute is the best speed, and Mr. Hunt advises 4,800 feet per minute. These are both reasonable speeds, but above 6,000 feet per minute, the loss by centrifugal action is much increased.

In order to show how difficult it is to slip the rope in the groove, the Chicago Link-Belt Machinery Co. attached a 50-lb. weight to a ⅞-inch manilla rope, and on a 24-inch pully with a 45-degree angle in its face, a weight of 350 lbs. at the other end was necessary in order to slip the rope in the groove. Let T_2 = tension on the driving side, T_1 = tension on the following side, Y = co-efficient of friction, and N = arc of contact in fraction of the circumference. According to Unwin's formula, $\log. \frac{T_2}{T_1} = 2.729\,NY$, whence $\log. \frac{T_2}{T_1} = \log. \frac{350}{50} = \log. 7 = .845098$, $N = .5$, therefore for this case the co-efficient of friction $Y = .619$. Ropes do not drive pulleys by adhesion alone, but it is more by wedging action due to the angle of the grooves.

Rope is not very expensive, and compares favorably with belting and gearing. Its noiseless movement, evenness of transmission,

* Transations of A. S. M. E., 1890.

† American Machinist, 12-8-88.

and exact alignment being unnecessary, place it far in advance for long transmissions.

The following table contains data taken from several rope transmissions in Chicago. The horse-power in the table is that which the plant was transmitting at that time. The values T_2, T_1, Y, are solved by Unwin's formulas, previously given. The co-efficient of friction being .731 in every case and 45-degree angles in all of the grooves. The first ten transmissions are run by manilla rope, the next five by rawhide, and No. 16 by cotton rope.

No. of drive.	No. of coils of rope.	Diameter of rope.	Horse-power transmitted.	Distance between centers, in feet.	Diameter of driver in feet.	Diameter of follower in feet.	Revolutions of driver per minute.	Revolutions of follower per minute.	Arc of contact for small pulley.	Velocity of rope in feet per second.	$T_2 - T_1 = P$ = the driving force per rope in lbs.	T_2 = Tension on the driving side per rope in lbs.	$T_2 - T_1$ at 1,000 feet per min. in lbs. per rope.	T_2 at 1,000 feet per minute in lbs. per rope.	Weight of Tension Weight in lbs.
1	2	.75	2	15'3"	4.5	1.33	200	675	.462	47.12	10.155	11.56	28.71	32.610	36
2	2	.75	32	15'3"	4.5	1.42	200	635	.468	47.102	186.830	221.41	528.00	597.500	96.8
3	20	.875	225	32	10.0	3.83	106	276	.469	55.397	111.794	126.348	371.25	419.957	900
4	7	.875	21	18	10.0	3.33	85	255	.439	44.506	37.074	42.70	99.00	114.46	220.1
5	3	.875	19	14	6.0	1.75	255	834	.454	80.085	43.510	49.56	209.00	238.60	28.08
6	4	.875	20	25	8.0	2.00	60	240	.464	41.890	65.67	73.17	165.00	183.46	100.00
7	10	1.25	450	20	15.0	7.00	130	280	.437	102 630	241.058	278.60	1485.00	1715.56	300.00
8	4	1.25	175	25	8 0	2.00	60	240	.464	25.132	957.42	1086.30	1443.75	1638.11	150.00
9	6	1.75	98	35	16.0	5.00	75	240	.450	62.830	142.97	163.60	539.00	616.75	No wt.
10	10	1.75	52	44	5.0	18.00	75	21	.450	19.64	145.6	166.6	171.6	196.35	No wt.
11	2	.75	224	18	4.0	1.33	275	825	.476	57.60	8.495	9.570	35.297	39.85	.100
12	5	.75	85	23	6.0	1.75	235	800	.495	73.304	318.9	350.47	429 00	478 20	56
13	10	.75	60	18	8.0	4.00	85	170	.464	35.605	92.68	105.164	198.00	224.66	311
14	1	.75	5	60	3.0	1.5	75	150	.496	11.78	233.42	260.07	165.00	183.83	No wt.
15	10	1.00	170	24	9.25	3.5	89	235	.460	43.066	217.1	246.93	561.00	1638.33	250
16	24	3.00	1,000	35	7.50	27.	62	17	.410	24.03	953.6	1124.65	1375.00	1621.94	No wt.

NOTES ON A RAILROAD RE-SURVEY.

By B. A. Wait, '92.

The road was one of the main trunk lines across northern Iowa. The route is for the most part through rolling prairie, and runs nearly at right angles to the largest streams. The company had only the location notes, and the object was to get complete notes of everything on the right-of-way, not only for maps but also for use in making a number of improvements.

The party consisted of a chief who was also transitman, two chainmen for track measurements, two chainmen for location of section corners, levelman, and rodman. In addition, two section-men were taken off of each successive section, one to drive stakes and one to dig for corners.

The transit was used only to run in the curves and to take the angles of the road with the land-lines. The transitman kept the hand-car just ahead of the chainmen, dropped the stakes, and took the notes. The chaining was done along the rail except around curves. The head chainman marked the stakes and laid them over the chain-marks on the rail. The stakes were driven, by one of the section-men, seven feet to the right of the center of the track. The rear-chainman gave the distance out by measuring with a pole from the edge of the rail. The rear-chainman read all "pluses," and in running in curves acted as rear-flagman.

The beginning and ending of curves were set by eye by sighting along the rail for some distance back, except on very light curves, when they were set with the transit. The transit was set over these points and the deflections were taken at every 100-ft. station. The tangent points could be set correctly within five feet by eye, and this is accurate enough where the back-sights are of considerable length. This method is shorter than setting them with the transit, unless the beginning of the curve can be set from the end of the preceding one.

Levels were taken at every station, one on top of the tie and another on the natural surface. Readings were also taken at the bottom of all culverts, streams, and cattle-passes. Elevations of high-water marks were taken whenever possible. Bench-marks were established every half-mile. The benches were made by driving spikes into telegraph poles or signal posts, or they were taken on some part of the depots or other buildings.

The land-line party measured on all section-lines both ways from the track to the nearest established corner of that section. If a section corner was found within one hundred feet of the track no measurements were taken on the other side. In many places the highways had been graded over the corners, and the pick and shovel carried by the second section-man were necessary. About eighty-five per cent of the corners looked for were found, and nearly one half of those were covered. The corners covered over a foot deep were rarely found. When the corners were found they were always "tied in" from the sides of the roads or from fence corners. The head chainman kept the notes. Distances to all streams were recorded, as well as the depth of the water and length of the bridge.

A tracing of the plat of every town was made from the records at the county seat, and enough angles and measurements were taken to connect the surveys of the road with that of the town. Everything on the right-of-way was located with reference to the track. The notes of station-ground surveys were recorded in a book for that purpose. The sketches were made on a scale of fifty or a hundred feet to the inch. The station surveys were made by whichever party was ahead.

The transit book was one made for that survey. It was 8x9 inches, and on each page was a square divided into quarters to represent the section and its divisions. The track had been previously sketched in from an old map. The notes were recorded along the margin. All chain and transit notes, except station surveys, were recorded in this book. Streams and hills near the track were sketched in by the transitman.

The plan of the work kept all the parties together. The method was easy and expeditious, and all the data necessary was determined with sufficient accuracy.

SQUARE DRIFT-BOLTS.

By J. H. Powell, '91, and A. E. Harvey, '91.

In No. 4 of the "Selected Papers of the Civil Engineers' Club of the University of Illinois," John B. Tscharner gives a very thorough discussion of a series of experiments on the holding power of round drift-bolts. The writers made a series of experiments with square bolts to determine the best relation between the diameter of hole and the size of bolt, and also to determine the relative holding power of square and round bolts.

The experiments were made with the University testing machine. The bolts were of steel, 1-inch square, about 30 inches long, the ends square except that the sharp edges were hammered down slightly. The timber used was pine, about such as that used in Mr. Tscharner's experiments. Holes $\frac{16}{16}$, $\frac{15}{16}$, $\frac{14}{16}$, and $\frac{13}{16}$-inches in diameter were bored as nearly as possible perpendicular to the face and grain of the timber. The rods were driven with a sledge to a depth of 6 inches, care being taken to start the rod centrally over the hole.

As a result of the 20 tests, 5 for each sized hole, the average holding power was found to be as in Table I.

TABLE I.

Size of Rod.	Size of Hole.	Holding Power in Pounds.	
		6 inches Depth.	Per inch of Depth.
1 inch square.	$\frac{16}{16}$ inches.	3972	662
1 inch square.	$\frac{15}{16}$ inches.	4260	710
1 inch square.	$\frac{14}{16}$ inches.	4660	777
1 inch square.	$\frac{13}{16}$ inches.	4050	675

From the table we see that a $\frac{14}{16}$-inch hole gives the maximum holding power.

After the bolts were withdrawn the timber was split and the condition of the wood surrounding the holes examined, from which it appeared that in the holes larger than $\frac{14}{16}$ inches, only the corners of the bolt had held effectively; while in the smaller holes the wood fibers were so crushed and torn as to largely decrease their power to hold the bolt.

As compared with Mr. Tscharner's conclusions our experiments seem to show that for holes of the same size but larger than $\frac{13}{16}$ inches (the size which he found to give a maximum holding power for 1-inch round rods), the holding power of the 1-inch square bolt is greater than that of the 1-inch round bolt, the quality of the timber being the same in both cases. (See Table II.)

TABLE II.

DIAMETER OF HOLE.	$\frac{16}{16}$	$\frac{15}{16}$	$\frac{14}{16}$	$\frac{13}{16}$
Round Rod	....	375 lbs.	633 lbs.	788 lbs.
Square Rod	662 lbs.	710 lbs.	777 lbs.	675 lbs.

Table II. shows the holding power per inch of depth of a 1-inch round rod and a 1-inch square rod in different sized holes. From the table it is seen that the maximum holding power of the round rod is greater than that of the square rod. Since the cost of boring and driving is the same in each case, and since the amount of iron in the round rod is only 0.7854 of that in the square one, we must decide that round drift-bolts have the advantage over square ones, both as regards holding power and economy.

COST OF BRICK PAVEMENTS.

By A. D. Thompson, '93.

Brick have been used for paving purposes in this country and in Europe until brick pavements are no longer an experiment. They have been tested under all conditions, and have fulfilled the requirements of a good pavement far beyond the expectations of engineers. Because of the cheapness, noiselessness, and durability of brick pavements, many cities are investigating the merits of this paving with a view to adopting it, and there is a call for data on the subject. This call has been amply responded to in all cases but the cost. Since this is a matter of such wide interest, it seems proper that central Illinois, which may be called the home of brick pavements, should give some data on this part of the question.

This pavement is laid with one course of brick and with two courses of brick, the former method being, of course, the cheaper.

In the latter method, the ground is first brought to the required grade and convexity. Then from three to five inches of gravel or cinders is placed on this and thoroughly rolled. This is followed by a course of brick laid flat with their length parallel to the street, all joints being well broken. One inch of sand comes next, and is followed by a course of brick on edge with their length at right angles to the curbing and with the joints well broken. This course is tamped and rolled thoroughly, and then fine sand is broomed into the joints and about one-half inch of sand is left on top.

In the one-course method, the ground is brought to the required grade and convexity, and is rolled solid. On this is placed from five to seven inches of gravel tamped and rolled solid. The brick is then laid on edge in about two inches of clean sand. The length is laid at right angles to the curbing, all joints being well broken. After this has been rolled and tamped thoroughly, about one half inch of sand is broomed into the joints.

It is evident that the only ways in which this method differs from the two-course method are:—1st, one course of brick is done away with; 2d, more work is necessary in preparing the ground and in the gravel foundation; and 3d, more gravel is used.

Of course the cost of such work will vary with the conditions existing at different places, and with the nearness of material, amount of grading, and cost of labor. Below are the particulars for work done in Illinois.

In all the cases cited the grading was comparatively light, and labor cost from $1.25 to $1.60 per day.

Bloomington was one of the first cities to test this method of paving, having laid the first in 1874. Since then, about 160,000 square yards have been put down at a cost of about $1.65 per square yard. The brick used are 2x4x8 inches and cost from $8.00 to $8.50 per thousand. They are manufactured in the city. Sand cost 80 cents per cubic yard delivered. Cinders were employed for a foundation.

Decatur has about 235,000 square yards of brick pavement, which is the most of any city in central Illinois. It has all been laid since 1884 at a cost of from $1.34 to $1.50 per square yard. Two grades of brick were used in the work. The bottom course, or softer burned brick, are 2⅜x4x8 inches and cost $8.00 per thousand; while the top course, or harder burned brick, are 2¼x3½x7½ inches and cost $9.00 per thousand. The brick are made in the city. The sand cost 75 cents and gravel 60 cents per cubic yard.

Champaign laid about 7,000 square yards of brick pavement in 1885 at a total cost of $1.87 per square yard. Last year 7,000 square yards were laid at a cost of $1.57 per square yard. The brick are 2x4x8 inches, of which 120 lay a square yard. They are made in the city and cost $9.00 per thousand delivered. The contractor made the following estimate of the cost per square yard, including profit: Grading, 9 cts, the dirt to be moved not more than 400 ft; gravel and sand, using gravel for foundation, 15 cts; brick, at $9.00 per thousand, $1.08; plank curbing, per square yard of pavement, 5 cts; laying and tamping the brick, 15 cts; sundry expenses, 5 cts; making a total of $1.57 per square yard.

Springfield has laid about 10,000 square yards within the past three years, at a cost of from $1.48 to $1.62 per square yard. The brick used are 2 x 4 x 8 inches and cost $9.00 per thousand delivered on the ground. Sand and gravel cost $1.50 per cubic yard delivered on cars at Springfield.

Danville laid about 26,500 square yards of brick pavement last year, at a cost of $1.45 per square yard. Two kinds of brick were used promiscuously,—one from Bloomington and the other from Grape Creek. The Bloomington brick are 2x4x8 inches and cost from $8.00 to $8.50 per thousand delivered on cars at Bloomington. The Grape Creek brick are 4x4x12 inches.

The only city using the one-course system of brick in central Illinois is Peoria. Considerable pavement has been laid in that city at a cost of from $1.50 to $1.70 per square yard. The brick are 4x5x12 inches, and thus by laying only one course the pavement is five inches deep against six inches where the two-course system is used with common sized brick. Sand and gravel cost from 75 cts to 90 cts on the streets.

Steubenville, O., uses only one course of common sized brick, which has cost from 95 cts to $1.00 per square yard. The one-course method with common sized brick is well adapted to cities having light traffic, and is being adopted by many of the smaller cities.

In all of these cases, the first cost, or contract price, has been given. The cost of repairs has been omitted because whenever any repairs have been necessary, the cost has been too small to be taken into consideration.

INTERLOCKED VS. UNPROTECTED RAILROAD GRADE CROSSINGS.

By W. M. Hay, '91.

The rapid growth of the network of railroads of this country has been marvelous. As this network becomes more and more interlaced, the number of railroad crossings is greatly increased. This fact has become a potent and perplexing question, especially to railroad managers, who desire to know to what extent they may oppose a new road from crossing their established lines. When railroad crossings can not be avoided, the question arises as to what should be done to reduce their disadvantages to a minimum. It therefore remains to determine from an economical standpoint whether the new line shall cross the old one at grade, that is, on a level, or by an over or an under crossing. If at grade, the question then arises as to the advisability of establishing an interlocking switch and signal system at such a crossing, whereby the usual stop may be avoided.

That such problems as the above present themselves for consideration, there is no doubt; yet that they are very frequently ignored, is proven by the fact that over nine tenths of the crossings of Illinois are unprotected grade crossings. The remainder of the crossings either are provided with interlocking and signaling apparatus, or are over or under crossings. An act of the State Legislature, passed in 1887, provides that when a system of approved interlocking switch and signal apparatus shall be constructed and maintained at any crossing which shall prevent the possibility of trains colliding, then trains may pass over such crossing without first coming to a stop. Laws of essentially the same nature have been passed in many of the states. In the eastern states advantage of such laws has been taken, and interlocking and signaling devices are rapidly coming into more general use. The time and expense involved in stopping trains at unprotected grade crossings, shows that the day can not be far distant when all railroads will find it to their interest to provide interlocking devices at such places. These appliances would afford not only greater safety, higher speed, and more convenience to the traveling public, but (as is shown farther on) would also reduce the operating expenses of the road.

As is well known, an interlocked grade crossing is one which is provided with signals and switches located at certain points near the crossing and operated by a series of interlocking levers, under control of an operator, in such a manner that it is impossible, either through the negligence of the operator or of the inattention of the engine-man, for two trains to collide at the crossing. The details of the interlocking and signaling apparatus for a single track grade crossing, are about as follows: At 300 feet each side of the crossing on both roads, derail switches are placed, which are operated by the interlocking levers in a tower at the crossing. To guard against the accidental opening of each switch when a train is passing over it, a thin iron bar, about 40 feet long, is hinged to the outside of the switch rail. This bar, called a detector bar, moves in a vertical plane and is so hung that it can not be moved lengthwise without being raised. It is so long that it can not be raised between the trucks of a car, thus making it impossible to move the switch while a train is passing over it. When the track is clear this bar is raised by the first movement of the lever which controls the switch. Near this switch the home signal is located. This signal is of the semaphore pattern and is placed on the engine-man's side of the track. The signal-blade is movable about its horizontal axis, and usually is painted red on the face farther from the crossing. The distant signal is located 1,200 feet beyond the home signal and is of similar pattern with the exception that the farther face of the blade is painted green.

All switches and signals are operated by the series of interlocking levers in the tower at the crossing. These levers are painted and numbered to correspond to the movements they control. The levers operating derail switches are painted black, the home signal levers red, and the distant signal levers green. The connection between the tower and the derailing switches is generally made by rods, and with the home and distant signals by wire. For a single track crossing six levers are generally required, two operating the four derailing switches, and four operating the four home and the four distant signals.

The normal position of all signals is at danger with derail switches open. To allow an approaching train on one road to pass the crossing, the man in the tower must first close the derail switches for that road by moving the switch lever operating these switches. This movement automatically locks the switch and signal levers of the other road and at the same time unlocks the signal levers of the first road. The signal man then moves the signal lever which operates the signals on the side of the approaching train, which first brings the home and then the distant signal to the safety position. The approaching train then has a clear track. After the train has passed, the signal man must first bring the distant and then the home signal to the danger position, before the derail switches can again be opened.

If, after the train has procured a clear track, an engine-man of an approaching train on the other road should attempt to cross, by disregarding the danger signals, his train would be derailed at the derailing switch, and the spirit of the law carried out, which says that the apparatus shall prevent the possibility of trains colliding at the crossing. Accidents of this nature have very seldom if ever occurred, and so far as can be ascertained not an accident has yet occurred through the fault of the interlocking apparatus.

Next, let the attention of the reader be turned to the expense of (1) the interlocked grade crossing, and (2) the unprotected grade crossing.

An interlocked grade crossing similar to that described above costs about $3,000, including cost of erection. The annual expense is however of much more importance than the first cost. As the levers demand constant attendance, the services of two men will be daily required, whose salaries may be taken at $45 per month each. This gives as the yearly cost of operation $45 x 12 x 2 = $1,080. The annual cost of repairs, inspection, depreciation, etc., will be about $120. The annual cost of operation and maintenance then is $1,200. As capital can generally be obtained at 5 per cent interest, the original cost of $3,000 may be procured at an annual expense of $3,000 x .05 = $150. Adding this to the cost of operation and maintenance we find that an annual outlay of $1,350 will be required to provide and maintain an interlocking switch and signal apparatus at a single track crossing.

Next, consider the expense of the unprotected grade crossing with the usual stopping of trains. Careful estimates make the expense of stopping a train from 35 to 75 cents, and sometimes more. Taking 40 cents as an average expense, independent of the kind and length of train, we find the expense per annum of a daily train to be $.40 x 365 = $146.00. Considering an average traffic of 10 daily trains each way for each road, we have $146.00 x 10 x 4= $5,840 as the total annual expense which the crossing brings to the two roads. This sum does not include the pay of a gateman who is oftentimes needed at such places.

Comparing the annual expense of interlocked grade crossing with the above result we find that as far as economical advantages are concerned the system of interlocking is far superior to the unprotected grade crossing. The reason then for the scarcity of interlocking devices is not at first thought so quickly apparent, yet if we examine into the question we may find several plausible, if not possible, reasons for this deficiency: 1. The roads may fail to agree upon what proportion of the annual expense each should bear, as one road may be benefited more than the other and yet refuse to pay more than half the expense. 2. The expense of stopping at a grade crossing is paid in loss of time, discomfort, wear and tear of the rolling stock, etc., and goes on continually, draining the resources of the company without notice; while the expense of interlocking is paid in cash and is thus much more noticeable. 3. Some roads may be so situated that they can not afford the additional cash outlay, or may be waiting for more improvements in interlocking devices. Whatever be the reasons, it is evident that an interlocking switch and signal apparatus under the conditions assumed above would more than pay for itself during the first year of its operation.

NOTES ON ALUMINUM AND ITS ALLOYS.

By E. S. Keene, '90.

The first researches in the preparation of aluminum date back to 1807, but it was not until 1854 that it was produced pure, and its properties determined. It was then considered one of the precious metals, and was valued at $240 per pound. Three years later the cost had been reduced to $32 per pound. A steady decrease has since continued until to-day, commercially pure aluminum can be bought for $1 per pound. It is not found in the metallic state, but occurs chiefly in the form of silicates, and in this form is more widely distributed than any of the other metals. Its cost is due to the difficulty in extracting the metal from the ores. In color it is a silvery white, but after being worked it has a slightly blueish tint.

Lightness is one of the most striking properties of aluminum. A cubic inch of the metal weighs .09 pounds, while an equal amount of cast-iron weighs .26 pounds, making aluminum therefore weigh about one-third as much as cast-iron. The specific gravity of cast aluminum, as determined by Prof. Stratton is, for 99 per cent pure, 2.622; for 97½ per cent pure, 2.647; aluminum with 10.6 per cent silicon, 2.645. Deville gave the specific gravity of pure aluminum as 2.56.

Aluminum is one of the most malleable and ductile of all metals. It may be hammered into sheets as thin as gold-leaf, or drawn into the finest wire. Its melting point, as given by different authorities, is from 1,200 to 1,400 degrees, F. Impurities help to raise the melting point. It is satisfactorily welded by electricity, but is very red-short, and will not bear hammering at a high heat. Although it may be rolled cold, aluminum is most malleable at about 300 degrees F. At above 400 degrees F. it becomes red-short. Cold-rolled, or hammered, it becomes hard, and requires frequent annealing to keep it from cracking. This is done by heating to about 800 degrees F., at which temperature a bar of iron will appear slightly red in the dark. Aluminum at this temperature will not appear red. This temperature may be determined in a practical way by drawing a pine stick across the surface, the mark of which will burn slowly away. After being heated the metal should be allowed to cool very gradually. Light articles may be annealed by plunging into water after being heated. Wire may be annealed by placing it in boiling water and allowing it to cool with water.

In experimenting with its effects in cast-iron, J. W. Keep has found that aluminum turns the combined carbon to graphite, that is, turns a white iron-gray. It also aids in increasing tensile strength and aids in obtaining sound castings, which are susceptible of a high polish and are free from oxidation. The same writer found that in wrought-iron and steel castings aluminum prevented blow holes, raised the tensile strength, and doubled the power to resist shock.

In order to find a better and cheaper substitute for German silver, which industry in the United States amounts to upwards of $6,000,000 annually, Eugene H. Cowles, after experimenting with upwards of two hundred different mixtures, found that the addition of 1.25 per cent of aluminum to a manganese, copper alloy, converted it from one of the most refractory of metals in the casting process into one of superior casting qualities and more non-corrodible in many instances than either German or nickel silver. This metal he calls silver bronze, and is composed of manganese 18, aluminum 1.25, silicon 5, zinc 13, and copper 67.5 per cent. Pure aluminum has been used for instruments of precision, but only to a limited extent. The pure metal is scarcely rigid enough, and the makers find that in working, the metal is apt to tear under the tool, and does not give clean threads. *Tiers Argent*, an alloy of 95 parts aluminum and 5 parts of silver, has been used, which gives better results, as, while it is not much heavier, it is more rigid, harder, and works better under tools. It withstands the corroding action of the atmosphere nearly as well as aluminum. An alloy of nickel and aluminum might be used for such purposes, as a small per cent of nickel hardens aluminum without destroying its other properties. As aluminum can be obtained absolutely free from iron, it can be used to advantage for apparatus where non-magnetic properties are required.

In the drawing press, as stated by Oberlin Smith, the metal does not appear to stand as much strain in bending as brass or "gelding," but in drawing will apparently stand more than either without annealing. Aluminum, therefore, has the very desirable property in drawing deep articles, it does not require the frequent annealings which are required in brass and iron.

Such excessive claims have been made for aluminum that the public has been led to believe that it might be used for anything, and that with cheap aluminum all other metals would be superseded. Although aluminum is a wonderful metal, there is no danger, as has been said, of its "revolutionizing the world." That it has some bad qualities is shown by the following statement, made by Alfred E. Hunt, President of the Pittsburgh Reduction Co., in a lecture before the Boston Society of Arts: "For many purposes the pure metal cannot be so advantageously used as that containing three or four per cent of impurities. The pure metal is very soft and not so strong as the impure. The thin coat of oxide which it gains on exposure gives it a pewtery appearance which makes it undesirable for table ware. It becomes pasty as low as 1,000 degrees F., melts at 1,300 degrees F., and loses its tensile strength and much of its rigidity as low as 400 to 500 degrees. It is inferior to copper as a conductor of electricity; in fact, it is only half as good. Its lack of rigidity is an obstacle to its use for many purposes, such as castings. In rolling it, not nearly so much draft can be given in the rolls as in the case of rolling steel. In cold rolling it requires to be annealed oftener than steel. Alloys of the metal increase its brittleness more than they do its hardness. Its tensile strength per square inch is not greater than that of common cast-iron, and only about one-third that of structural steel, while its compressive strength is less than one-sixth that of cast-iron. The modulus of elasticity of cast-aluminum is about 11,000,000, being only one-half that of cast-iron and one-third that of steel. Under transverse test, a one inch square bar of cast iron, four feet, six inches between supports, will sustain a load of 500 pounds, with a deflection of two inches, while a similar bar of aluminum would deflect over two inches with a load of 250 pounds."

It combines with iron in all proportions, but none of the alloys with that metal are valuable except those with very small per centages of aluminum. The addition of aluminum does not lower the melting point of steel, as has been claimed, nor does it increase its fluidity.

Ten per cent aluminum bronze (ten per cent of aluminum with ninety per cent of copper) has a tensile strength of from 70,000 to 75,000 pounds per square inch in castings. Rolled into plates, the tensile strength is from 100,000 to 120,000 pounds per square inch. It is a very close, dense metal of a beautiful yellow color and susceptible of taking a very high polish. Unlike any other varieties of bronze, which are red-short, it may be worked at a high heat as easily as wrought-iron. One great advantage it has over other varieties of bronze or brass is that it is comparatively free from oxidation in the air. In castings it has a specific gravity of about 7.8. Its melting point is about the same as ordinary brass. Five per cent bronze has a tensile strength of about 60,000 pounds per square inch. In seven per cent bronze the tensile strength is from 60,000 to 70,000 pounds per square inch.

The following tables show tests, made by the writer, on cast aluminum and aluminum bronze. The metal used in the test was kindly furnished by the Pittsburgh Reduction Co., of Pittsburgh, Pa. The pieces were ingots, each ingot being cut into two or more test pieces. The pieces used in the tests for tensile strength were melted and cast into cylinders for the compression tests.

The flow of the metal under tensile test seems to be very local. The per cent of elongation reducing rapidly in increasing length from the point of fracture. Under compression the silicon and 99 per cent pieces kept their cylindrical shape to the point of fracture, but the 97½ per cent piece, at a load of 30,000 pounds, had become very much distorted. At 50,000, the 99 per cent piece was flattened to almost one-third its original length and showed a small crack in the side. The cracks in all of the pieces were in spiral form.

TENSILE TESTS.

		Sectional dimensions, inches.	Dimensions of reduced parts, inches.	Per cent. elongation.	Elastic limit, lbs. per square inch.	Ultimate strength per square in.
1	99 per cent. aluminum	.229 x .664	.1825x.515	23	5820	16180
2	99 per cent. "	.225 x .612	.173x.548	21	6500	17140
3	97½ per cent. "	.254 x .663	.232x.650	12.2	4540	10660
4	97½ per cent. "	.256 x .662	.218x.630	14.3	4600	12090
5	Al. with 10.6 silicon . .	.671 x .258	.661x.248	8.2	. . . .	18510
6	Al. with 10.6 silicon . .	.660 x .257	.658x.239	5	. . . .	19130
7	7 per cent. al. bronze.	.452 diam.	.412 diam.	13 3	33420	60210
8	7 per cent. al. bronze.	.433 diam.	.398 diam.	15 2	41230	64580
9	7 per cent. al. bronze.	.446 diam.	.408 diam.	12.4	26700	62350
10	5 per cent. al. bronze.	.458 diam.	.453 diam.	8	24300	57716
11	10 per cent. al. bronze	.305 diam.	.288 diam.	19.2	48700	74790
12	10 per cent. al. bronze	.312 diam.	.293 diam.	18.	47600	72820

COMPRESSION TESTS.

Load, pounds.	99 per cent. aluminum. Length x Diameter, Inches.	97½ per cent. aluminum. Length x Diameter, Inches.	Aluminum with 10.6 per cent. Si. Length x Diameter, Inches.
0	1.299 x .965	1.548 x .974	1.175 x .983
500	1.298 x .965	1.548 x .974	1.173 x .983
1,000	1.298 x .965	1.546 x .974	1.173 x .983
1,500	1.298 x .965	1.545 x .974	1.172 x .983
2,000	1.296 x .966	1.543 x .9745	1.171 x .9835
3,000	1.294 x .967	1.537 x .976	1.171 x .9836
4,000	1.286 x .970	1.534 x .977	1.170 x .9838
5,000	1.279 x .972	1.529 x .979	1.168 x .984
6,000	1.267 x .976	1.526 x .981	1.167 x .984
7,000	1.252 x .983	......	1.167 x .9845
8,000	1.233 x .991	1.513 x .985	1.165 x .9842
9,000	1.212 x 1.000	......	1.164 x .9844
10,000	1.180 x 1.017	1.494 x .992	1.1626 x .9846
11,000	1.150 x 1.032	......	1.1614 x .986
12,000	1.116 x 1.050	1.458 x 1.007	1.160 x .9865
25,000	.748 x 1.288	1.108 x 1.187	1.078 x 1.073
31,600	......	Failed.	......
40,000	.515 x 1.55	......	......
41,300	......	......	Failed.
50,000	.482 x 1.612	......	......

EFFECT OF COUNTERBALANCE ON LOCOMOTIVES.

By S. D. Bawden, '90.

In the locomotive strong forces are at work, necessitating strong parts to stand the wear and tear of use, and one of the things for the engineer yet to overcome is the necessity of much weight to give corresponding strength. The weights thus used in the locomotive, and falling within the scope of this paper, may be separated into two classes—the reciprocating parts and the revolving parts. Of these, the revolving parts can be easily balanced, by placing equal weights on the opposite side of the axis of rotation; but the reciprocating parts vary in velocity, and therefore can be balanced by a given weight for only one position. It is possible to exactly balance the reciprocating parts at the dead centers, or at the quarters, or, indeed, at any point in the revolution, but they will not be balanced for other points. For this reason, with respect to the reciprocating parts on a locomotive, an approximate counterbalance is used, which gives an excess of weight in some positions, and less than the required amount in others. As the speed of the locomotive increases, the centrifugal effect of this excess of counterbalance increases, until it may become more than the portion of the weight of the locomotive assigned to the wheel in question. The purpose of this paper is to investigate somewhat the relation of this centrifugal force and the weight of the locomotive as transmitted through the driving-springs.

In the driving-wheel of the locomotive we have a crank-pin and its boss, which are eccentric with respect to the axis of revolution of the wheel. Neglecting the weight of the rim, spokes, etc., in Fig. 1., let

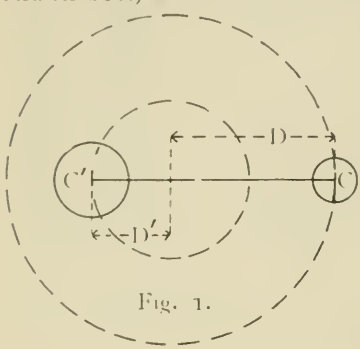


Fig. 1.

C = weight of the crank-pin and boss,

D = distance of center of gravity of C from axis.

Place opposite C a weight (C') at a distance (D') from the axis, so that

$$CD = C'D' \qquad (1)$$

Then these weights are in statical balance; *i. e.*, the wheel will be balanced in any position whatever in which it may be placed about the axis; and, as can easily be proved, the wheel will be also in running balance. Stating this as a rule—A running balance is a statical balance, and *vice versa*.

Next comes the question, whether, if we consider the weight of the wheel, its rim, spokes, etc., having the wheel in running and statical balance, and add an eccentric weight, the weights which have already been balanced will have any effect upon the new weight. As shown above, the revolving weights in the locomotive may easily be balanced but it is the reciprocating weights that cause the difficulty. On account of this, the builders of locomotives have experimented till they should find the proportion of the weights of the reciprocating parts which, placed opposite the crank-pin, would give the best effect. In this way they reduce the excess of counterbalance but do not remove it entirely, and it is this excess which is considered as an eccentric weight in the following discussion.

With the wheel in statical or running balance, the center of gravity lies in the axis. With an eccentric load added to the balanced load, the center of gravity is moved from the axis to some point between the eccentric load and the axis. In Fig. 2, let C, C', D, D', be as in Fig. 1. Added to C and C' is the weight of the rim,

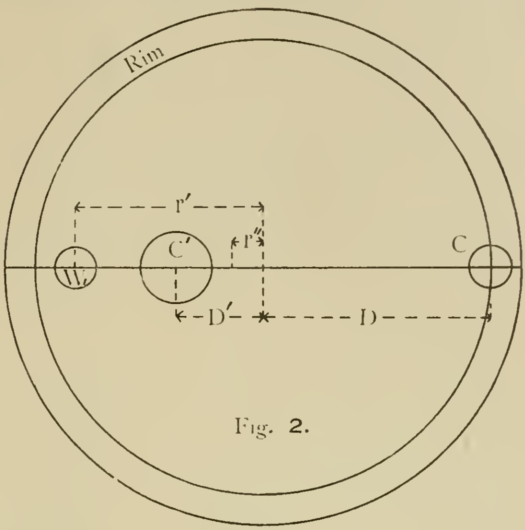


Fig. 2.

spokes, hub, etc. These are all to be considered as balanced, and fulfilling the conditions of Fig. 1. Then the center of gravity of all these weights will be at H, the axis of revolution.

Let W_0 = the balanced load = C+C'+Rim+etc.,

W_1 = the eccentric load,

r' = distance of center of gravity of eccentric load from axis,

r'' = distance of new center of gravity, after W_1 is added, from axis.

Then W_0+W_1 = weight of the whole wheel.

r'' is found from the relation,

$$(W_0+W_1)r''=W_1r' \qquad (2)$$

$$r''=\frac{W_1\,r'}{W+W_1} \qquad (3)$$

Let v'' = velocity of new center of gravity, as it revolves about axis, in feet per second,

v' = velocity of W_1 in feet per second.

$$\text{Then } \frac{W_1\,v'^2}{g\,r'}=F_1=\text{centrifugal force of } W_1 \qquad (4)$$

$$\frac{(W_0+W_1)v''^2}{g\,r''}=F_2=\text{centrifugal force of whole wheel.} \quad (5)$$

Substituting in (5) the value of r'' as found in (3)

$$F_2=\frac{(W_0+W_1)^2\,v''^2}{g\,W_1\,r'} \quad (6)$$

Let N = the number of revolutions per second,

Then $2\pi r'N=v'$ and $2\pi r''N=v''$ (7)

$4\pi^2r'^2N^2=v'^2$ and $4\pi^2r''^2N^2=v''^2$ (8)

Substituting in the second equation of (8) the value of r'' as found in (3),

$$4\pi^2\left\{\frac{W_1}{W_0+W_1}\right\}^2 r'^2N^2=v''^2 \quad (9)$$

$$4\pi^2r'^2N^2=\left\{\frac{W_0+W_1}{W_1}\right\}^2 v''^2 \quad (10)$$

But from (8), $4\pi^2r'^2N^2=v'^2$,

$$\text{Therefore } v'^2=\left\{\frac{W_0+W_1}{W_1}\right\}^2 v''^2 \quad (11)$$

Substituting the value of v'^2 from (11) in (4), we have

$$F_1=\frac{(W_0+W_1)^2\,v''^2}{g\,W_1\,r'} \quad (12)$$

$$\text{But from (6) } F_2=\frac{(W_0+W_1)^2\,v''^2}{g\,W_1\,r'} \quad (13)$$

Therefore $F_1=F_2$ (14)

This proves, then, that an eccentric weight has the same effect in producing centrifugal force, whether acting alone, or placed in a balanced wheel.

Since there is an excess of counterbalance in the wheel of the locomotive, the center of gravity of the wheel will not lie in the axis, but between the axis and the excess of weight. The centrifugal tendency, then, of the wheel, will be the same, whether we consider the mass of the whole wheel concentrated at the center of gravity of the wheel, or only the excess of counterbalance concentrated at the center of gravity of that excess of weight.

The locomotive driving-wheel is so placed that it can move vertically, either up or down, but in each case there is a resistance to its motion; above, there is the pressure of the weight of the locomotive, transmitted through the driving-springs; below, there is the rail. This latter, of course, is to be considered as a continuous beam, and of so much rigidity that its action may be neglected. It is true that we should expect, with just as much reason, to find effects from the excess of counterbalance in other directions than the vertical, and such effects have been experimented upon by others, but the scope of this paper is simply to investigate the vertical action of the weights in question.

The motion of the wheel may be compared to that of a body revolving about an axis, and free to move vertically, up or down, against resistances. In Fig. 3, let

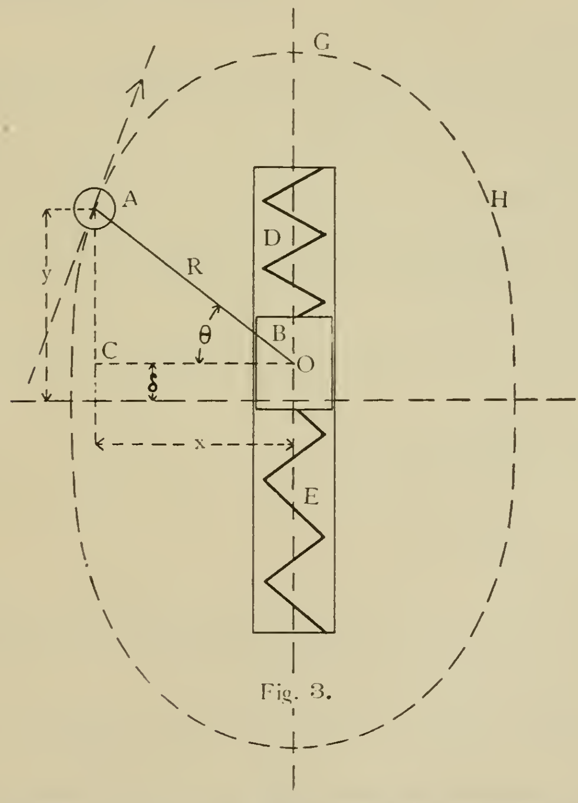


Fig. 3.

A=center of gravity of wheel, with mass of wheel concentrated there, B = axis (free to move vertically against springs D, E),

R = radius of center of gravity of wheel.

In order to simplify the conditions of the problem, we will consider that the wheel is revolving at a uniform angular velocity, and also neglect the time that it takes the springs to act.

Let θ = angle made by R, at any moment, with the horizontal; as before, let

F = the centrifugal tendency of the wheel, which may be calculated as in (5).

This force acts in the direction of the radius R, and, since we assumed that θ grows constantly, and the weight of the wheel is constant, F is a constant force. Then the vertical component of this force is, in all cases,

$F \sin \theta$ (15)

If a unit force, or load, gives a deflection of the spring = S, then the total deflection at any moment is equal to the total force acting times the unit deflection, or

$FS \sin \theta$ (16)

Let this be represented by δ, as shown on the figure, then

$\delta = FS \sin \theta$ (17)

The vertical distance of the center of gravity of the wheel from the horizontal axis equals

$R \sin \theta + \delta$ (18)

Referring to the horizontal and vertical axes as co-ordinate axes,

$y = R \sin \theta + \delta$ (19)

Substituting from (17),

$y = R \sin \theta + FS \sin \theta$ (20)

In the same way, the horizontal distance of the same point from the vertical axis is

$x = R \cos \theta$ (21)

When $\theta = 90°$, the value of $F \sin \theta$ reaches a maximum, and equals F. At that point, then, the greatest deflection of the springs will occur, and will equal FS, remembering that we assumed that the time of action of the springs is *nil*.

To judge of the time allowed the springs for action, take a driving-wheel 63 inches in diameter. If the locomotive move at the rate of 40 miles per hour, it will go 3,520 feet per minute. The number of revolutions per minute = 213.4, and each revolution would take .281 seconds. But in half a revolution the force has given the deflection δ and returned to its normal position, so that the time taken in deflection and recovery is only .1405 seconds.

Unwin defines a suddenly applied load as a load applied to a structure with6ut velocity, but at one instant; and such a load, not exceeding the elastic limit, produces twice the stress of an equal steady load. The case in hand comes under this definition, since, when $\theta=O°$, the deflecting force is o, and it increases with the revolution. In the locomotive, flat laminated springs are used, so that the formulæ for beams apply, and the deflection under the suddenly applied load is twice that which would occur under a steady load, or

$$\delta=2\delta \qquad (22)$$

in which δ^1 is the deflection under the same load acting steadily.

As the theoretical curve assumed that the springs took no time to act, while we should naturally expect them to influence the movement because of the resistance which they offer, it was determined to investigate their action to some degree.

With this idea in view, a machine as shown in Fig. 4 was constructed, having, as in the theoretical machine, a spindle free to move vertically while revolving, although against the resistance of springs.

The machine consists, essentially, of a wooden frame, braced, and clamped rigidly to the bed of a lathe. Through the upper and lower cross-pieces two hollow brass rods are fitted to slide vertically. To these rods is clamped a block, carrying a spindle, which has at one end a rod which works freely in a slot attached to the face-plate of the lathe; and on the other end another rod, upon which is a weight, which may be fastened at any point, in order to give different radii, and thus different centrifugal forces at the same speed.

The machine has proved itself, on the whole, not altogether satisfactory. It was not rigid enough, and for that reason the curves are not as satisfactory as might be desired. The centrifugal force of the weight combined with its leverage on the brass rods tended to bend them, and for that reason, in Fig. 6, the curve, which should always remain outside of the circle, passes within. However, the machine served its purpose in so far as it shows that the springs do retard the maximum, so that, whereas it should be on the vertical axis, it is carried over, in some cases more than 20°. The pencil point which traced the curves was placed at the center of gravity of the weight, so that it records the movements of the weight.

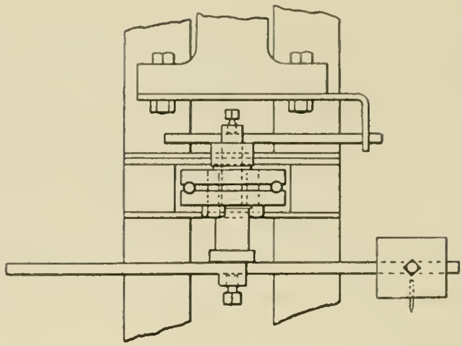


Fig. 4. Scale = $\frac{1}{8}$.

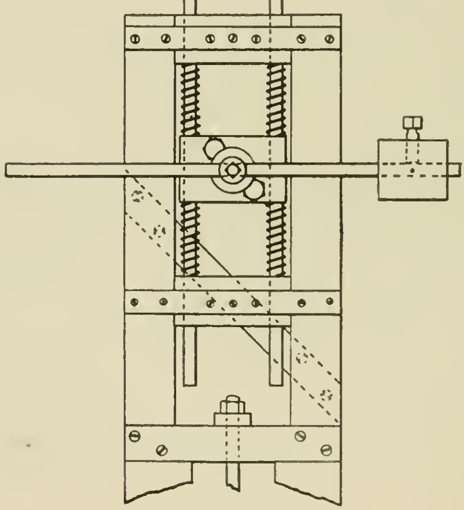


FIG. 4.

The method of obtaining a curve was as follows: A drawing-board, clamped to the carriage of the lathe, and with a sheet of paper stretched upon it, was moved up until the pencil point touched it. Then the lathe was started and the curve traced; and the number of revolutions per minute counted by means of a speed indicator. After that, the carriage was run back and the radius of the center of gravity of the weight measured.

Owing to the fact that the data had to be obtained while other machines in the shop were being used, the speed of revolution varied considerably during the experiments, and in all probability the speed noted is not exactly the same speed as that at which the curve was traced.

The springs used were of steel wire, B. & S. Wire Gauge No. 10. Their temper proved unsatisfactory and lacked uniformity. The weight used was 3.19 pounds. In the machine four springs were used, two on each brass rod, one above the block, and the other below, in each case. They were intended to be exactly alike, and are so considered in the calculations.

To calculate the strength of these springs and the theoretical deflections under the various loads put upon them, Reauleaux's formulæ for spiral springs may be used, which are as follows:

$$l = n\sqrt{(2\pi r)^2 + (\text{pitch})^2} \qquad (23)$$

$$\delta = \frac{32\,P\,l\,r^2}{\pi\,G\,d^4} \qquad (24)$$

In the case of this machine the load is distributed between two springs and is equal to the centrifugal force.

Hence $P = \frac{1}{2}F$ for each spring. (25)

The data obtained from the machine are as follows:

Outside diameter of coils $= \frac{27}{32}'$

$d = .1019'$

Hence $2r = .74'$

$r = .37'$

$n = 8$

$\text{pitch} = \frac{1}{2}'$

Whence $\delta = .022366\ P$ (26)

The following table gives the results of the experiments, showing the different loads and the deflections corresponding. The notation is as follows:

r = distance of center of gravity of the weight from the axis of revolution, in inches,

N = number of revolutions per minute,

v = velocity of weight, in feet per second, as calculated from the formula: $v = \frac{2\pi r N}{12 \times 60}$

F = centrifugal force in pounds, as calculated from (4):

$$F = \frac{W\,v^2}{g\frac{r}{12}}$$

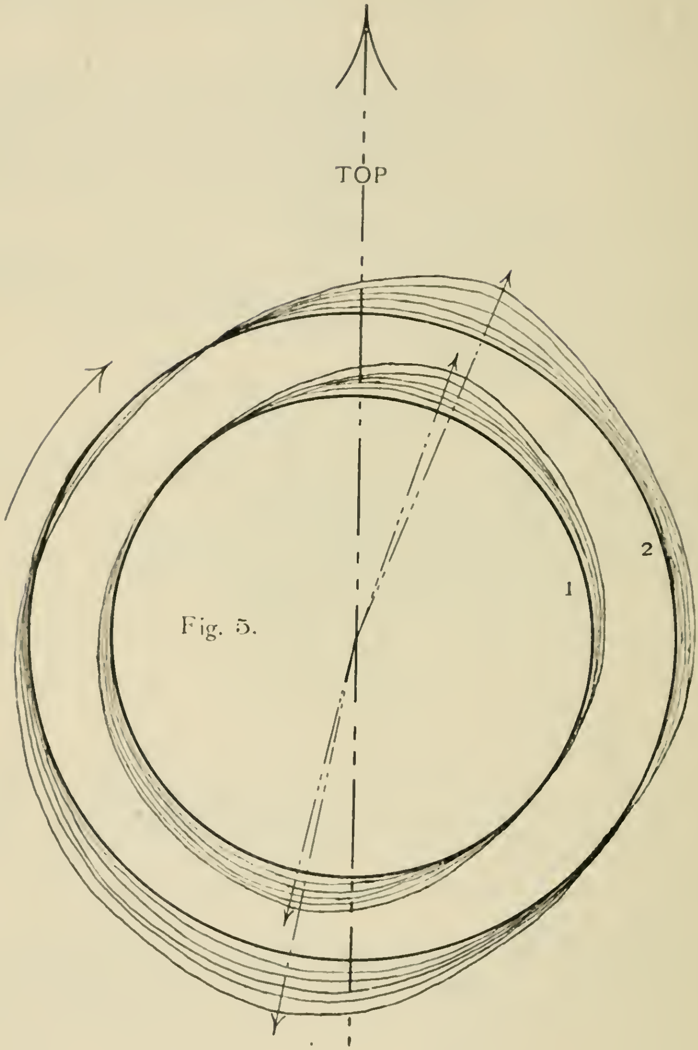


Fig. 5

$P = \frac{1}{2}F$ = load on each spring, as in (25),

δ = theoretical deflection of spring in inches, and equals .022366 P as in (26),

δ_o = observed deflection in inches, as measured on Figures 5 and 6,

n = angle at which maximum occurs, measured to the right of vertical axis.

The first column gives the number of the curve as given on the Figures 5 and 6.

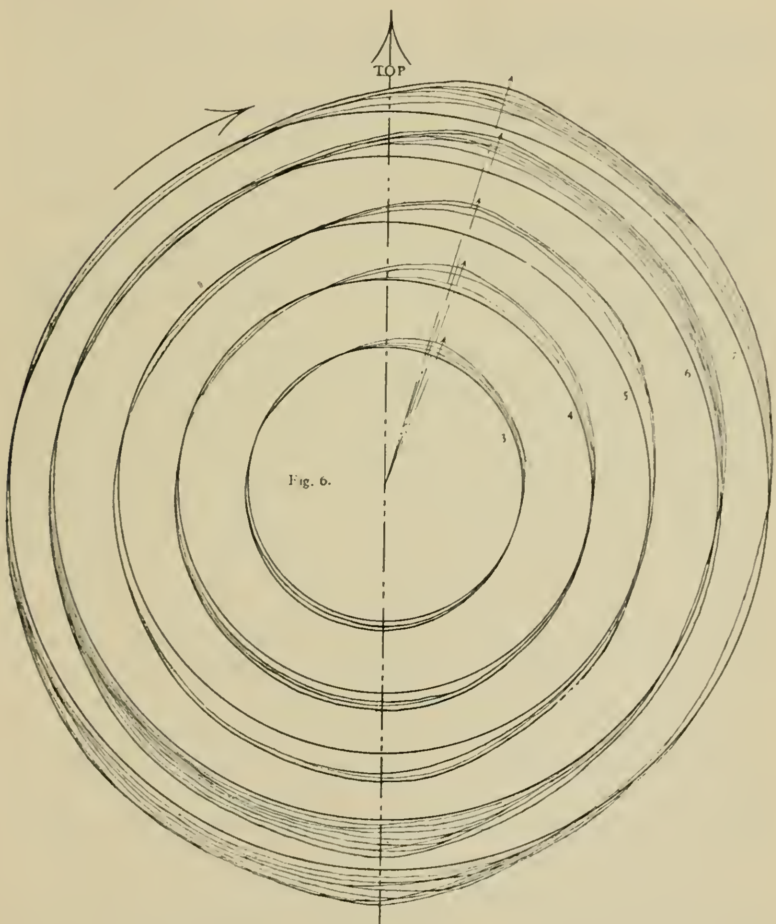


FIG. 6.

TABLE OF RESULTS.

No	r.	N.	v.	F.	P.	δ	δ_0	n.
3.	2.41	272	5.720	16 14	8 07	.181	.23	21.5°
4.	3.59	252	7 895	20 64	10 32	.231	.42	19°
5.	4.31	256	9.629	25.57	12 78	.286	.54	17.5°
6.	5.81	264	13 385	36 66	18.33	.410	.65	17.5°
7	6.59	264	15.183	45 58	20.79	465	.76	16°
1.	2.41	440	9.254	42.24	21 12	.472	.42	19°
2	3 16	440	12.134	55 39	27 69	619	.55	22°

It will be noticed that the deflections, as observed on the curves, do not correspond to the theoretical deflections. A possible reason for this, is that the springs for Fig. 6 are a different set from those used in Fig. 5, and they began to take a set, which increased with the pressure upon them, until in No. 7 the springs were about ⅛' shorter than when they were put into the machine. That made about ¼' of lost motion between the two springs, in which space the weight had no resistance from the springs.

As has been said before, these sources of error serve to render the results satisfactory, only in so far as they serve as suggestions for further investigation.

As the effect of the centrifugal force of the excess of counterbalance increases with the speed, the lifting effect must increase. The force exerted in the cylinder by the steam, transmitted through the rods to the crank-pin of the wheel can be found; and thence the force tending to rotate the wheel, considered as acting at the circumference of the wheel, where it rests on the rail. This force can be found for any point in the revolution, and for the same point the weight on the rail may be found, this last varying, of course, with the direction and amount of the centrifugal force. Thus, having found, for any point in a revolution, the rotative force at the rail and the weight on the rail, the ratio between them is easily determined, which we may call the co-efficient of slip.

Now, the ratio of the force applied horizontally at the rail, and which will just produce slipping, to the weight on the rail, is called the co-efficient of friction or adhesion. Values for this co-efficient are given by Haswell, and vary, according to the condition of the rail, from .09 to .33.

Mr. J. N. Barr discusses in the *Railroad Gazette* (February 6, 1891, p. 92), the relations between the co-efficient of slip and the co-efficient of adhesion, and finds, experimentally, that the former does exceed the latter at times, and summarizes his conclusions as follows:

"1. Flat places on driving-wheel tires are not entirely due to lack of uniformity in the wearing quality of the same.

2. The flat places have a tendency to group themselves where the co-efficient of slip is the greatest.

3. They vary in depth with the pressure on the rail, and when the pressure does not exceed 11,000 pounds, the imperceptible slip produces but little abrasion.

4. Imperceptible slip does not appear at random on any part of the wheel, but in special localities as fixed by the maximum values of the co-efficient of slip.

5. The counterbalance should be made as light as possible, consistent with smooth riding.

6. The weight of the reciprocating parts should be as light as possible."

These conclusions were drawn from experiments on an engine going at the rate of 40 miles an hour. Others have called attention to the fact that these spots have a tendency to group themselves at corresponding points on the wheels of a locomotive.

However, the data are so meager that it would be foolish to state that any given spot was caused by any certain action. But may it not be assumed in the light of the imperfect experiments just described, that the centrifugal force of the excess of counterbalance, taken in connection with the driving-springs of the locomotive, has considerable to do with the location of the worn places in the tires?

PRINTS FROM ETCHED METALS.

By L. W. Peabody, '91.

The specimen to be etched must present a perfectly smooth plane surface on the side from which the print is desired. The requisite finish may be secured after the piece leaves the machine by a careful use of a file and emery paper, care being taken to remove all file or other tool marks, as these will appear in the prints.

It will be a matter of great convenience to have the side opposite the etching surface parallel with it. Yet if the specimen is of considerable size this is not absolutely necessary, as the uneven side may be blocked up with wood or other material for the press.

However, the former method will be found more satisfactory. When the surface is sufficiently polished, it should be suspended face downward in a shallow dish containing the etching fluid; but should never touch the bottom so as to prevent free access of the acid. The specimen may be held by any suitable clamp which will overlap the edges of the containing vessel thus forming a support.

Considerable range is permissible in the proportions of the etching fluid. Either of the following volumetric proportions have been found good in practice.

H_2SO_4 ......(con.)	3	parts.
HCl ...... "	1	"
H_2O	9	"
H_2SO_4 ......(con.)	1	"
H_2O	3	"

The length of time that the metal should be immersed is largely a matter of experience, as the acid acts on no two pieces with the same rapidity. The operator must examine the specimen from time to time to determine when the desired end is reached. The metal must remain in the acid until the etching surface when covered with printers ink will give a good impression. Practice and judgment will determine this point.

When the action is complete all acid must be washed from the specimen and the etched surface dried immediately to prevent rusting. This may be done by placing in hot water for a short time, the heat being quite sufficient to dry the surface on removal.

Ordinary printers' ink is used exclusively in making prints. This should be spread in a thin, even coat over a flat piece of marble or glass. A common printer's roller is used to ink the etched surface. This requires considerable care, as the ink must be spread evenly over the entire surface. Pass the roller over the slab and etching alternately for each print. No deviation from this will insure good results. After the specimen is inked it is ready for the press. For small and medium sized pieces an ordinary copying press can be used. Place either a thin piece of soft rubber or a couple of blotters on a plane, smooth board, and over these a white sheet of moistened paper. The specimen should now be placed face downward upon the white paper, and the whole placed in the press. If the top is parallel with the etched surface, place a sheet of rubber or blotters on the top and subject to a pressure of about 500 lbs. per square inch. If the top is irregular it may be built up and covered with a board, when the sheet of rubber is used as before.

After use the etching plate should be thoroughly cleaned, dried, and coated with vaseline to avoid all rusting.

NOTES ON AN ELECTRIC STREET RAILWAY PLANT.

By W. A. Boyd, '91.

Tests were made on an electric street railway plant, consisting of an 80 horse-power Ideal engine, making 250 revolutions per minute, driving a United States dynamo of 40,000 Watts capacity. The method of driving is by friction belts between the pulleys. The engine pulley is six feet in diameter, and the dynamo pulley about three feet. Four belts, 4½ inches wide, cover the circumference of the dynamo pulley. These are prevented from coming off by flanges on the pulley. The pressure between the pulleys is maintained by a screw on the sliding frame of the dynamo.

This plant furnishes power for about two miles of street car track between the cities of Champaign and Urbana, Ill. Also power for two small motors and about one hundred incandescent lights. Ordinarily two motor cars, carrying motors of twenty nominal horse-power each, are run. For additional traffic trailers and more motor cars are added.

Ten tests of this plant were made, each test lasting twenty minutes, this being the length of one complete trip. The tests were begun when the cars were at the end of the line. Indicator cards were taken each minute during the test. During this time speed indicators were run continuously from the engine and dynamo shafts. The speed of the engine, while taking a card, was read from a tachometer.

In the morning, between the hours of 9 and 12, the power required varied from 9.1 to 54.6 horse-power. The average for the time, while running two cars only, was 20.7 horse-power. In the afternoon, between the hours of 2 and 5, the power ranged from 11.5 to 55.23 horse-power. The average power required during the time was 21.07 horse-power. The average power required for the day was 20.88 horse-power.

To determine the frictional loss due to increased pressure on the bearings, successive positions of the tightener screw were arranged, advancing the dynamo by 32nds of an inch. Table I. gives the average of a number of cards taken at these positions. Of these positions Nos. 1–5 are below the limit for ordinary running, and No. 10 is above the limit for cool bearings. Table II. gives another set of values taken at a later time for positions advancing the dynamo by 64ths of an inch. The positions, 1–4 in the second set, lie between 6 and 8 in the first set. They show a slight increase in engine friction, but a decided decrease in the total friction.

To determine the velocity ratio of driver and follower, continuous readings were taken from both while running light. The value thus obtained was compared with the values for different positions, obtained when running cars, and the per cent slip calculated for these positions. These results are given in Table III., together with the mechanical losses due to friction. An examination of this table shows that for all powers under 30 horse-power the total sum of frictional losses and losses due to slip is a minimum for the loose position; while for powers greater than 30 the most economical point is at the tighter positions.

In order to obtain the pressure on the bearings in this case, a lever 48 inches long was bolted to the tightener wheel, and the pull required read from a spring balance. By several trials the pull required to move the dynamo on its frame alone was 14 pounds. The pull required to move the dynamo while in running position was 20½ pounds. The mean radius of the screw was .6887 inches, and the pitch ¼ of an inch. Using .15 as the co-efficient of friction, the pressure on the bearings was found to be 2,160 pounds.

As a comparison between this system of driving and driving by means of belting, a calculation was made taking as an extreme case the distance between driver and follower equal to one inch. Using the ordinary formulae ior belting, the pressure on the bearings necessary to transmit the maximum power was found to be 884 pounds. This gives the pressure on the bearings but little more than two-fifths of the pressure required by the present method of driving. The width of the belt taking into consideration centrifugal action was calculated and found to be ten inches for a one-quarter inch belt.

These results seem to show that for street railway work, or where the demands for power vary so much, the ordinary belt driving is superior in economy to driving direct by means of friction pulleys.

TABLE I.

Engine.	Dynamo and Engine Friction.									
	1	2	3	4	5	6	7	8	9	10
3.047	4.318	4.583	4.774	4.71	4.871	4.418	5.184	5.705	5.831	6.498

TABLE II.

Engine.	Dynamo and Engine Friction.			
	1	2	3	4
3.312	3.77	4.327	4.619	4.338

TABLE III.

Set.	Position.	I. H. P.	Eng. friction.	H. P. Trans.	Slip per cent.	Mech. loss H. P.
1	4	20.036	3.312	16.724	.38	1.522
2	4	19.875	3.312	16.563	.383	1.522
3	3	19.549	3.312	16.237	.85	1.307
4	3	19.45	3.312	16.138	1.387	1.307
5	2	28.92	3.312	25.608	1.555	1.015
6	1	29.01	3.312	25.698	3.087	.458

LIME-CEMENT MORTAR.

It is common practice, particularly in the construction of large buildings, to add hydraulic cement to lime mortar, on the supposition that the cement gives additional strength. Gen. Gilmore, in his "Practical Treaties on Limes, Hydraulic Cements, and Mortars," says: "Most American cements will sustain, without any great loss of strength, a dose of lime paste equal to that of the cement paste; while a dose equal to half to three-quarters of the volume of cement paste may safely be added to any energetic Rosendale cement, without producing deterioration in the quality of the mortar, to a degree requiring any serious consideration." In order to test these conclusions the four series of experiments described below were made.

For the sake of brevity the conditions common to all the series are described here once for all.

The lime employed was a good quality of ordinary fat lime. It was slaked in an earthen jar at least two days before being used. The proportion of water added to the dry lime in slaking was a little more than two to one by weight. The lime paste was kept at a constant consistency by weighing the jar each day and adding water to make up for the loss by evaporation.

Two kinds of hydraulic cement was tried, a German Portland and Black Diamond Louisville (Ky.) Rosendale. The usual tests for soundness showed both cements good in this respect. The following results were obtained for fineness:

	PORTLAND.	ROSENDALE.
Retained on a No. 50 sieve	1 per cent.	15 per cent.
Retained on a No. 75 sieve	7 "	9 "
Retained on a No. 100 sieve	7 "	4 "
Passing a No. 100	85 "	72 "

The following results for tensile strength were obtained from briquettes stored in air:

	Pounds per Square Inch.	
	PORTLAND.	ROSENDALE.
When 7 days old	150	75
When 21 days old	300	...
When 28 days old	320	225
When 70 days old	360	250

The sand used was such as passed a No. 18 sieve and was caught on a No. 30 sieve, and was therefore practically "standard sand," as recommended by the committee of the American Society of Civil Engineers. It was fairly sharp, and contained a large per cent of silica. It was thorougly washed and dried before being used.

The mortar in all cases consisted of two volumes of sand to one of the lime-cement paste. The weight of a unit of volume of each ingredient was first determined, and the proportions were then adjusted by weighing. The cement and the sand were thoroughly mixed dry, the lime was then added and all well mixed, and finally enough water was added to bring the mass to a proper consistency. Since lime will not harden under water all the specimens were stored in the air.

The breaking was done on a home-made cement testing machine giving results accurate to half pounds for light pulls, and correct to two pounds for the greater pulls. The machine was so arranged as to give a central pull upon the test specimen.

COHESIVE STRENGTH OF LIME AND LOUISVILLE CEMENT MORTAR.

By E. C. Eidmann, '91.

The mortar was put into the molds by hand with as nearly the same pressure as possible, and remained in the molds twenty-two hours. In determining the strength of a mortar of any particular age at least five briquettes, representing two or more moldings, were broken and an average taken.

Figure 1 gives the strength of the different mortars at various ages. It will be noticed that the strength of some mortars are shown as being greater than others at a succeeding age. In these cases the briquettes are of different moldings. Owing to the different conditions of the atmosphere and the inexperience of the experimenter, the moldings might not have been made exactly the same. In all mortars over seven days old, the 20 per cent cement and 80 per cent lime mortar is weaker than all lime; but as soon as more cement is added, say 30 per cent, a greater strength than all lime is produced.

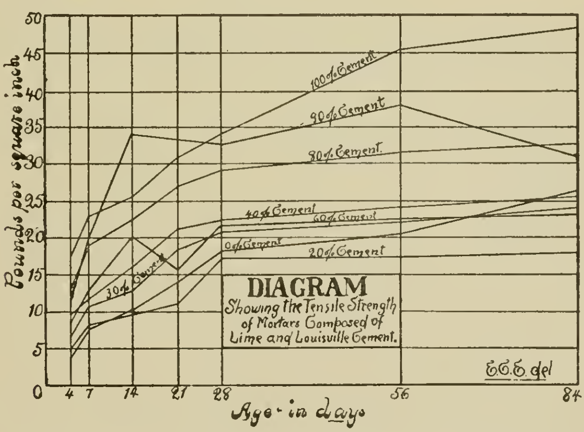


Fig. 1. Cohesive Strength of Louisville Cement and Lime Mortar.

Notice that the 60 per cent mortar is but little, if any, stronger than that containing only 30 per cent of cement; and hence, if it is not desirable to use more than 60 per cent of cement, it is not economical to use more than 30. Notice that the 30 per cent cement mortar when four days old is nearly 50 per cent stronger than the all lime mortar, but that the difference in strength steadily decreases until at 84 days old the all lime mortar is stronger or at least equally as strong. As in most cases it matters little whether the strength is obtained in a few days or not, it is best, and by far the cheapest, to use all lime in these cases rather than put in as high as even 60 per cent of the cement. According to the diagram the mortar containing 20 per cent of cement and 80 per cent of lime is not so strong as all lime.

Concerning the addition of small per cents of lime to cement mortar the diagram gives no very definite conclusions. Apparently a small per cent of lime decreases the strength of the mortar in a greater ratio than the proportion of the lime added; and consequently the addition of small per cents of lime to cement mortar is not economical, at least as far as the strength is concerned. Of course the addition of lime to cement mortar will decrease the activity of the latter, but this phase of the subject is not now under consideration.

COHESIVE STRENGTH OF PORTLAND CEMENT AND LIME MORTAR.

By Chas. D. Vail, '91.

The briquettes were put into the molds by hand. Although great care was taken to give them uniform pressure, this must have been the source of greatest error.

Fig. 2 represents graphically the results obtained from the experiments. All points in the curves of the diagram are the mean of five briquettes.

In the diagram it will be noticed that the relative proportions of lime and cement vary regularly, except the 90 per cent and 30 per cent cement. The first was put in to test the reliability of the claim that a small per cent of lime in cement mortar does not seriously injure it. This statement is made by Gen. Gilmore, and appears to be supported by Mr. Kinkead's experiments.* From Fig. 2 we see that 20 per cent of lime in cement mortar weakens it, but that with 10 per cent of lime the mortar seems to be fully as strong as 100 per cent cement mortar.

As to adding cement to lime mortar the experiments show conclusively that it is not economical, because the strength is not noticeably increased until 40 per cent of cement is added.

The conclusions drawn from the experiments are: (1) The addition of lime to cement mortar, up to 15 per cent, does not injure the mortar; but with the addition of more than this the strength

*No. 4 of "Selected Papers of the Civil Engineers' University of Illinois."

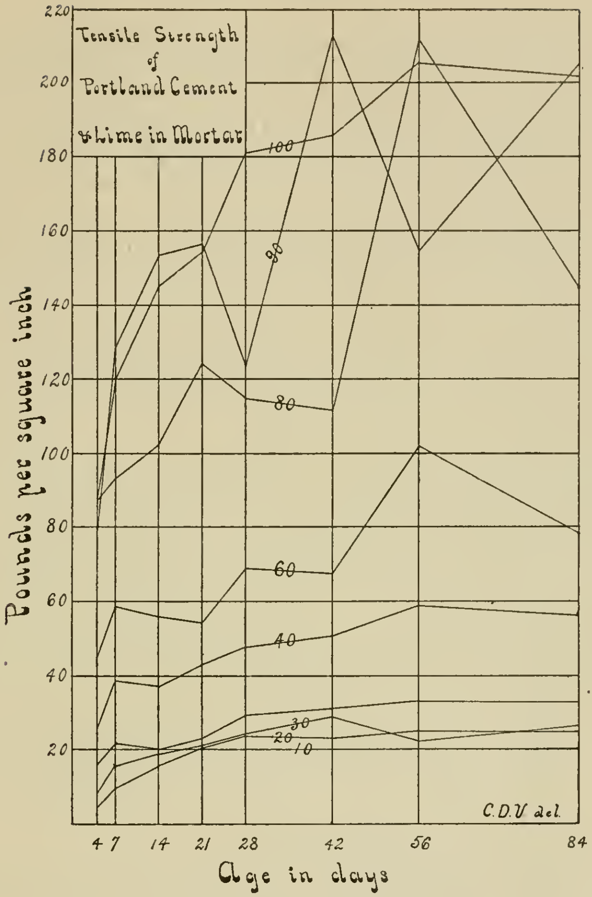


FIG. 2. COHESIVE STRENGTH OF PORTLAND CEMENT AND LIME MORTAR.

decreases more rapidly than the cost. (2) The addition of cement, up to 40 per cent, to lime mortar is not wise, because first it does not noticeably increase the strength, and second it greatly increases the cost.

ADHESIVE STRENGTH OF LIME AND LOUISVILLE CEMENT MORTAR.

BY F. H. ENO, '91.

The method of making the tests consisted in cementing two brick together cross-wise, with their broad faces in contact; and then measuring the force required to pull them apart.

Before being used, the brick were immersed in water about 30 minutes, when they were taken out and cemented together immediately after the water had dripped from their surfaces. The mortar was carefully put on one brick and the other brick placed crosswise on it, and given considerable pressure and at the same time a twisting motion which helped to exclude the air and make a better bed for the top brick. The attempt was made to use as nearly as possible the same pressure a mason would use if laying the brick in a wall. They were left to set, in the air, under the weight of an additional brick. As the brick averaged a trifle over 4½ pounds each this made the weight on the mortar joint about 9 pounds. The brick were hand-molded and moderately smooth. No appreciable difference in the adhesion of the mortar to the rough and smooth sides of the brick was detected.

The testing machine was so arranged as to certainly bring the pull perpendicular to the face of the mortar joint.

Fig. 3 represents graphically the results obtained from this series of experiments. The numbers on the plotted lines show the per cent of cement in the cementitious material. The results as plotted are the mean of at least five experiments. Tests were made daily for the first seven days; but were not plotted for lack of room. In all about 800 experiments were made.

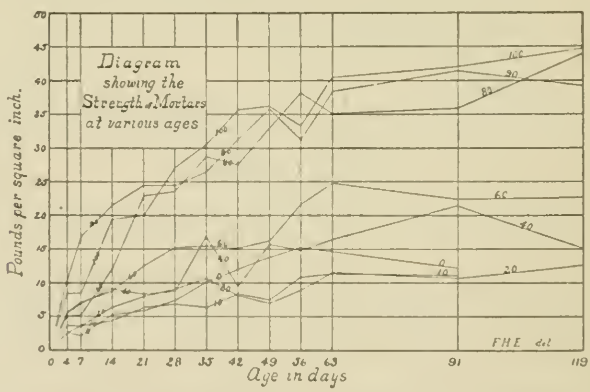


FIG. 3. ADHESIVE STRENGTH OF LOUISVILLE CEMENT AND LIME MORTAR.

The diagram shows very clearly that to add from 10 to 20 per cent of lime paste to cement mortar does not materially affect its ultimate strength. The substitution of 10 per cent lime saves 2.5 per cent of the cost of the original cement, while the substitution of 20 per cent of lime saves 5.0 per cent; while the cost of the lime thus substituted is scarcely appreciable. Notice that the addition of more than 20 per cent of lime paste to cement mortar very materially reduces the strength. Therefore we draw the conclusion that it is economical to add not more than 20 per cent of lime paste to cement mortar. This only partially sustains Gen. Gilmore's statement referred to in the first paragraph of article (page 67).

An examination of Fig. 3 shows that a mortar containing 20 per cent of cement and 80 per cent lime paste is weaker than an all-lime mortar. Therefore the substitution of 10 or 20 per cent of cement in a lime mortar for an equal volume of lime paste decreases the strength and at the same time increases the cost. Hence this practice is decidedly uneconomical—at least as far as strength is concerned.

With all the mortars, it was found that after having gained some age the adhesion to the brick was greater than the cohesion between the particles of the mortar. For example, for the first 7 days, in 73 per cent of the tests the adhesion was weaker than the cohesion; while for the remaining time, in only 14 per cent of the tests was the adhesion the weaker.

In conclusion it may be well to state that the results obtained for the adhesion to the brick and by cohesion in the briquettes can be compared only relatively, since the mortar was compacted differently in the molds than it was between the brick and was subject to various other differences.

ADHESIVE STRENGTH OF PORTLAND CEMENT AND LIME MORTAR.

By T. H. Frederickson, '91.

The experiments were made with German Portland cement and lime mortar and brick, in the same manner and subject to the same conditions as described above by Mr. Eno.

Although the tests were made to obtain the adhesive strength of the mortar to brick, the mortars consisting of 40, 20, 10, 0 per cents of lime and 60, 80, 90, 100 per cents of Portland cement respectively, separated from the brick through failure of adhesion; while the mortars consisting of 60, 80, 90, 100 per cents of lime and 40, 20, 10, 0 per cents of cement respectively gave results for the cohesive strength (except in first 3 to 7 days, when adhesion was the greater). Or in other words, with the mortar in which the lime predominates separation is through the failure of cohesion, and with the mortar in which the cement is in excess the separation is due to the failure of adhesion.

Fig. 4 shows graphically the relative and absolute strength, at various ages, of mortars composed of different per cents of lime and Portland cement.

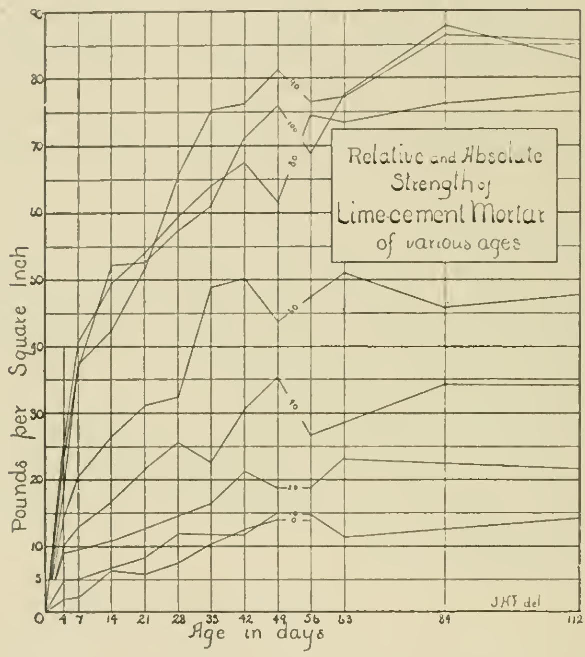


FIG. 4. ADHESIVE STRENGTH OF PORTLAND CEMENT AND LIME MORTAR.

From the diagram it is seen that the strength of the mortars containing the 80, 90, and 100 per cents of the cement are practically the same, which would seem to show that the addition of a little lime to cement mortar does not materially decrease the strength. Notice that the mortar containing only 60 per cent of cement is considerably weaker than that containing 80 per cent, which shows that more than 20 per cent of lime causes a considerable decrease of strength. A study of the lower portion of the diagram shows that 10 per cent of cement added to lime mortar does not materially increase its strength.

Table 1 was derived from the diagram, and shows approximately the effect of introducing each additional per cent of cement into lime-cement mortar. The values for the strength were those of the 8–16 weeks' tests, when the ultimate strength seems to have been attained.

TABLE 1.

INCREASE IN COST AND STRENGTH BY SUCCESSIVE ADDITIONS OF CEMENT TO LIME MORTAR.

Per cent of lime..............	100	90	80	60	40	20	10	0
Per cent of cement	0	10	20	40	60	80	90	100
Successive increase in strength.	1	.2	.56	1.21	1.62	2.25	2.40	2.41
Successive increase in cost....	1	.7	1.11	1.68	2.14	2.39	2.49	2.50
Strength ÷ cost..............	1	.28	.51	.7	.75	.95	.97	.96

This table shows that all-lime mortar is perhaps the most efficient mortar, when great strength is not required and water is not encountered; otherwise the high per cents of cement mortars are unnecessary and practically as efficient.

Taking the prices of cement and lime at Chicago, *i. e.*, cement @ \$3.25 per bbl. of 400 lbs., or 0 8 cents per lb., and lime @ 60 cents per bbl. of 200 lbs., or 0.3 cents per lb , the relative and absolute cost of equal volumes of cementitious material in the various mortars is as in Table 2.

TABLE 2.

COST, STRENGTH, AND EFFICIENCY OF THE SEVERAL MORTARS.

Cementitious Material.						Mortar.		
Composition in per cents.		*Cost per Cubic Yard of Mortar.				Strength.		Relative Efficiency, *i.e.* str'ngth ÷ cost.
Lime.	Cement.	Lime.	Cement.	Total.	Rel'tive.	Pounds p'r sq.in.	Rel'tive.	
0	100	\$1.00	\$7.46	\$7.46	1.00	85	1.00	1.00
10	90	.10	6.71	6.81	.91	84	.98	1.09
20	80	.20	5.97	6.17	.82	78	.92	1.11
40	60	.40	4.48	4.88	.65	48	.57	.86
60	40	.60	2.98	3.58	.48	35	.41	.85
80	20	.80	1.49	2.29	.31	20	.24	.76
90	10	.90	.75	1.65	.22	14	.16	.74
100	0	1.00	00	1.00	.13	12	.15	1.05

*Cost of sand not included.

In a cubic yard of brick masonry, containing 500 brick (8¼ x 4 x 2¼) laid with ¼ to ⅝-inch joints, there are 10,000 cubic inches of mortar. It was found that about 160 pounds of Portland cement was required to produce this amount of mortar. The cost of the cement, at 0.8 cents per pound, was $1.28. Had 20 per cent of lime been used with the cement, a mortar nearly as strong and one not so apt to set before being used, would have been obtained at a saving of 25 cents. That is to say, by the addition of 2 or 3 cents worth of lime 18 cents worth of cement would have been saved.

The additions of small per cents of cements to lime mortar may slightly quicken the activity, and certainly does cause the mortar to work better; but we could not, for these reasons alone, recommend this practice, since, while the cement does add slightly to the strength, the increased cost is such as to render the practice unprofitable. Small per cents of lime, up to 25 per cent, may be added to cement mortar without materially weakening it, while at the same time considerably diminishing the cost, and also retarding the activity, thereby allowing the mason sufficient time to place the mortars before it begins to set.

RAILWAY TRANSITION CURVES.

BY ARTHUR N. TALBOT, PROFESSOR OF MUNICIPAL ENGINEERING.

A transition curve, or easement curve, as it is sometimes called, is a curve of varying radius used to connect circular curves with tangents for the purpose of avoiding the shock and disagreeable lurch of trains, due to the instant change of direction and also to the sudden change from level to inclined track. The primary object of the transition curve, then, is to effect smooth riding when the train is entering or leaving a curve.

The generally accepted requirement for a proper transition curve is that the degree-of-curve shall increase gradually and uniformly from the point of tangent until the degree of the main curve is reached, and that the super-elevation shall increase uniformly from zero at the tangent to the full amount at the connection with the main curve and yet have at any point the appropriate super-elevation for the curvature. In addition to this, an acceptable transition curve must be so simple that the field work may be easily and rapidly done, and should be so flexible that it may be adjusted to meet the varied requirements of problems in location and construction.

Without attempting to show the necessity or the utility of transition curves, this paper will consider some forms of such curves, and especially the transition spiral.

THE TRANSITION SPIRAL.*

The Transition Spiral is a curve whose degree-of-curve increases directly as the distance along the curve from the point of curvature.

Thus, if the spiral is to change at the rate of 10° per 100 feet, at 10 feet from the beginning of the spiral the curvature will be the same as that of a 1° curve; at 25 feet, as of a 2° 30' curve; at 60 feet, as of a 6° curve. Likewise, at 60 feet, the spiral may be compounded with a 6° curve; at 80 feet, with an 8° curve, etc.

This curve fulfills the requirements for a transition curve. Its curvature increases as the distance measured around the curve. The formulas for its use are comparatively simple and easy. The field work and the computations necessary in laying it out and in connecting it with circular curves are neither long nor complicated, and are similar to those for simple circular curves. The curve is

---

*The author desires to express his obligation to Mr. J. K. Barker, '92, for valuable aid in the preparation of drawings, the calculation of tables, and the checking of formulas.

extremely flexible, and may easily be adapted to the requirements of varied problems. The rate of change of degree-of-curve may be made any desirable amount according to the maximum curve used, or according to the requirements of the ground.

As the derivation of the formulas is somewhat long, their demonstration will be given first. The explanation and application of these formulas to the field work and to the computations will be given separately, a knowledge of the demonstration not being essen tial to the application.

In Fig. 1, AEL is the transition spiral connecting the initial tangent with the main or circular curve LH. A is the beginning of the spiral and will be known as P.S., point of spiral. AP is the prolongation of the initial tangent and will be used as the axis of X. L is the beginning of the circular curve LH, and will be called P.C.C., point of circular curve. D is the point where the circular curve produced backward gives a tangent DN parallel to the tangent AP, and will be called the P.C. of the produced simple curve. BD is also the offset between the tangent of a curve with a transition spiral, and a curve without the spiral but having the same change of direction as the former.

The degree-of-curve of the spiral at any point is the same as the degree of a simple curve having the same radius of curvature as the spiral has at that point. The radius of the spiral changes from infinity at the P.S. to that of the main curve at the P.C.C. The spiral and a simple curve of the same degree will be tangent to each other at any given point; *i. e.*, they will have a common tangent.

The following nomenclature will be used:

R = radius of curvature of the spiral at any point.

D = degree-of-curve of the spiral at any point. At the P.C.C., D becomes the degree of the main curve.

a = rate of change of D per station of 100 feet measured on the curve.

s = length in feet from the P.S. to any point on the spiral.

L = total length of the spiral measured in stations of 100 feet.

I = total central angle of the whole curve, or twice BCH of Fig. 1, H being the middle of the circular arc.

Δ = angle showing the change of direction of the spiral at any point, and is the angle between the initial tangent and the tangent to the spiral at the given point. For the whole spiral it is equal to PTL. The latter is also equal to DCL.

θ=deflection angle at the P.S., from the initial tangent to any point on the spiral. For the point L, it is BAL.

ϕ=deflection angle at any point on the spiral, between the tangent at that point and a chord to any other point. For L, ϕ is TLA.

x=abscissa of any point on the spiral, referred to the P.S. as the origin and the initial tangent as the axis of X. For the point L, x=AM.

y=ordinate of the same point, measured at right angles to the above axis. For the point L, y=ML.

t=abscissa of the P.C. of the main curve produced backward; *i. e.*, of a simple curve without the spiral. For the point D, t=AB.

o=offset between the initial tangent and the parallel tangent from the main curve produced backward, or it is the ordinate of the P.C. of the produced main curve. If D is the P.C., BD is o. It is also the radial distance between the concentric circles LH and BK.

T=tangent-distance for spiral and main curve=distance from A to the intersection of tangents.

E=external-distance for spiral and main curve.

C=long chord AL of the transition spiral.

The length of the spiral is to be measured along chords around the curve in the same way that simple curves are usually measured. The best railroad practice, in the writer's opinion, considers curves up to a 7° curve as measured with 100-ft. chords, from 7° to 14° as measured with 50-ft. chords, and from 14° upwards as measured with 25-ft. chords; that is to say, a 7° curve is one in which two 50-ft. chords together subtend 7° of central angle, a 14° curve one in which four 25-ft. chords together subtend 14° of central angle. The advantages of this method are two-fold,—the length of the curve as measured along the chords more nearly approximates the actual length of the curve, and the radius of the curve is almost exactly inversely proportional to the degree-of-curve. The latter consideration is an important one, simplifying many formulas. With this definition of degree-of-curve, the formula $R=\frac{5730}{D}$ will give no error greater than 1 in 2000. For a 10° curve the error in the radius is .15 feet, and for a 16° curve .06 feet. The resulting difference in the alignment or distance for the ordinary length of spiral will be considerably less than this amount. For the transition spiral, then, the error either in alignment or distance will be well within the

—6

limits of accuracy of the field work, and hence the relation $R=\frac{5730}{D}$ will be considered true.

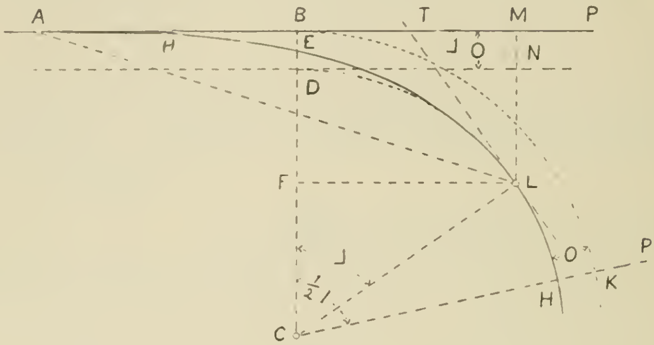


FIG. 1.

DEMONSTRATION OF FORMULAS.—From the definition of the transition spiral, we have, remembering that the value of a as defined above requires the length of curve to be measured in 100-ft. units (*stations*) instead of feet,

$$D=a\,L=\frac{a\,s}{100}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

From the calculus the radius of curvature

$$R=\frac{ds}{d\Delta}.$$

Substituting the expression $R=\frac{5730}{D}$ and solving,

$$d\Delta=\frac{a\,s\,ds}{573000}.$$

Integrating, $\Delta=\dfrac{a\,s^2}{1146000}=\dfrac{a\,L^2}{114.6}$

Changing Δ from circular measure to degrees,

$$\Delta=\tfrac{1}{2}\,a\,L^2,\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

which is the intrinsic equation of the Transition Spiral.

Since from (1) $a=\dfrac{D}{L}$, we also have

$$\Delta=\tfrac{1}{2}\,D\,L=\tfrac{1}{2}\,\frac{D^2}{a}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

From these equations it will be seen that

(a) the change of direction of the spiral varies *as the square of the length* instead of as the first power of the length as in the simple circular curve, and

(b) that the transition spiral for any angle Δ will be twice as long as a simple circular curve.

To find the co-ordinates, x and y, of any point on the spiral, we have by the calculus $dy = ds \sin \Delta$ and $dx = ds \cos \Delta$. Expanding the sine and cosine into an infinite series, substituting for ds its value in terms of $d\Delta$, and integrating, we have

$$y = \frac{1070.5}{(a)^{\frac{1}{2}}} \left\{ \tfrac{1}{3}\Delta^{\frac{3}{2}} - \frac{1}{42}\Delta^{\frac{7}{2}} + \frac{1}{1320}\Delta^{\frac{11}{2}} - \text{etc.} \right\} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

$$x = \frac{1070.5}{(a)^{\frac{1}{2}}} \left\{ \Delta^{\frac{1}{2}} - \frac{1}{10}\Delta^{\frac{5}{2}} + \frac{1}{216}\Delta^{\frac{9}{2}} - \text{etc.} \right\} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

As Δ here is measured in circular measure and is only ½ when the angle is 28.°65, these series are rapidly converging, especially for smaller angles.

Changing the angle Δ from circular measure to degrees, and dropping the small terms,

$y = .291\ a\,L^3 - .00000158\ a^3\,L^7$ .... (6)

For values of Δ less than 15° the last term may be dropped, and up to 25° the term will be small. $D\,L^2$ may also be written in place of $a\,L^3$. Also

$x = 100L - .00075\ a^2\,L^5$ .... (7)

Or $x = 100L - .00075\ D^2\,L^3$ .... (8)

The last term in eq. (7) or (8) may be used as a correction to be subtracted from the length of the curve in feet.

To find the deflection angle θ for any point on the spiral, as BAL for the point L, divide equation (4) by equation (5).

$\tan\theta = \tfrac{1}{3}\Delta + \frac{1}{105}\Delta^3 + \frac{26}{155925}\Delta^5$, etc. But from the tangent series for $\tfrac{1}{3}\Delta$,

$\tan\tfrac{1}{3}\Delta = \tfrac{1}{3}\Delta + \frac{1}{81}\Delta^3 + \frac{2}{3645}\Delta^5$, etc. Subtracting one from the other, we get a series which is rapidly decreasing when Δ is less than 40°. Investigating this difference, remembering that Δ is in circular measure, it is found that the error of calling the two equations equal is less than 1' for $\Delta = 25°$ and decreases rapidly below this. As Δ will rarely reach 25° and as the resultant error of direction will be corrected at the P.C.C. when $\Delta - \theta$ is turned off, we may write

$$\theta = \tfrac{1}{3}\Delta = \tfrac{1}{6}a\,L^2 = \tfrac{1}{6}\,\frac{D^2}{a} \qquad \text{.......... (9)}$$

Between 20° and 40°, .000053 Δ^3 (where Δ is in degrees) will give the numbers of minutes correction to be subtracted from $\tfrac{1}{3}\Delta$ to give θ.

To find the tangent at the terminal point of the spiral, L, lay off a deflection angle from LA equal to $\Delta - \theta$. When Δ is not over 20°, $\tfrac{2}{3}\Delta$, or 2θ may be used. This since FLT=PTL=Δ, and FLA =PAL=θ.

The tangent at any other point on the spiral is found in the same manner, using the θ and Δ for that point.

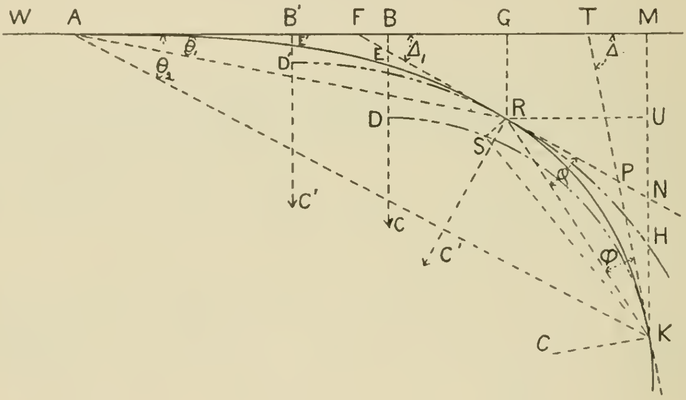


FIG. 2.

At any point on the spiral to find the deflection angle for a second point. In Fig. 2, let L_1 be the distance from the P.S. to R, and L the distance from the P.S. to any other point on the spiral, as K. Let FRN be the tangent at R, and RFM=Δ_1 its angle with the initial tangent. Let KTM=Δ be angle of tangent at K with initial tangent, equal to total change of direction of the spiral up to that point. KRN=Φ=required deflection angle. Then

$$\tan\,(\Phi + \Delta_1) = \frac{\mathrm{UK}}{\mathrm{RU}} = \frac{y - y_1}{x - x_1}.$$

Substituting for the co-ordinates their values from equations (4) and (5), and also developing $\tan \tfrac{1}{3}\,\dfrac{\Delta^{\frac{3}{2}} - \Delta_1^{\frac{3}{2}}}{\Delta^{\frac{1}{2}} - \Delta_1^{\frac{1}{2}}}$ into a series, and subtracting the latter from the former, an expression for the difference will be found, which amounts to but a small fraction of a minute for any value of Δ up to 35°. Hence we may write

$\Phi + \Delta_1 = \frac{1}{3}(\Delta_1 + \Delta_1^{\frac{1}{2}}\Delta^{\frac{1}{2}} + \Delta)$; whence by substitution and reduction,

$$\Phi = \tfrac{1}{2}a\,L_1\,(L-L_1) + \tfrac{1}{6}a\,(L-L_1)^2 \qquad (10)$$

It will be noticed that the first term is the deflection angle for a simple curve of the same degree as the spiral at the point R (called the osculating circle), and of length equal to the distance between the two points; while the second is the deflection angle at the P.S. from the initial tangent for an equal length of spiral. If the second point had been chosen on the side nearer the P.S., the second term would have an opposite sign from the first. Equation (10) may then be written with the plus and minus sign.

The spiral then deflects from a circle of the same degree-of-curve at the same rate that it deflects from the initial tangent. D'RH, in Fig. 2, represents the circular curve tangent to spiral at R, the two having the same radius at that point and both being tangent to FRN. The deflection angles between points on the spiral and on the circle RH, and also between the spiral and RD' are the same as for the same length of spiral from A. In the same way at K, RKT=SKT—SKR, the latter angle being equal to the deflection from initial tangent at A for a length of spiral equal to KR.

It may also be readily shown from (2) that the difference in direction of the two tangents, $\Delta - \Delta_1$, is the central angle for this simple curve plus the spiral angle, both for a length equal to the distance between the two points.

It may also be shown that the distance between a point on the spiral and on this osculating circle is the same as the ordinate y from the initial tangent for this length.

To find the offset o. From Fig. 1, BD = BF — DF = BF—CD vers DCL. But o=BD, BF=y for end of spiral, DCL = Δ for whole spiral, and CD=R. Hence, $o = y - R$ vers Δ. Substituting for y, R, and Δ their values in terms of the length of the whole spiral, and reducing, we have for o in feet

$$o = .0725\ a\ L^3 = .0725\ D\ L^2 \qquad (11)$$

where D and L refer to the whole length of the spiral.. The other terms of the series are so small that they may be dropped when Δ is less than 30°. It will be seen that o is approximately one-fourth of the ordinate of the P.C.C., which of course should be true if E, the middle point of the spiral, is opposite D, the P.C.

To find t, or AB. From Fig. 1, AB = AM—BM = x—FL = x—R sin Δ. Expanding and reducing,

$$\left.\begin{array}{l} t = 50\,L - .000125\,a^2\,L^5 \\ \text{or}\quad t = 50\,L - .000125\,D^2\,L^3 \end{array}\right\} \qquad (12)$$

Hence to find t, from one-half the length of the spiral in feet subtract $\frac{1}{8000}$ of the product of the square of the degree of the main curve by the cube of the length of the spiral, the latter being expressed in stations of 100 feet.

A comparison of t with the abscissa found by substituting ½ L in equation (8) shows that BD cuts the spiral at a point only .00005 D^2L^3 feet from the middle point of the spiral. This is $\frac{4}{10}$ of the correction used in equation (12) for finding t from ½ L. For our purpose we may say that BD bisects the spiral. It also follows that the spiral bisects the line BD, since BE = $\frac{1}{8}\,y$.

If the offset is given. From (11) and (3) we have

$$L = 3.714\sqrt{\frac{o}{D}} \qquad (13)$$

$$\Delta = 1.857\sqrt{o\,D} \qquad (14)$$

$$a = .269\sqrt{\frac{D^3}{o}} \qquad (15)$$

$3\frac{5}{7}$, $1\frac{6}{7}$, and $\frac{7}{26}$ may be used for these co-efficients with advantage.

To find the tangent-distance T, consider in Fig. 1 that AB intersects CH, H being the middle of the circular curve, at some point P outside the diagram. Then AP = AB + BP. BP = BC tan BCH.

Hence $T = t + (R + o)\tan \frac{1}{2} I$ . . . . (16)

t and o tan ½ I may be computed separately and added to the T found from an ordinary table of tangent-distances.

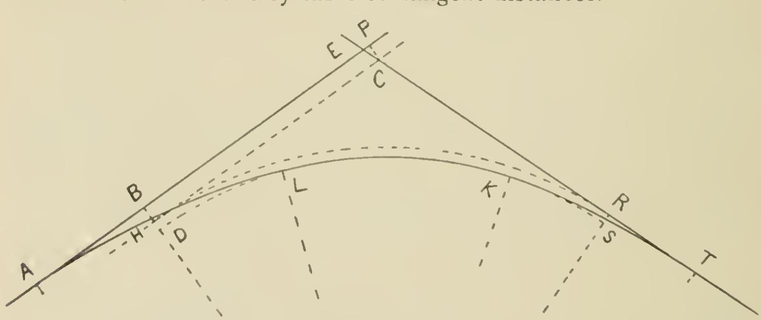


FIG. 3.

(16) gives T for the same transition spirals at each end of the main curve. It may be desirable to make one spiral different from

the other. To find an expression for the tangent-distances for this case, proceed as follows: In Fig. 3, let RS=HD=o_2, BD=o_1, AB=t_1, RT=t_2, AE=T_1, TE=T_2, R=radius of main curve DLKS, $R+o_2$=radius of HR, and I=angle PER.

Then $T_1=t_1+$HC—PE, and

$T_1= {}_1+(R+o_2)$ tan ½ I—$(o_1—o_2)$ cot I............ ...(17)

Similarly, $T_2=t_2+(R+o_2)$ tan ½ $I+(o_1—o_2)$ cosec I.

When I is more than 90°, the last term of (17) becomes essentially positive.

To find the external-distance, E=HP. In Fig. 1, HP=KP+HK. Hence

$E=(R+o)$ exsec ½$I+o$. ....(18)

To find the long chord, C=AL. In Fig. 1, ML=AL sin MAL, or $C=\dfrac{y}{\sin\theta}$. Putting this in terms of the length of the curve,

$C=100L$—(.0004 a^2L^5 or .0004 D^2L^3), ...(19)

in which C is in feet and L in stations. It will be seen that the last or correction term is $\frac{8}{15}$ of the correction for x as given in equation (7).

The middle ordinate for any arc is equal to the middle ordinate for an equal length of circular curve of the same degree-of-curve as the spiral at the middle point of the arc considered. This degree-of-curve is the average of the D's, at the end of the given arc. This is an approximate formula which is true whether one end of the chord is at the P.S. or not.

The ordinate for any other point along the chord may be found as follows. If l is the half arc, l' the distance from the middle point of the arc to the required chord-ordinate, y the ordinate from the initial tangent for a distance l from the P.S., and y' the same for distance l', then the required ordinate from the chord equals the corresponding ordinate for a circular curve of same degree-of-curve as middle point of arc, minus or plus y', plus or minus $\frac{l'}{l}y$; the first sign being used for ordinates on the side of the middle point away from the P.S. and the second when toward it.

Summary of Principles.—For convenience of reference the principal formulas will be repeated here.

$$D = a L \quad \text{.......... (1)}$$

$$\Delta = \tfrac{1}{2} a L^2 = \tfrac{1}{2} D L = \tfrac{1}{2} \frac{D^2}{a} \quad \text{.......... (2)}$$

$$\theta = \tfrac{1}{3} \Delta = \tfrac{1}{6} a L^2 = \tfrac{1}{6} D L = \tfrac{1}{6} \frac{D^2}{a} \quad \text{.......... (9)}$$

$$\phi = \tfrac{1}{2} a L_1, (L - L_1) + \tfrac{1}{6} a (L - L_1)^2$$

$$= \tfrac{1}{2} D (L - L_1) + \tfrac{1}{6} (D + D_1)(L - L_1) \quad \text{.......... (10)}$$

$$o = .07\tfrac{1}{4}\, a L^3 = .07\tfrac{1}{4}\, D L^2 \quad \text{.......... (11)}$$

$$t = 50 L - .000125 \, (a^2 L^5 \text{ or } D^2 L^3) \quad \text{.......... (12)}$$

$$T = t + (R + o) \tan \tfrac{1}{2} I \quad \text{.......... (16)}$$

An inspection of the formulas and demonstrations will show the following properties of the transition spiral:

1. The degree-of-curve D at any point on the spiral equals the product of the rate of change of D per 100 feet by the distance from the P.S. expressed in stations of 100 feet. (Eq. 1.)

2. The angle Δ between the initial tangent and the tangent at any point on the spiral (the change of direction, corresponding to central angle of circular curves) equals:

(a) One-half the rate a multiplied by the square of the distance in stations;

(b) One-half the product of the distance in stations by the degree-of-curve of the spiral at the given point, or one-half of the angle for a circular curve of this degree-of-curve and of the same length;

(c) One-half the square of the degree-of-curve at the point divided by the rate of change of D.

This is true for any point along the spiral. For the terminal point, D becomes the degree of main curve. For the same angle Δ, the spiral is twice as long as a circular curve. (Eq. 2.)

3. The deflection angle θ at the P.S., from the initial tangent to any point on the spiral, as PAL in Fig. 1, is $\tfrac{1}{3}\,\Delta$, or one-sixth of the product of the rate and the square of the distance from the P.S expressed in stations. It is also one-third of the deflection angle for a simple curve of the same degree as the spiral at the given point. (Eq. 9.)

4. The angle between tangents at any two points on the spiral is $\Delta - \Delta_1$ or the difference between the respective angles of these tan-

gents with the initial tangent. $\Delta - \Delta_1 = \frac{1}{2}a\,(L^2 - L_1^2)$. It is also one-half of the sum of the central angles of two simple curves of length equal to the distance between the two points and of degree equal respectively to the degree-of-curve of the spiral at the two points. (Eq. 2.)

5. The deflection angle at any point on the spiral from its tangent to the P.S. is $\Delta - \theta$; or when Δ is less than 20°, it is also $\frac{2}{3}\Delta = 2\theta$. This enables the tangent at any point to be found. (Eqs. 2 and 9.)

6. The deflection angle from a tangent at any point on the spiral to any other point on the spiral is the sum or difference of (1) the deflection angle for a simple curve of same degree as the spiral at the given point and of length equal to the distance between the points, and (2) the spiral deflection angle at the P.S. for a length equal to the distance between the two points. The latter angle is *plus* if the desired point is further from the P.S., and *minus* if nearer, than the point from which the deflections are made. See illustrations under Field Work. (Eq. 10.)

7. The spiral diverges from its osculating circle (circular curve of same degree) at any point at the same rate that the spiral deflects from the initial tangent, and the distance between the circle and spiral is the same as the y for an equal length of spiral.

8. The offset o between the initial tangent and the parallel tangent from the main curve produced backward in feet, equals .0725 times the product of the rate by the cube of the length of the whole spiral in stations, or .0725 times the square of the length of spiral and the degree of main curve. This ordinate is approximately one-fourth of the ordinate y of the end of the spiral. The spiral bisects the offset at a point half-way between the P.S., and the P.C.C. (Eq. 11.)

9. The distance t from the P.S. to this offset is found by subtracting the correction $.000125a^2L^5$ from the half length of the curve in feet. (Eq. 12.)

10. The long chord is found by subtracting the correction, $.0004\,D^2L^3$ from the length of the curve in feet. (Eq. 19.)

11. Other properties may be found by ordinary trigonometric operations.

The Field Work.—Before running the curve, the value of a must be decided upon. If it is desired to connect a given tangent with a given curve, the offset o between the tangent being known, a may be calculated from equation (15), page 84. This method of work may be a great convenience in location. Generally, however, considerations of maximum degree-of curve, the length of tangents, and the speed of trains will determine the value of a to be used. In mountainous country, with 16° maximum and low speeds, a change 1° in 10 feet ($a=10$) will be suitable. For high speeds and 6° maximum, $a=2$ will give an easy-riding curve, and for some locations a value even lower than 1 may be desirable. For electric and elevated roads, values as large as 25 may be necessary. It will be seen that the curve is applicable to a wide range of work.

If the degree-of-curve at any required point is an integral number, the principle that the deflection angle is one-third of that for a simple curve may be used. Thus for $a=10$, at 40 feet from the P.S., the D of the spiral will be 4°. Calculate one-third of the deflection angle for 40 feet of 4° curve. It may be seen that $\frac{1}{10}$ of the D gives the required deflection per foot for the point whose curvature is D.

If desired, the calculations may be made by means of a table as shown hereafter. Or the powers of L may be taken from a table of squares and cubes, the lower decimals dropped, and the multiplication by the simple factors remaining may be made easily and rapidly. Thus, when $a=2$ to determine θ for a point 234 feet (2.34 stations) from the P.S., find the square of 234 (54756), change the decimal point so that it will become the square of 2.34 (5.48), and from equation (9) $\theta=\frac{1}{6}aL^2=\frac{1}{6}\times 2\times 5.48=1°\ 49'$. For o and y the table of cubes may be used in a similar way.

The field work after the P.S. has been determined is similar to that of circular curves. The deflection angles are turned off by the transit, and the measurements are made along chords as in laying out circular curves. Since it is not necessary to make succeeding chords the same length as the first, the stationing may be kept up, and the even stations and +50's put in as usual. Herein is an advantage over methods requiring a regular length of chord to be put in. When the transit is moved to a point on the spiral, the tangent is found by laying off from the chord to the P.S. an angle $=\Delta-\theta$. For usual limits this is also 2θ. Finally, the circular curve is run in from the P.C.C., the tangent to the curve first having been found.

If it is necessary to use a transit-point on the spiral, the tangent at that point is found as before, and the deflections are calculated by equation (10) and will equal the deflections for a circular curve of the same degree as the spiral at the transit-point minus or plus the spiral deflection angle at the P.S.—minus if toward, and plus if from the P.S.—the length used in both cases being the distance from the transit-point to the point to be set.

In running from the P.C.C., to the P.S., use a similar method. Here D is the degree of main curve. After finding the tangent at the P.C.C., the following rule may be used: To find the deflection angle for any point on the spiral at a distance L from the P.C.C., calculate the deflection angle for a D° curve and length L, and also the deflection at the P.S. for a spiral of length L. Subtract the latter from the former. The remainder will be the required angle. If the new point is to be used as a transit-point, the new tangent may be obtained by laying off an angle equal to deflection of circular curve of length L and of same degree as the spiral at the new point, plus the spiral deflection for length L.

As an illustration, let the P. S. be at sta. 16 + 21, 17 the new transit-point, and 17 + 50, the point to be set. Assume a to be 4. Then the deflection angle at the P.S. for sta. 17 may be found from equation (9) as follows: Station 17 is 79 feet from the P.S., and hence $L = .79$. $79^2 = 6241$, and $.79^2 = .62$. Since $\frac{1}{6} \times 60 = 10$, we may get θ in minutes by multiplying aL^2 by 10. Hence $\theta = 10 \times 4 \times .62 = 25'$. $\Delta = \frac{1}{2} \times 4 \times .62 \times 60 = 75'$. $\phi = 75' - 25' = 50'$ With the transit at 17, a deflection angle of 50' from the line to the P.S. will give the tangent. The degree-of-curve at 17 is $4 \times .79 = 3.^\circ16$, which has a deflection angle of 0'.95 per foot. To get the deflection angle to set 17 + 50, take deflection angle for 50 feet of 3°.16 curve = $47\frac{1}{2}'$, and also the deflection angle for 50 feet of spiral = 10'; then $\phi = 47' + 10' = 57'$, with which 17 + 50 may be set. If the point were on the side nearer the P.S., as 16 + 50, the deflection angle would be $47' - 10' = 37'$.

To facilitate the computation, a transit-point may be chosen at a point where the spiral has an even degree-of-curve. For example, 16+96 will be 3° curve, and the circular deflections from this curve are more easily calculated.

If desired, the spiral may be located by ordinates from the tangent or from a circular curve tangent at any point on the spiral. Thus, in Fig. 2, the ordinates from AB, from RD', from RH, and from KSD, as calculated from equation (6), with L as the distance from A, R, or K, will give points on the spiral.

To locate the P. S.—If the tangents have been run to an intersection, the tangent-distance T may be calculated by equation (15) and the P. S. measured in.

In case a simple curve has been run without a transition, the distance of the P. S. back of the P. C. used is $t + o \tan \frac{1}{2} I$, where I

is the angle between the tangents, The new curve will come inside the old, but will not be exactly parallel to it.

If a simple curve has been run, as DLH in Fig. 1, and also a tangent AB, with an offset $o = BD$ between them, the spiral to connect them may be located by finding a from equation (15), which is $a = .269\sqrt{\frac{D^3}{o}}$. With this value of a, l may be calculated or found from the table as explained below. This method is a great convenience where it is desired on account of the ground to throw the curve in or out without changing the tangent, or where a similar change in the tangent is desired without a change in the curve,—the connection being made by means of a suitable spiral.

To replace a simple curve by a spiral and new curve, without varying far from the old line and so keep on the old embankment, proceed as follows. In Fig. 4, the line TNH is the old curve. It is desired to throw the track out a distance $HK = p$, in order to

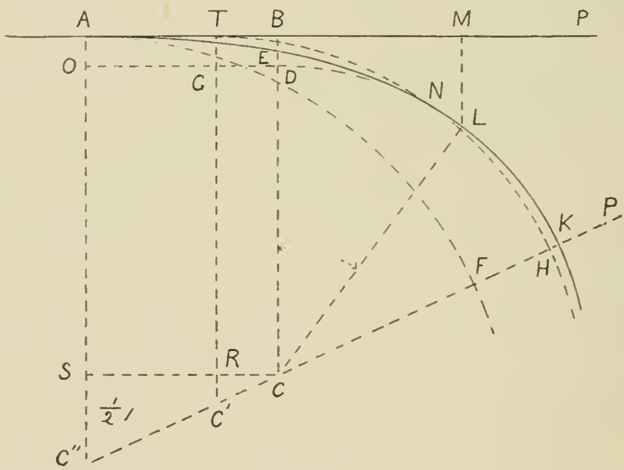


FIG. 4.

in a spiral by throwing it in at the P. C. P is the intersection of tangents, which comes outside the diagram. Let R_1 be the radius of the old curve, and R of the new. $HP - KP = p$, or R_1 exsec ½ $I - (R+o)$ exsec ½ $I = p$. Hence

$$R_1 - R = o + \frac{p}{\text{exsec } \frac{1}{2} I},$$ from which the degree of the new curve may be found.

Also AT=AP—TP=t—(R_1—R—o)tan ½ I=t—p cot ¼ I, by which the P. S. may be located. A value of p may be chosen to cause the least re-lining of track.

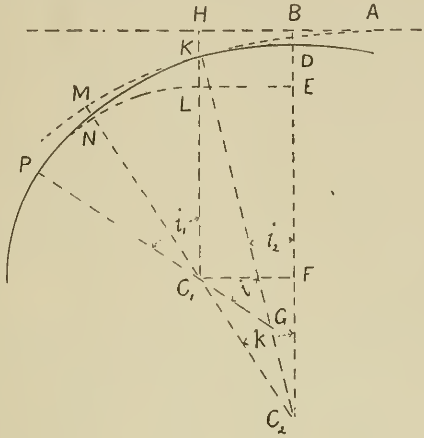


FIG. 5.

Compound Curves.—The spiral may be used to connect curves of different radii, choosing that part of the spiral having curvature intermediate between the degrees of the two curves; thus, connect a 3° and an 8° curve by omitting the spiral up to D=3° and continuing until D=8°. In Fig. 5, DK is a D_1° curve, which it is desired to connect with a D_2° curve, the transition to commence at K. D_2 is greater than D_1. The degree of the spiral at K is D_1. Suppose the spiral to be run backward from K to a tangent at A. The continuation of this spiral from K to P, where it becomes a D_2° curve, may be run from K the same as from any point on the spiral according to the method before described, and no part of the spiral from K to A need be located. The length of spiral between K and P=$l=\dfrac{D_2-D_1}{a}$; and the angle between tangents at K and P is ½ l (D_1+D_2), or the average of that for a length l for both curves.

The spiral may also be used to connect two curves having a given offset between them.

TABLES.—The computations may be shortened by means of the following tables. Table I. may be used for any value of a. Table II. is for a change of 10° per 100 feet, and Table III. for 3⅓°.

The first column contains the distance in feet from the P.S.; the second, the degree-of-curve of the spiral; the third, the spiral angle Δ, the fourth, the deflection angle θ from the initial tangent; the fifth, the offset o of the initial tangent from the main curve produced backward; the sixth, the ordinate y from the initial tangent as the axis of X; the seventh, a correction to be subtracted from the length of the spiral in feet to find x; the eighth, a correction to be subtracted from half the length of the curve in feet to find t. To find the long chord c, subtract $\frac{8}{15}$ of this x correction from the length of the curve in feet.

To find intermediate values, interpolate by multiplying one tenth of the difference between consecutive values by the number of additional units. Thus Table II. gives Δ for 140 feet as 9° 48'; for 150 feet, as 11° 15'. One tenth of the difference between these is 8'.7. For 146.8 feet, add 6.8×8.7=59' to 9° 48', giving 10° 47'.

This interpolation gives a slight error in Δ which may be neglected for a less than 8, and may not need considering above that. To find exact values, deduct the following from the interpolated quantities: For a length in feet ending with 1, .027'; 2, .048'; 3, .063'; 4, .072'; 5, .075'; 6, .072'; 7, .063'; 8, .048'; 9, .027'. For other spirals, multiply these corrections by a. For $a=10$, the greatest error is .75'. This difference arises from the fact that the square of numbers does not increase uniformly.

Interpolation in the other columns gives accurate results.

Table I. has been carried to several decimal places to permit a use with any value of a. To do this, multiply the tabulated value opposite the desired length by the a of the spiral,—except for the x and t corrections, when the square of a must be used as the multiplier. Thus, if $a=2$, multiply the tabulated Δ, θ, o, or y by 2 and the t and x corrections by 4. This may be utilized when it is desired to correct a fixed tangent with a given circular curve, since when a and L have been found the other quantities may be calculated by means of this table. A similar table for every foot of length would not be very bulky. The value of y obtained in this way is subject to error when Δ is more than 16° for large values of a.

The tables are of such size that they may be cut out and inserted in the ordinary engineer's field book.

TABLE I. TRANSITION SPIRAL. $a = 1$.

Length	D	Δ	θ	o	y	x COR.	t COR.
10	0°.1	0° 00′.3	0° 00′.1	.000	0.000	0.0000	0.0000
20	0 .2	01 .2	00 .4	.001	.002		
30	0 .3	02 .7	00 .9	.002	.008		
40	0 .4	04 .8	01 .6	.005	.019		
50	0 .5	07 .5	02 .5	.009	.036		
60	0 .6	0 10 .8	0 03 .6	.016	.063	.0001	
70	0 .7	14 .7	04 .9	.025	.100	.0001	
80	0 .8	19 .2	06 .4	.037	.149	.0002	
90	0 .9	24 .3	08 .1	.053	.212	.0004	.0001
100	1 .0	30 .	10 .	.073	.291	.0008	.0001
110	1 .1	0 36 .3	0 12 .1	.097	.387	.0012	.0002
120	1 .2	43 .2	14 .4	.126	.503	.0019	.0003
130	1 .3	50 .7	16 .9	.160	.639	.0028	.0005
140	1 .4	58 .8	19 .6	.199	.798	.0041	.0007
150	1 .5	1 07 .5	22 .5	.245	.982	.0058	.0010
160	1 .6	1 16 .8	0 25 .6	.298	1.191	.0080	.0013
170	1 .7	1 26 7	28 .9	.357	1.429	.0108	.0018
180	1 .8	1 37 .2	32 .4	.424	1.696	.0144	.0024
190	1 .9	1 48 .3	36 .1	.499	1.995	.0189	.0031
200	2 .0	2 00 .	40 .	.582	2.327	.0244	.0041
210	2 .1	2 12 .3	0 44 .1	0.673	2.690	.031	.0052
220	2 .2	2 25 .2	48 .4	.774	3.097	.039	.0065
230	2 .3	2 38 .7	52 .9	.885	3.538	.049	.0082
240	2 .4	2 52 .8	57 .6	1.005	4.020	.061	.0101
250	2 .5	3 07 .5	1 02 .5	1.136	4.544	.074	.0124
260	2 .6	3 22 .8	1 07 .6	1.278	5.111	.090	.015
270	2 .7	3 38 .7	1 12 .9	1.431	5.724	.109	.018
280	2 .8	3 55 .2	1 18 .4	1.596	6.383	.131	.022
290	2 .9	4 12 .3	1 24 .1	1.773	7.091	.156	.027
300	3 .0	4 30 .	1 30 .	1.963	7.850	.185	.031
310	3 .1	4 48 .3	1 36 .1	2.166	8.66	.218	.036
320	3 .2	5 07 .2	1 42 .4	2.382	9.53	.255	.043
330	3 .3	5 26 .7	1 48 .9	2.612	10.45	.298	.050
340	3 .4	5 46 .8	1 55 .6	2.857	11.42	.346	.058
350	3 .5	6 07 .5	2 02 .5	3.116	12.46	.400	.067
360	3 .6	6 28 .8	2 09 .6	3.391	13.56	.460	.077
370	3 .7	6 50 .7	2 16 .9	3.681	14.72	.528	.088
380	3 .8	7 13 .2	2 24 .4	3.988	15.94	.603	.100
390	3 .9	7 36 .3	2 32 .1	4.311	17.23	.686	.114
400	4 .0	8 00 .	2 40 .	4.651	18.59	.779	.130
410	4 .1	8 24 .3	2 48 .1	5.01	20.02	.881	.147
420	4 .2	8 49 .2	2 56 .4	5.38	21.51	.994	.166
430	4 .3	9 14 .7	3 04 .9	5.78	23.08	1.118	.186
440	4 .4	9 40 .8	3 13 .6	6.19	24.73	1.254	.209
450	4 .5	10 07 .5	3 22 .5	6.62	26.45	1.403	.234
460	4 .6	10 34 .8	3 31 .6	7.07	28.24	1.566	.261
470	4 .7	11 02 .7	3 40 .9	7.54	30.12	1.743	.291
480	4 .8	11 31 .2	3 50 4	8.03	32.07	1.937	.323
490	4 .9	12 00 .3	4 00 .1	8.54	34.11	2.146	.358
500	5 .0	12 30 .	4 10 .	9.07	36.23	2.374	.396

TABLE I.—*Continued.*

Length	D	Δ		θ		o	y	x COR	t COR
510	5°.1	13°	00'.3	4°	20'.1	9.63	38.44	2.621	.437
520	5 .2	13	31 .2	4	30 .4	10.20	40.73	2.888	.482
530	5 .3	14	02 .7	4	40 .9	10.80	43.12	3.175	.530
540	5 .4	14	34 .8	4	51 .6	11.42	45.59	3.486	.582
550	5 .5	15	07 .5	5	02 .5	12.07	48.15	3.820	.637
560	5 .6	15	40 .8	5	13 .6	12.74	50.69	4.18	.697
570	5 .7	16	14 .7	5	24 .9	13.43	53.56	4.56	.762
580	5 .8	16	49 .2	5	36 .4	14.14	56.40	4.98	.831
590	5 .9	17	24 .3	5	48 .1	14.89	59.34	5.42	.905
600	6 .0	18	00 .	6	00 .	15.65	62.39	5.89	.984
610	6 .1	18	36 .3	6	12 .1	16.44	65.52	6.40	1.069
620	6 .2	19	13 .2	6	24 .4	17.26	68.77	6.94	1.159
630	6 .3	19	50 .7	6	36 .9	18.10	72.11	7.51	1.255
640	6 .4	20	28 .8	6	49 .6	18.97	75.56	8.13	1.358
650	6 .5	21	07 .5	7	02 .5	19.87	79.11	8.78	1.467

TABLE II. TRANSITION SPIRAL. $a=10$.

Length	D	Δ		θ		o	y	x COR	t COR
10	1 .00	0	03	0	01	0.00	0.00	0.00	0.00
20	2 .	0	12	0	04	.01	.02		
30	3 .	0	27	0	09	.02	.08		
40	4 .	0	48	0	16	.05	.19		
50	5 .	1	15	0	25	.09	.36		
60	6 .00	1	48	0	36	.16	.63	0.01	0.00
70	7 .	2	27	0	49	.25	1.00	.01	
80	8 .	3	12	1	04	.37	1.49	.02	
90	9 .	4	03	1	21	.53	2.12	.04	.01
100	10 .	5	00	1	40	.73	2.91	.08	.01
110	11 .00	6	03	2	01	.97	3.87	.12	.02
120	12 .	7	12	2	24	1.26	5.02	.19	.03
130	13 .	8	27	2	49	1.60	6.38	.28	.05
140	14 .	9	48	3	16	1.99	7.97	.41	.07
150	15 .	11	15	3	45	2 45	9 79	.58	.10
160	16 .00	12	48	4	16	2.97	11.87	.80	.13
170	17 .	14	27	4	49	3.56	14.23	1.08	.18
180	18 .	16	12	5	24	4 23	16.87	1.44	.24
190	19 .	18	03	6	01	4 97	19 81	1.88	.31
200	20 .	20	00	6	39½	5.79	23.07	2.42	.40
210	21 .00	22	03	7	20½	6.70	26.65	3 09	.52
220	22 .	24	12	8	03¼	7.69	30 58	3 89	.65
230	23 .	26	27	8	48	8.78	34 86	4.85	.81
240	24 .	28	48	9	34¾	9 96	39 49	5.99	1.00
250	25 .	31	15	10	23½	11.24	44 49	7.33	1.23

TABLE III. TRANSITION SPIRAL. $a=3\frac{1}{2}$.

Length	D	Δ	θ	o	y	x COR	t COR
10	0°.20'	0° 01'	0° 00 ⅓	0.00	0 00	0 00	0 00
20	0 .40	0 04	0 01 ⅓	.00	.01		
30	1 .00	0 09	0 03	.01	.03		
40	1 .20	0 16	0 05 ⅓	.02	.06		
50	1 .40	0 25	0 08 ⅓	.03	.12		
60	2 .00	0 36	0 12	.05	.21	.00	0 00
70	2 .20	0 49	0 16 ⅓	.08	.33		
80	2 .40	1 04	0 21 ⅓	.12	.50		
90	3 .00	1 21	0 27	.18	.71		
100	3 .20	1 40	0 33 ⅓	.24	.97	0.01	
110	3 .40	2 01	0 40 ⅓	.32	1.29	.01	0.00
120	4 .00	2 24	0 48	.42	1.68	.02	
130	4 .20	2 49	0 56 ⅓	.53	2.13	.03	
140	4 .40	3 16	1 05 ⅓	.67	2.66	.05	.01
150	5 .00	3 45	1 15	.82	3.27	.06	.01
160	5 .20	4 16	1 25 ⅓	.99	3 97	.09	.01
170	5 .40	4 49	1 36 ⅓	1 19	4 76	.12	.02
180	6 .00	5 24	1 48	1.41	5 65	.16	.03
190	6 .20	6 01	2 00 ⅓	1.66	6 65	.21	.035
200	6 .40	6 40	2 13 ⅓	1 94	7.75	.27	.05
210	7 .00	7 21	2 27	2 24	8 97	.35	.06
220	7 .20	8 04	2 41 ⅓	2 58	10.31	.44	.07
230	7 .40	8 49	2 56 ⅓	2 95	11.77	.54	.09
240	8 .00	9 36	3 12	3 35	13.38	.67	.11
250	8 .20	10 25	3 28 ⅓	3.78	15.11	.83	.14
260	8 .40	11 16	3 45 ⅓	4 25	17 00	1.00	.17
270	9 .00	12 09	4 03	4.76	19 02	1.21	.20
280	9 .20	13 04	4 21 ⅓	5.31	21.20	1.45	.24
290	9 .40	14 01	4 40 ⅓	5.90	23 55	1.73	.29
300	10 .00	15 00	5 00	6 53	26 05	2.05	.34
310	10 .20	16 01	5 20 ⅓	7 20	28 72	2 41	.40
320	10 .40	17 04	5 41 ⅓	7 92	31 57	2.83	.47
330	11 .00	18 09	6 03	8 69	34 59	3 30	.55
340	11 .20	19 16	6 25	9 49	37.80	3.82	.64
350	11 .40	20 25	6 48	10 35	41.19	4.42	.74
360	12 .00	21 36	7 11 ½	11.25	44.78	5.08	.85
370	12 .20	22 49	7 35 ¾	12.21	48 56	5 82	.97
380	12 .40	24 04	8 00 ½	13 22	52 53	6.65	1.11
390	13 .00	25 21	8 26	14 28	56 71	7 56	1.27
400	13 .20	26 40	8 52 ⅓	15.39	61.10	8.58	1.44
410	13 .40	28 01	9 19 ⅛	16.56	65 69	9.69	1 62
420	14 .00	29 24	9 46 ¾	17 79	70.49	10.92	1.83
430	14 .20	30 49	10 15	19 07	75 51	12.27	2 06
440	14 .40	32 16	10 43 ½	20.41	80.74	13.75	2.30
450	15 .00	33 45	11 13	21.81	86.19	15 36	2.58

The transition spiral was probably first used on the Pan Handle Railroad in 1881, by Mr. Elliot Holbrook. The principal part of the treatment here given was made before the writer's attention was called to Mr. Holbrook's use of the curve, and it is believed that most of the formulas and methods appear here for the first time. By Mr. Holbrook's method, the deflection angles were always calculated from the co-ordinates, x and y,—a long and tedious process, especially if accurate results are obtained; and for a transit-point on a spiral, the deflection angles were calculated from tan

$$\varphi = \frac{y—y.}{x—x.}$$

If the properties of the transition spiral were more generally understood and appreciated, it would be more largelv used.

The Tapering Curve.

The Tapering Curve is a compound curve consisting of a series of circular curves of the same length, whose degree of-curve increases by some constant difference up to the degree of the main curve. Thus, if the taper is 1° for each 30 feet, the approach from a tangent to a 6° curve will be made by 30 feet of 1° curve, 30 feet of 2° curve, 30 feet of 3° curve, 30 feet of 4° curve, and 30 feet of 5° curve, after which the 6° curve is run in.

If the degree of the main curve is not a multiple of the common difference of the tapers, at the end of the last full chord a fractional chord is used, proportional to the difference of the degree of the main curve and last taper. Thus, for a taper of 2° 30' per 30 feet, an 8° curve would be reached by 30 feet of 2° 30' and 30 feet of 5° curve, ending with 6 feet of 7° 30' curve; since 8° is in excess of 7° 30' by one-fifth of the change 2° 30', one-fifth of a full chord is used.

In order to run the curve with the transit at the beginning of the tapering curve or at some corresponding point—thus saving setting at each P. C. C.—a table giving deflection angles to the different P. C. C's, is used. The formulas for the calculation of these tables may be shown as follows:

In Fig. 6, let AEL be a tapering curve composed of a number of equal arcs, AH, HK, and KL, and LS the main curve which produced backward to D will give a tangent parallel to AP. Denote the points of compound curve by P. C. C. The following nomenclature will be used:

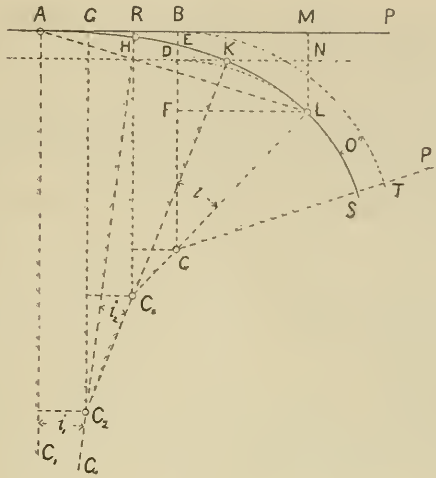


FIG. 6.

D = degree of the main curve, and R its radius.

d = degree of arc of taper of number denoted by subscript.

r = radius, distinguished in the same way.

i = central angle of any arc, distinguished in the same way.

Δ = sum of the central angles up to a given P. C. C.

θ = deflection angle at P. T. C. to end of any arc.

Φ = deflection angle at any P. C. C. to end of any arc.

L = total length of the tapering curve (in stations).

c = length of chord of one curve (in stations).

n = number of the chord considered, counting from the P. T. C. Other terms are as used in the transition spiral.

Since the degree of the tapers increases in arithmetical progression,

$\Delta = \frac{1}{2}\, n\,(n+1)\, i$. Also, since $L = n\, c$, $\Delta = \frac{1}{2}\, D\, L$, and hence the curve will be twice as long as the main curve for the same central angle.

To find the deflection angle at the P.T.C.,—

$\tan\theta = \dfrac{y}{x}$. The values of the co-ordinates may be shown to be

$x = 100c\,[\cos \frac{1}{2} i_1 + \cos 2 i_1 + \ldots\ldots + \cos \frac{1}{2} n^2 i_1] = c\Sigma \cos \frac{1}{2} n^2 i_1.$

$y = 100c\, \Sigma \sin \frac{1}{2} n^2 i_1.$ Whence

$$\tan\theta = \frac{\Sigma \sin \frac{1}{2} n^2 i}{\Sigma \cos \frac{1}{2} n^2 i}.$$

The co-ordinates may also be expressed as follows:

$x=(r_1-r_2)\sin i_1+(r_2-r_3)\sin (i_1+i_2)$..............to n terms.

$y=(r_1-r_2)\text{vers } i_1+(r_2-r_3) \text{ vers } (i_1+i_2)$..............to n terms.

The deflection angle at any P.C.C., between the tangent at that point and a line to the P.T.C. will be $\Delta-\theta$.

The deflection angle to any other P.C.C. may be found from

$$\phi=\frac{y_1-y_2}{x_1-x_2}.$$

It may be shown that

$o=y-R \text{ vers } \Delta.$

$t=x-R \sin \Delta.$

$T=t+(R+o) \tan \tfrac{1}{2}I.$

$E=(R+o) \text{ exsec } \tfrac{1}{2}I+o.$

$$C=\frac{y}{\sin \theta}.$$

From these formulas concise tables may be computed for use in field work. In case the degree of main curve is not an even multiple of the constant increase of degree, these formulas will need modification. The computation is somewhat tedious, and the interpolation for partial chords can not be made with accuracy.

Tables IV. and V. give the deflection angles for a change of 1° in 30 feet, and for 2° 30' in 30 feet. The columns are headed with the distances from the P.T.C. To find a deflection angle for the transit at a given distance from the P.T.C., look down the corresponding column for "transit;" in the same horizontal line with this and in the column headed with the distance of the required point from the P.T.C. is the deflection angle. Thus, for a change of 1° in 30 feet, with transit at 1+20, the deflection to 0 is 1° 06', and to 2+10 is 2° 03'. The degree of the next taper, or the degree of the main curve with which the taper compounds, is also given opposite P.C.C. o, t, and Δ are for the whole tapering curve up to a length given by the column heading. The degree of main curve divided by the increase of degree will give one more than the number of chords to be used.

The field work is similar to that of the transition spiral—except that a uniform chord length must be used—and need not be described. Some inconvenience comes from the necessity of taking even chords and disregarding the usual station stakes on the taper,

TABLE IV. 1° TAPER FOR 30 FEET.

0	+30	+60	+90	1+20	1+50	1+80	2+10	2+40	2+70
Transit	0° 09'	0° 22' ½	0° 42'	1° 07' ½	1° 39'	2° 16' ½	3° 00'	3° 49' ½	4° 45'
0° 09'	Transit	0 18	0 40½	1 09	1 43½	2 24	3 10½	4 03	5 01½
0 31½	0 18	Transit	0 27	0 58½	1 36'	2 19½	3 09	4 04½	5 06
1 06	0 49½	0 27	Transit	0 36	1 16½	2 03	2 55½	3 54	4 58½
1 52½	1 33	1 07½	0 36	Transit	0 45	1 34½	2 30	3 31½	4 39
2 51	2 28½	2 00	1 25½	0 45	Transit	0 54	1 52½	2 57	4 07½
4 01½	3 36	3 04½	2 27	1 43½	0 54	Transit	1 03	2 10½	3 24
5 .24	4 55½	4 21	3 40½	2 54	2 01½	1 03	Transit	1 12	2 28½
6 58½	6 27	5 49½	5 06	4 16½	3 21	2 19½	1 12	Transit	1 21
8 45	8 10½	7 30	6 43½	5 51	4 52½	3 48	2 37½	1 21	Transit
P.C.C.	2°	3°	4°	5°	6°	7°	8°	9°	10°
$\lrcorner$	0° 18'	0° 54'	1 48	3 00	4 30	6 18	8 24	10 48	13 30
o	0.03	0.14	0.38	0.77	1.36	2.18	3.28	4.69	6.45
t	15.01	30.01	45.01	60.00	74.99	89.95	104.90	119.80	134.66
c	30.00	60.00	90.00	119.99	149.96	179.91	209.81	239.63	269.35

TABLE V. 2° 30' TAPER FOR 30 FEET.

0	+30	+60	+66	9+0	1+14	1+20	1+50	1+80	2+10
Transit	0° 22' ½	0° 56¼	1° 04' ⅔	1° 45'	2° 35'	2° 48¾	4° 07½	5° 41'	7° 29½
0° 22½	Transit	0 45'	0 55	1 41¼	2 37	2 52½	4 18¾	6 00	7 56
1 18¾	0 45	Transit	0 13½	1 07½	2 09½	2 26¼	4 00	5 48¾	7 52½
1 37⅓	1 02	0 13½	Transit	....	....	....	....	....	....
2 45	2 03¾	1 07½	....	Transit	1 12	1 30	3 11¼	5 07½	7 18¾
4 19	3 32	2 29½	....	1 12	Transit	....	... ...	....	....
4 41¼	3 52½	2 48¾	....	1 30	....	Transit	1 52½	3 56¼	6 15
7 07½	6 11¼	5 00	....	3 33¾	....	1 52½	Transit	2 15	4 41¼
10 04	9 00	7 41¼	....	6 07½	....	4 18¾	2 15	Transit	2 37½
13 30½	12 19	10 52½	....	9 11¼	....	7 15	5 03¾	2 37½	Transit
P.C.C.	5°	7° 30'	8°	10°	12°	12° 30'	15°	17° 30'	20°
$\lrcorner$	0 45	2 15	2 42	4 30	6 54	7 30	11 15	15 45	21 00
o	0.10	0.40	0.45	0.99	1.67	1.97	3.43	5.48	8.20
t	15.00	29.99	32.24	44.97	56.44	59.93	74.82	89.62	104.27
C	30.00	60 00	65.99	89.98	113.94	119.92	149.76	179.43	208.8

but this is not a very serious drawback. If intermediate points are desired, a tape may be stretched along the chord, and the proper ordinate taken from tables for the purpose and measured off at the desired point. Interpolations in the tables will not give accurate results. 30 feet seems to be preferred for the length of chord, since it is just the length of a rail, but 50-ft. chords would be more advantageous in some respects.

The tapering curve was introduced by Mr. William Hood, Chief Engineer of the Southern Pacific Railway, and has been extensively

—8

used on the Southern Pacific, Northern Pacific, Missouri Pacific, and other Western roads. It makes a good transition curve, and does not vary much from the transition spiral. However, it lacks flexibility, this property being secured only by a wide range of tapers, necessitating many tables.

The Railroad Spiral.

The Railroad Spiral, as developed by Wm. H. Searles, C. E., is a multiform compound curve, differing from the tapering curve by using the central angles of the successive arcs as constant quantities, and varying the length of arc or chord to secure different spirals. The first arc has 10' central angle, the second 20', the third 30', and so on to the end of the transition curve. Mr. Searles has published a little hand-book of tables and explanations for this curve. Tables of deflection angles with the transit at any chord point are given. These deflections are constant whatever the chord length. Thus, the deflection to the end of the 8th chord is 2° 07', whether the length of curve be 8×10 feet or 8×21 feet, and the central angle subtended will also be the same. However, the degree-of-curve of the arcs will vary with a change in length of chord. This necessitates a set of tables giving the degree-of-curve for the last chord in the curve. As this is not an integral number, the one nearest the degree of the main curve is chosen. This is allowable, since it consists in compounding the last arc with the main curve. As several chord lengths with the corresponding number of chords will give about the same degree-of-curve, a variety of spirals for any main curve is secured. About sixty tables are given in Searles' "The Railroad Spiral," to which the student is referred for further information.

The "railroad spiral" approaches very near the true transition spiral. With the tables given, the calculations and field work are simple and rapid. Deflections for points between the chord points are found by interpolating in the tables, but only chord points may be used as transit-points. An objection has been made that the degree-of-curve for any chord is not an integral multiple of the number of the chord. This, however, is not of great importance.

Other Methods.

The Cubic Parabola.—The Cubic Parabola is a curve whose ordinate from the tangent varies as the cube of the distance from the P. C., measured along the tangent. Its equation is $y = cx^3$, c

being a constant. Within a small limit, the degree of curve varies nearly as the distance along the tangent, and Δ as the square of this distance. Hence, within this limit, the curve approaches closely to the true transition spiral; in fact, all its valuable properties for a railway transition curve are approximations of the transition spiral. As soon as x differs materially from the length of curve, a correction has to be made, otherwise the curve must be laid out by ordinates from the tangent, a very objectionable method. The radius of curvature finally begins to increase. Many attempts have been made to utilize this curve, but both field work and computations are too intricate and inconvenient if the curve has any considerable length, and it has no advantage over the transition spiral.

THE PENNSYLVANIA METHOD.—The Pennsylvania Railroad uses 200 feet of 30' curve at the ends of a simple curve. For sharp curves 100 feet of 1° curve is put in at either end. The super-elevation begins with zero at the P.C., and increases uniformly to the full amount at the beginning of the main curve. The claim is made that in this manner the complete super-elevation is attained while the car is on a light curve where the wheels keep to the outer rail, and that the shock incident to gaining the super-elevation while on the tangent is avoided. Of course, the field work is simple. It is claimed that this method is very efficient, but it is open to criticism.

METHODS OF TRACK-MEN.—When simple curves are left without transition curves, many track-men "ease" the curve by throwing the P. C. inward a short distance and gradually approaching the tangent a few rail-lengths away, while the main curve is reached finally by sharpening the curve for a short distance. Even this is better than no easement curve.

Another simple method consists in utilizing one of the properties of the transition spiral. In Fig. 1, page —, let ABK be the original track line, B being the P. C. At some point in the curve a convenient distance from the P. C., say 100 feet, throw the track inward any distance to L. At B, the old P. C., throw the track to E a distance half as great. Measure back from the P. C. an equal distance, 100 feet, to A for the beginning of the easement. Between A and L, line the track by eye. The remainder of the main curve must then be thrown inward the same distance as at L. On long curves, the latter work would make the method objectionable.

Conclusion.

An examination of these methods will show that the transition spiral possesses the requirement that the degree-of-curve shall increase uniformly along the spiral, and that the tapering curve and Searles' railroad spiral meet the requirements to a sufficient degree. The transition spiral and the railroad spiral are extremely flexible, but the former has been shown to have some advantages over the latter. An advantage is claimed for the tapering curve that when 30 feet is taken for the chord length the rails when previously bent will fit the separate arcs; thus, for a change of 2° 30' for each 30 feet, the first rail may be bent for a 2° 30' curve, the second for a 5°, the third for a 7° 30' curve, etc. As the first joint on the curve may come a half rail length from the P. T. C., the claim for accuracy is not strictly true, while for flat tapers it is of little importance. With the spiral, an average curvature for the rail-length may be chosen. In any event, the lining will easily throw the track to proper centers.

In the matter of field work and computations, the transition spiral as outlined in the preceding pages is preferable to either of the others. It may be used with any main curve, even if of fractional degree; any length of chord may be used in measurement under the same restrictions as circular curves; and the deflections and co-ordinates to a point not at the end of the common chord may be accurately and quickly found. If a more compact form of table is desired, giving the deflection angles from points on the spiral, a table of the form and size given for tapering curves on page 100 may be prepared. The writer believes that the ordinary transit-man, with a little thought and study, can understand and use the transition spiral as easily as circular curves, and that the advantages of this method are such that if they were more generally known it would be more generally used.

Most of the usual formulas of the various location problems, like "Required to change the P. C. so that the curve may end in a parallel tangent," may be used without modification with curves having transition endings, by simply considering the whole intersection angle including the angle in the spirals. This is true whenever the same amount of spiral is used with the new curve. If the degree-of-curve changes and with it the length of the spiral, the difference between the o's in the two cases must be allowed for. With a littte practice in using such formulas with spirals, the engineer will find no difficulty.

The objection is sometimes raised that even if track is laid out with a carefully fitted spiral there would be no possibility of keeping it in place by the methods of the ordinary track-man. This identical objection could be made with the same force against carefully laid out circular curves, yet no engineer would recommend abolishing that practice. Even if, in re-lining, the transition curve is considerably distorted, it remains an easement, and will be in far better riding condition than a distorted circular curve. By marking the P.S. and the P.C.C. with a stake or post, with possibly on long spirals an intermediate point, the track-man will be able to keep the spiral in as good condition as though it were of uniform curvature.

Properly constructed spirals would frequently allow the use of sharper curvature—since the riding quality of curves may be the governing consideration in the selection of a maximum—and thus make a saving in construction. By fitting curves with proper transition spirals, roads using sharp curves may partially relieve the objection of the public to traveling by their routes. The transition curve has, then, a financial value largely overbalancing its cost. The adoption of such curves by many of our principal railways proves their efficiency, and the future will see a much more general adoption.

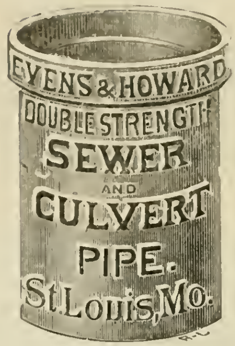
OUTPUT DAILY 200 TONS.

MANUFACTURES

Fire Brick,

Sewer Pipe,

Gas Retorts,



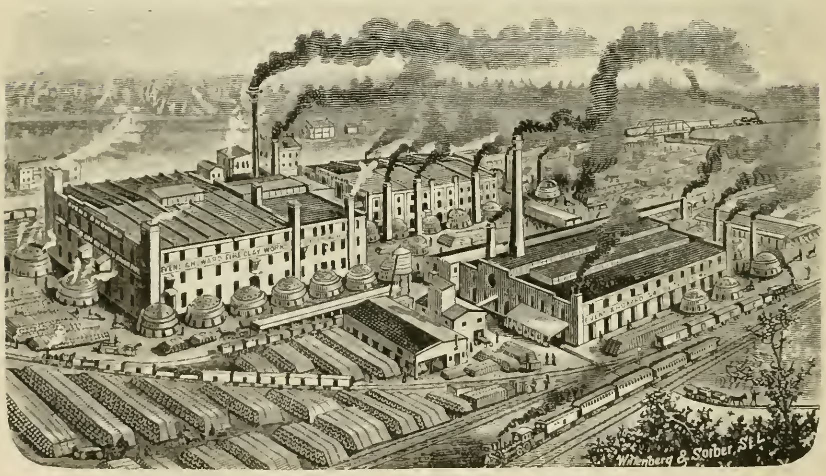
Furnace

Linings,

Flue Pipe,

Chimney Tops.

Prices Furnished on Application for Material on Contracts.



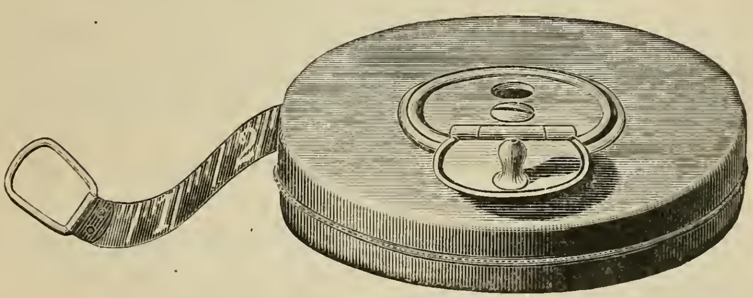
EVENS & HOWARD'S

FIRE BRICK AND SEWER PIPE

Are used by all the leading dealers and consumers throughout the West, and that their excellence is gaining for them new friends daily is shown by the increased demands supplied by them. Write for descriptive circulars.

EVENS & HOWARD, St. Louis, Mo.

GEO. M. EDDY & CO.,



MANUFACTURERS OF

Measuring Tapes for all Purposes.

345 TO 343 CLASSON AVENUE, BROOKLYN N. Y.

Steel Tapes of all kinds, for Engineering purposes, a specialty. Also, light Steel Standard Measures, one-eighth inch wide, graduated each five or ten feet, with Reel for rough work; will not break; warranted U. S. Standard Measure. Send for catalogue.