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Gravel Road. (Courtesy Iowa Highway Commission) *Frontispiece*

HIGHWAY ENGINEERING

RURAL ROADS AND PAVEMENTS

BY

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PREFACE

In writing a text-book on a subject which is growing as rapidly as highway engineering is at the present time one finds himself confronted with a varying practice. The student who desires the latest up-to-date matter on roads must consult contemporaneous engineering periodicals and literature and sift from them what he deems best suited to his purpose. In this work the author has endeavored to bring into a brief space the most recent and best practice as determined by his experience and research.

As this text is more especially concerned with rural roads, those types of roads most common in the rural districts, small cities, and towns, or best adapted for use therein, have been covered in greatest detail. Pavements have been treated largely with a view to their use for country roads, although the treatment is thought to be sufficiently comprehensive to form a beginning or short course for those desirous of taking up city paving work. The author is of the opinion that almost all of the principles of road building applicable to rural highways are equally applicable to city streets and vice versa.

While technical analyses and technical language have not been shunned, it has been constantly borne in mind that the book is intended primarily to form one of a series in agricultural education. It is believed, therefore, that the work is of such a character that it will be read with interest by the layman and, because here are brought together many ideas from many sources, will serve as a useful reference book for professional engineers, road builders, and road officers.

A method of calculating mixtures to conform to the Fuller maximum density curve for concrete, the New York sheet asphalt mixture, or any other selected or predetermined sieve analysis design, is given. This, as far as the author knows, is original and, he thinks, mathematically correct and rigid, avoiding much of the guesswork of the older presentations. He has also illustrated his straight-line method for plotting granulometric analyses, which seems to have advantages over the ordinary method. Tentative methods for testing sand-clay mixtures are included; these, while not yet standardized by technical organizations, are in daily practical use. A graded mixture for gravel roads based upon the maximum density curve is suggested. The surveying and location of roads has been gone into with considerable detail, because with the present inability of the railways to serve the public adequately the author looks for increased business by motor transport and consequently greater interest to be manifested in constructing new lines of highway and straightening and shortening old.

In the preparation of the text, naturally many sources have been consulted. Throughout, references have been subtended; if any have been overlooked it has been unintentional. However, those sources most freely consulted are here mentioned:

Periodicals:

"Engineering and Contracting."
"Engineering Record" } "Engineering News-Record."
"Engineering News" }
"Good Roads."

Highway Engineering Text-books:

Baker's "Roads and Pavements."
Blanchard and Drowne's "Text-book on Highway Engineering."
Blanchard's "Highway Engineers' Handbook."
Harger and Bonney's "Handbook for Highway Engineers."
Richardson's "Modern Asphalt Pavements."
Richardson's "Asphalt Construction."
Hubbard's "Dust Prevention and Road Binders."

Hubbard's "Highway Inspectors' Handbook."
Spalding's "Text-book on Roads and Pavements."
Tillson's "Street Pavements and Paving Materials."
Frost's "Art of Road Making."
Judson's "City Roads and Pavements."

Publications of Engineering and Other Technical Societies:
American Society for Testing Materials.
American Society of Civil Engineers.
American Society for Municipal Improvements.
American Road Builders' Association.
National Paving Brick Manufacturers' Association.
National Conference on Concrete Road Building.
National Highways Association.
Portland Cement Association.

National and State Publications:
Office of Public Roads and Rural Engineering, United States Department of Agriculture.
Bureau of Standards, United States Deprtment of Commerce and Labor.
Many State Highway Departments and Reports of Highway Engineers.

Other Engineering and Technical Text-books:
Taylor and Thompson's "Concrete, Plain and Reinforced."
Hool's "Reinforced Concrete Construction."
Turneaure and Maurer's "Principles of Reinforced Concrete Construction."
Johnson's "Materials of Construction."
Mills' "Materials of Construction."
Benson's "Industrial Chemistry."
Middleton's "Building Materials."
Wellington's "Economic Theory of the Location of Railways."
Lavis' "Railroad Location."
Pence and Ketcham's "Surveying Manual."
Nagle's "Field Manual for Railroad Engineers."
Merriman's "American Civil Engineers' Pocket Book."

Abraham's "Asphalts and Allied Substances."
Ries and Watson's "Engineering Geology."

Commercial Literature:

The bulletins and catalogues of manufacturers of road materials and road machinery.

To the authors and publishers of all the sources used the author's sincere thanks are due, as well as to Professor C. E. Mickey and other associates in the University of Nebraska.

GEORGE R. CHATBURN.

LINCOLN, NEBRASKA,
September, 1920

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CHAPTER I

INTRODUCTION

GOOD ROADS A BUSINESS PROPOSITION

The business transactions of the world are measured in money, but no medium of exchange can measure many of the most valuable things mankind enjoys—for example, good health, fresh air, the education obtained in the common schools, the roads traveled upon. Poor health is a direct source of expense and indirectly the cause of great money losses. Men have given thousands of dollars to prevent the erection of buildings which would cut off their supply of sunlight and fresh air. The lack of an education is so great a handicap to the individual and so detrimental to the welfare of the nation that the greatest of all taxes are those paid to keep up the schools. Bad roads are stagnation and even death to trade and commerce, resulting in large losses of time and money. The great blessings that come with the enjoyment of these things and the serious disadvantages and losses of their absence are fully realized; yet, due to the lack of knowledge of intimate relationships existing between the various interests of life, a definite value in dollars and cents cannot be placed upon any one of these useful and necessary elements. Local conditions, individual differences, sentiment, supply and demand, and many other factors must enter into an estimate of what a thing is worth. But, notwithstanding this, many efforts have been made by road economists to evaluate the benefits derived from good and the losses due to bad roads. Several years ago the United States Office of Public Roads published a bulletin in which an effort was made to show that the cost of hauling on the country roads was annually about $900,000,000; and that with uniformly good roads there might be a saving of more than $600,000,000. Professor L. W. Chase makes a very plausible calculation to show that the average farmer in Nebraska would save each year $147 if the road leading from his farm to his market were dragged after each rain. Interesting and instructive as such claculations are, they are nevertheless futile because uniformly good roads would themselves change other conditions and affect markets.

The chief value of good roads is not in the actual money saving they produce, but they are desirable for the same reason that a man buys a carriage or a carpet; they appeal to his desire for comfort, for beauty, for pleasure, for style. In the early days the pioneers lived in log, in sod, or other makeshift houses; people could do so to-day if they wished. A man could go to church or to a polite function wearing overalls and jumper, but he prefers other styles of clothing. In a great many things economic factors are of minor importance. Nevertheless, it is worth while to consider some of the

Economic Advantages of Good Roads

Good roads decrease the cost of transportation by allowing larger loads to be hauled or by saving in time.

Good roads save in the wear and tear of wagons, harness, horse-flesh, automobiles, trucks and tractors.

Good roads and the possibility of daily marketing allow the cultivation of crops not otherwise profitable—of intensive farming. Whole families have been known to support themselves upon small patches of 5 or 10 acres by gardening. Other crops would require 40 acres and still others 160 acres. As a rule, the smaller the number of acres required to support a family the more perishable the crop raised and the consequent greater need for good roads and quick marketing. The same rule applies to mercantile pursuits. Novelties that are perishable or liable to go out of style and be left on the merchant's shelves bring the greatest nominal profit, while the staple article that is good year after year is handled upon the smallest margin. The safer the investment the smaller the interest charges. Still, few large fortunes are made without assuming some risk. Occasionally, fruit crops bring $500 per acre; strawberries, melons, tomatoes, like high returns. Ordinarily with such crops the risk is great. Early frosts, insects, drought, glutted markets, and bad roads may cut down the profits. The safer such crops can be made by improved roads and stable markets the more intensive farming will be extended. The rural districts, due to the combining of farms brought about by the use of improved machinery and management and the prosperity of the farmers, are decreasing in population. Make it profitable to diversify farming and raise the more perishable crops and instead of farms growing larger and the rural population smaller, the farms will become smaller and the population larger.

Good roads give a wider choice in the time of marketing. This, in connection with the feasibility, due to good roads, of the rural delivery of mails, making it possible for the producer, through his daily paper, to keep in touch with the markets and take advantage of high prices, may mean considerable to the farmer in the course of a year.[1]

Effect on the Business Man of the Town.—Savings in

[1] This increase of the value of (farm lands reached by rural delivery) has been estimated as high as $5 per acre in some states. A moderate estimate is from $2 to $3 per acre. In the Western States especially the construction of good roads has been a prerequisite of the establishment of rural free delivery service. Better prices are obtained for farm products, the producers being brought into daily touch with the state of the markets, and thus being enabled to take advantage of information heretofore unattainable. To these material advantages may be added the educational advantages conferred by relieving the monotony of farm life through ready access to wholesome literature and the keeping of all rural residents, the young people as well as their elders, fully informed as to the stirring events of the day. The moral value of these civilizing influences cannot be too highly rated.—Report of the U. S. Postmaster General.

transportation will be more or less equitably distributed among the producer, middleman and ultimate consumer. Each will receive a portion. But suppose the whole or major part remained with the producer. As his profits increased so would his expenditures; he would buy lumber, nails, and other materials, to build larger and better barns and houses. He would install the modern conveniences: water, light, heat, and sanitary equipment; he would buy a new range for the kitchen, a new carpet for the floor, new furniture for the parlor, china and silver for the table, a piano for the daughter, a gold watch for the son, and an automobile for the whole family. A general increase in the prosperity of several members of a community is bound to make itself felt throughout the entire community.

Merchants want trade; they spend money advertising for it. But what good is advertising when the roads are impassable or even with difficulty traversable. Usually the poorest roads are just on the edge of town, where a large volume of traffic converges, and just as a chain is no stronger than its weakest link, so a road with a single bad place may divert much trade from a community. But every good road leading to town is a hand stretched out to welcome and invite trade.

Good Roads Reduce Overhead Charges.—Because marketing of crops must be confined to periods of good roads, there is at such seasons a glut in the market and a consequent reduction in prices paid the producer, but usually no corresponding reduction to the consumer. Warehouses and elevators have to be built larger than would be necessary were roads uniformly good the whole year round. A greater number of railroad cars must be provided to take care of the congested traffic, only to lie idle on side tracks in seasons of bad roads. Interest and overhead charges upon these extra buildings and equipment must eventually be paid by the producer, the middleman, and the consumer, reducing the profits of the first and second and increasing the expenses of the third. This depression is reflected and all commercial and financial interests are affected. The United States is said to be "handicapped in all the markets of the world by an enormous waste of labor in the primary transportation of our products and manufactures, while our home markets are restricted by difficulties in rural distribution which not infrequently clog all the channels of transportation, trade, and finance."

Primary Transportation is a term applied to transportation on a public highway whether it be of raw products to market or of finished products to the consumer. Transportation by railroads, canals, and ships may be denominated as secondary. Practically all **secondary transportation** is of products which were first or last or both the subjects of primary transportation. The Department of Statistics of the U. S. Government has studied [1] the production and marketing of twelve leading products. These twelve amount to 85½ billion pounds (42.7 million tons) per annum. All this must be transported primarily and much of it secondarily at a cost roughly [2] estimated as follows:

	Cents Per Ton Mi.
1. By wagons and horses:	
1. On poor earth roads	50
2. On good earth roads	20
3. On macadamized roads	11
4. On paved streets	6
2. By trolley cars:	
1. On steel track	2
2. Trackless paved roadway	5
3. By automobile or motor truck:	
1. Individual (not busy all time)	8
2. Co-operative (busy all the time)	5
4. By steam or gasoline tractor:	
1. Over earth roads, medium condition	12
2. Over earth roads, best condition	8
5. By steam railroad [3]	$\frac{3}{4}$

[1] U. S. Dept. of Agriculture, Bulletin No. 49, "Cost of hauling crops," by Frank Andrews.

[2] It must be remembered that no one knows the exact cost of primary transportation. It varies with constantly varying conditions.

[3] Secondary transportation. Average of all products. See reports of U. S. Railway Commission.

To go a little more into detail, from the same government bulletin it is ascertained that during the year 1905–6 the

Pounds of wheat hauled were	24,246,000,000
Value	$302,261,000
Cost of hauling 100 lbs	9 cents
Cost of hauling total	$21,821,400
Per cent of value	7.2

This may be looked at from another angle:

Cost of hauling wheat to market 9.4 mi. per 100 lb	9 cents
Cost of hauling same wheat from Omaha to New York per 100 lb	25.7 cents

$$\frac{\text{Cost of getting to railroad}}{\text{Cost of getting to seaboard}} = \frac{9}{25.7} = \frac{1}{2.85} = \text{approximately } \tfrac{1}{3}.$$

Or, the cost to a farmer in the Middle West of getting his wheat to the railroad is one-third the cost of getting it from his railroad station to the seaboard.

Again, the cost of hauling wheat on wagon roads per 100 lb. per mile is about	1 cent
The cost of hauling it on the railroad per mile is	$\frac{3}{80}$ cent

A ONE-CENT POSTAGE STAMP WILL PAY FOR TRANSPORTING 100 POUNDS OF WHEAT

With horses on a poor earth road	½ mi.
With horses on a good earth road	1 mi.
With horses on a macadamized road	2 mi.
With horses on a paved road	3 mi.
With a tractor on a good earth road	3 mi.
With a trolley on a paved road	4 mi.
With a motor truck on a good earth road	6 mi.
With a trolley on steel track	10 mi.
With a steam or electric locomotive on a steel track	25 mi.
With an ocean-going steamship	200 mi.
With an ocean-going sailing vessel	400 mi.

FIG. 1.—Cost of Transportation

Very roughly, then, a one-cent postage stamp will pay for transporting 100 lb. of wheat the distances shown in Fig. 1.[1]

All this goes to show that our rural road transportation is the most expensive and that any material saving in this item will, either directly or indirectly, greatly benefit all classes of people.

[1] The costs given in Fig. 1 were compiled before the War. They are now probably too low. Babson's Bulletin for February, 1919, gives the costs of hauling corn in nine widely separated localities from 23 to 52 cents per ton mile, average 39; by motor trucks from 11 to 36 cents, with an average of 18.

The Motor Truck Association of America compiled the costs shown below for the operation of trucks in large fleets such as are employed by interurban haulage companies:

MOTOR TRUCK COST PER DAY FOR FIVE-TON GASOLINE UNIT BASED ON 50 MILES PER DAY PER TRUCK AND 300 DAYS PER YEAR TAKEN FROM THE RECORDS FOR SIX TRUCKS

	A	B	C	D	E	F	Average	
	Amt.	Amt.	Amt.	Amt.	Amt.	Amt.	Amt.	Total
Direct Charges								
Driver	$5.00	$5.20	$5.00	$5.00	$5.17	$5.50	$5.13	
Tires	3.00	3.75	2.00	2.00	2.00	3.00	2.68	
Oil, etc.	3.00	....	.30	.50	.25	.25	.35	
Gasolene	3.00	4.00	3.50	4.65	2.08	3.75	3.50	
							——	$11.66
Indirect Charges								
Depreciation	$3.50	$4.19	$3.60	$3.40	$3.67	$4.00	$3.77	
Interest on Investment	1.20	1.26	1.08	1.22	1.10	1.00	1.15	
Insurance	1.50	2.54	1.26	2.10	.86	.50	1.47	
Garage	1.00	1.20	1.00	1.00	.89	1.00	1.01	
Maintenance	.50	....	.50	....	1.00	....	.75	
Overhaul	1.33	2.75	1.80	1.60	2.00	3.00	2.07	
License	.17	.27	.20	.20	.20	.20	.20	
Body upkeep	.25	....	.30	.10	.40	....	.27	
							——	10.69
Supervision	.50	2.93	2.05	1.90	....	....	1.90	1.90
Lost Time	2.20	....	1.67	3.40	2.50	1.97	2.57	2.57
Total	$23.45	$28.09	$24.26	$27.07	$22.12	$24.17	....	$26.82

The Amount of Haulage

The amount of haulage that passes over a given road is quite as important as the unit cost, for it, too, enters into the total cost of transportation. The "tonnage" may be roughly ascertained by a traffic census, or, in the case of farm products, by a computation based upon the "traffic area" served by the road and the products raised thereon. Either of these methods should be supplemented by estimates of persons familiar with the local conditions, especially by those who make it a business to deal in the products.

Estimating by Traffic Census.—The actual count of the vehicles with their character and loading is made for a period or periods sufficiently long, and varied enough as to day of week and months of year, to secure a reasonably true average. The number of loads, the average quantity in tons per load, the kind of vehicles used, and distance hauled are the factors sought to be ascertained. The enumerator should be supplied with a ruled tally sheet of convenient size, along the left-hand side of which are written, as far as it is possible to make out beforehand, the kinds of vehicles and loads that are likely to pass, with a few blank lines left for others to be entered. A tally mark is made in the right space as each vehicle passes; an estimate of the tonnage based upon actual weighing of a number of vehicles can be made up in the office later. Table I gives a summary of several such censuses made under governmental direction.

Estimating by Traffic Area.—From a map and field observations the traffic area served by a particular highway is outlined. The average crop production in the area must then be determined and from these the traffic tonnage estimated. If the land about a market center is of uniform quality and uniformly farmed, the average haul might be estimated from the mean distance of the land from the center. For example consider the community market to be at the center of the circle and the territory about divided into six sections (Fig. 2). The mean distance of every point directly to the center is $\frac{2}{3}r = .67r$; the

TABLE I.—TRAFFIC RECORD OF SEVEN IMPROVED ROADS [1]

Road No.	Location [2]	Length in Miles	Tons Per Day, Each Area	Average Haul (nearest mile)	Equivalent Annual Ton-miles	Merchants' and Producers' Estimate (ton-miles)	Traffic Area (acres)	Reported Costs (cents per mi.)
1	Lauderdale Co., Ala. (2)	28.3	58	10	367,849	228,046	154,437	16.0
2	Boone and Story Co., Iowa (16)	45.1	10	2	162,342	105,662	113,521	37.2
3	Cumberland and Sagadahoc Co., Me. (8)	32.1	18	4	227,451	.....	38,182	23.6
4	Leflora Co., Miss. (3)	24.1	33	7	197,386	90,628	60,736	36.2
5	Montgomery Co., Md. (1)	5.4	21	2	14,044	5,892	12,531	26.0
6	Muskingum Co., Ohio (2)	20.9	28	6	111,026	132,711	41,952	28.0
7	Jackson Co., Ore. (3)	50.5	11	4	51,810	32,170	73,881	36.6
	Totals and averages	206.4	26	5	1,131,953	.....	495,235	29.1

[1] Bulletin 136, U. S. Dept. of Agriculture.
[2] Figures in parentheses indicate the number of traffic areas.

radius of the circle which will divide the area of the sector into two equal areas is .71*r*; the mean distance from all points to the median line thence to the center is .81*r*; if all parts of the sector were squeezed up and concentrated along the median without changing their distances from the center the mean would be .64*r*; the center of gravity of the sector is .64*r* from the center of the circle. From the above it will appear that .67*r* would not be far from the average haul when the distribution of products is uniform over the district.

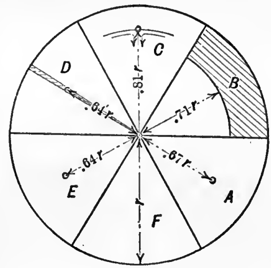


Fig. 2.

Tonnage.—The number of tons arising on these farms which is transported over the roads varies with the kind of crop, the amount of stock fed, stock kept for dairying, and other local governing conditions. Study of surveys made by Cornell Agricultural Experiment Station,[1] investigation of the U. S. Office of Public Roads,[2] U. S. Department of Agriculture, Bureau of Statistics,[3] and U. S. Census [4] lead to the conclusion that the acreage yield of marketable products is ordinarily between $\frac{1}{10}$ and $\frac{1}{2}$ ton per farmed acre, and that the farmed land is about 60 to 65 per cent of the nominal acreage of the farm.

A mathematical analysis will show that if a road serves a sector of one-sixth of a circle and the yield of marketed products is uniform over the sector the total tonnage is given by the equation

$$T=335.12\,qr^2;$$

where T = total tons per year;
q = yield of marketed crops per acre;
r = maximum haul = radius of the circle.

Dividing T by the number of working days per year gives the average daily haul for that road into the market. The average length of haul is theoretically $\frac{2}{3}r$.

The haul over any zone may be taken as made up of all that tonnage which originates outside the zone plus that originating within the zone times its mean distance from the inner edge of the zone.

These equations follow:

Haul over any zone having outer radius a and inner radius b concentric with the circle of maximum haul having a radius r is

$$H=T_r-T_a+\left(\frac{2}{3}\frac{a^3-b^3}{a^2-b^2}-b\right)(T_a-T_b)$$

$$=T_r-T_a+\frac{2a^2-ab-b^2}{3(a+b)}\,(T_a-T_b).$$

For the first mile, $a=1$, $b=0$,

$$H=T_r+\tfrac{2}{3}T_1.$$

[1] Bulletin 295, Cornell Agricultural Experiment Station.
[2] Bulletin 136, U. S. Department of Agriculture.
[3] Bulletin 49, Bureau of Statistics, U. S. Dept. of Agri.
[4] Reports of the 1910 U. S. Census.

TABLE II.—THEORETICAL AVERAGE TONNAGE ON EACH OF SIX UNIFORMLY DISTRIBUTED MARKET ROADS.[1]

Maximum Haul	Average Haul	Uniform Yield per Acre of								
		One-tenth Ton			One-fourth Ton			One-half Ton		
		Total Tons Per Year	Tons Hauled per day		Total Tons Per Year	Tons Hauled per day		Total Tons Per Year	Tons Hauled per day	
			Over first Mile	Over eighth Mile		Over first Mile	Over eighth Mile		Over first Mile	Over eighth Mile
1	0.66	33.5	0.07	....	83.8	0.17	....	167.5	0.34	
2	1.32	134.0	0.40	....	335.0	1.00	....	670.0	2.01	
3	2.00	301.6	0.96	....	754.0	2.40	....	1,508.0	4.80	
4	2.67	536.2	1.74	....	1,340.5	4.36	....	2,681.0	8.71	
5	3.33	837.8	2.75	....	2,094.5	6.87	....	4,189.0	13.74	
6	4.00	1,206.2	3.98	....	3,015.5	9.95	....	6,031.0	19.90	
7	4.67	1,642.2	5.43	....	4,105.5	13.58	....	8,211.0	27.15	
8	5.33	2,144.8	7.11	0.85	5,362.0	17.76	2.13	10,724.0	35.52	4.25
9	6.00	2,714.5	9.00	2.75	6,786.3	22.51	6.88	13,572.5	45.02	13.75
10	6.67	3,351.2	11.13	4.87	8,378.0	27.82	12.18	16,756.0	55.63	24.35
11	7.33	4,055.8	13.47	7.22	10,138.5	33.68	18.05	20,279.0	67.35	36.10
12	8.00	4,825.7	16.04	9.79	12,064.3	40.10	24.48	24,128.5	80.20	48.95
13	8.67	5,663.3	18.83	12.58	14,158.2	47.08	31.45	28,316.5	94.15	62.90
14	9.33	6,568.0	21.85	15.59	16,420.0	54.63	38.98	32,840.0	109.25	77.95
15	10.00	7,540.0	25.09	18.83	18,850.0	62.73	47.08	37,700.0	125.45	94.15

[1] From Bulletin 136, U. S. Department of Agriculture.

For the eighth mile

$$H = T_r - T_8 + \tfrac{23}{45}(T_8 - T_7).$$

Table II is a tabulation of the theoretical average tonnage on each of six uniformly distributed market roads taken from Bulletin 136, U. S. Department of Agriculture.

Mr. E. W. James, chief of Maintenance, U. S. Office of Public Roads, makes an analysis of the distribution of traffic over the roads of a township as laid out by the rectangular system of the United States land survey.[1] The market place is taken to be at the center of the township. His analysis shows

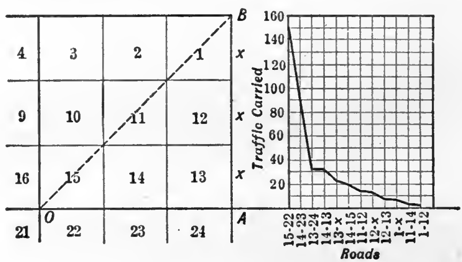


FIG. 3.

that 4.8 per cent of the total mileage carry 39.3 per cent of the traffic; that 9.5 per cent of the roads carry 63 per cent of the traffic, and that 14.3 per cent of the roads carry 71 per cent of the traffic. He thinks the analysis corroborates the observations of engineers to the effect that 20 per cent of the roads carry 80 per cent of the traffic. The relative importance of the type roads in the one-eighth area surrounding the center are given in the diagram, Fig. 3.

There seems to be sound reason for the high-class improvement of a few miles of road near to the market center.

Economic Investment.—Having determined by actual traffic census or by some other method of estimating the probable tonnage on any particular road, the saving in the haulage costs may be computed provided the cost of hauling over the several

[1] Engineering Record, Vol. 74, p. 439.

types of roads that it is practicable to build is known. The cost of hauling on earth roads is estimated to be about 20 cents per ton mile, on a well-paved road 8 to 10 cents. Assume the saving 10 cents with a daily tonnage of 20. The annual decrease of haulage cost would be $.10 \times 20 \times 300 = \$600$ per mile. Ignoring upkeep, the district could afford to pay 5 per cent interest on $12,000 to make this improvement. In deciding upon the type of roadway, maintenance and repair should be taken into account, also the value of the improvement to the non-commercial traffic. This is often of as much importance as the

FIG. 4.

commercial traffic, and is more frequently the final determining factor for or against the improvement.

Especially is this latter true since the character of rural road traffic has changed or is rapidly changing from horse-drawn to motor-driven.

Farm Trucks and Motor Transport.—The farmers are adopting, in addition to automobiles for passenger travel, light trucks to haul produce to market. (Fig. 4.) Also companies are being formed to operate motor-transports upon the hard-surfaced roads as soon as they are constructed, and sometimes upon earth roads. These make regular trips according to a published schedule, doing a business similar to that of the

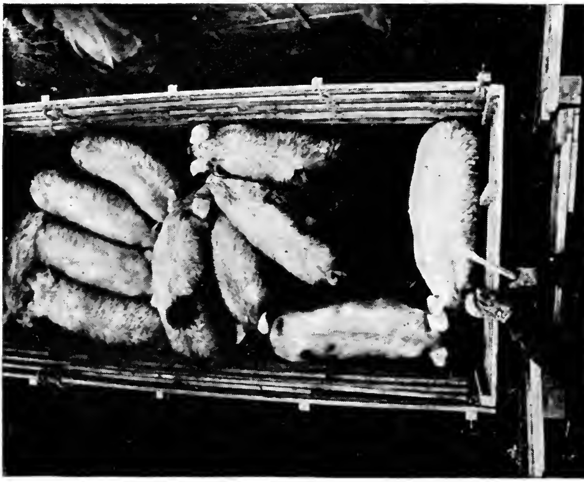


Fig. 5.—Truck Load of Hogs

Fig. 6.—Farm Trucks Unloading Hogs at the Market
—Courtesy Nebraska State Highway Department

railroads. It is said that short-branch railroad lines are not paying expenses, and that the railroads could well afford to give them up provided the products could get to the main lines. The motor truck seems to be filling the need. By arrangement trucks will go directly to the farm for loading and unload at the main line railroad station, thus saving the cost of one handling.

With hard-surfaced roads sufficiently strong to hold up the larger trucks a great deal more freighting will be done from town to town and from farm to market. Figs. 5 and 6 show trucks unloading hogs at the early market at Omaha. These hogs have been hauled some of them 50 miles, but within a few hours after leaving the farm they are at the market fresh and in the pink of condition. Had they been taken to the local railroad station they might have been twenty-four to thirty-six hours making the trip, often without feed or water.

Maintenance Costs.—The cost of maintenance is as variable as that of construction. Cost data are being better kept from year to year and probably in a few years will have become so standardized that definite calculations may be made. Roughly speaking, the annual cost of perpetually maintaining in first-class condition a mile of road 16 feet wide is:[1]

Earth road	$ 20 to $ 40	Author's Estimate.
Gravel	180 to 280	Bulletin 136, U. S. Agr.
Water-bound macadam	500 to 600	Bulletin 136, U. S. Agr.
Bituminous macadam	600 to 800	Bulletin 136, U. S. Agr.
Concrete Roads[2]	600 to 800	Author's estimate.
Brick Pavements[3]	400 to 500	Author's estimate.
Asphalt Pavements[3]	600 to 800	Author's estimate.

Upon such figures it would not usually be a strictly economical proposition to build hard roads unless the traffic is of considerable amount. For example, if the upkeep of an earth road is $50 per mile and that of a bituminous macadam $450, the saving in haulage would have to be $400, or there will have

[1] Based on pre-war prices. Should be practically doubled now, 1920.
[2] The life of a concrete road has not yet been determined.
[3] Based on a life of twenty-five years.

to be an annual tonnage of about $\frac{400}{.10} = 4000$, or an average daily tonnage of 133. This amount is frequently exceeded by roads leading into important market centers.

As intimated above, the convincing need for good roads is more social than economic. The better road pays for the same reason that it pays to live in a good house, that it pays to wear good clothes; it pays in advertising one's community; it pays in self-respect, self-satisfaction, comfort, and pleasure; just as all upward trends in civilization pay. The advent of the automobile most clearly demonstrated this. In the great agricultural communities of the Middle West, nearly every farmer owns a motor car. And while this has proven itself advantageous in that he can run into town and back for mail, supplies, or minor repairs, or do the daily marketing of his cream, eggs, and perishable products, while the horses he uses for farming are feeding and he is resting, nevertheless the machine was purchased primarily for social enjoyment. It is not at all unusual for farmers and their families to drive 20 miles into town after supper to enjoy a concert, to attend a lecture or theater or church service, or merely to visit with neighbors and friends. They return home in time for sleep, better-natured and happier because of the recreation and the invigorating influence of rapid motion through pure air. The motor car has virtually lessened distance. The farmer who now lives 15 miles from his community center is practically no more remote than was formerly the one living 3 miles. Of course, this argument presupposes good roads. The instant the roads become so poor the machine cannot be used, the original state of isolation obtains. It is no wonder, then, that every owner of a motor car becomes a good roads advocate.

To sum up: Good roads constitute a profitable business proposition.

For the Farmer:

1. More remunerative perishable and high-acre value crops can be raised, thus allowing, also, diversification of crops.

2. Cost of hauling will be decreased.
3. Can sell on the high market.
4. Children can attend school.
5. Family can attend church.
6. Physician will be constantly at hand.
7. Will have better mail service.
8. More social life.
9. Boys and girls contented to remain on farm.
10. Material increase in value of land.

Railroad Man:

1. Improved roads mean greater aggregate production, consequently more railway traffic.
2. Prevent freight congestion.
3. Promote new industries.
4. Attract tourists.

Publisher and Editor:

1. Improved roads by making possible rural delivery increase the circulation of newspapers and magazines.
2. Advertising columns are in greater demand.
3. If advertising pays all commercial interests are stimulated.

Hotel Proprietor:

Better roads mean more tourists and business travelers.

Touring by railway and automobile is rapidly becoming a national pastime. Soon it will be all but universal.

The Commercial Traveler:

With automobile and good roads he can double the number of towns he makes per day.

The User of an Automobile and Motor Truck:

1. Gets the benefit of the machine every day.
2. Time on road is minimized.
3. Longer tours projected with assurance.
4. Maintenance costs are decreased.

5. Larger loads may be carried.
6. Deliveries made more quickly and more regularly.
7. General cost of transportation per passenger decreased.
8. Pleasure and health enhanced.

Manufacturer and dealer in wagons, buggies, and automobiles:

Every mile of improved road means a greater demand for these vehicles.

Manufacturer and dealer in road machinery and road-making materials:

The roads cannot be improved without their products.

Manufacturer and dealer in all sorts of building materials and supplies, hardware and furniture:

Increased prosperity of farmers, merchants, and men of other callings and pursuits means a demand for newer, larger, and better houses, barns, sheds, and garages; for modern and efficient conveniences, applications, and furnishings.

Manufacturer and dealer in dry goods, groceries, jewelry, drugs, musical instruments—in short, all forms of mercantile and manufacturing business:

Because good roads are commercial feeders and every improvement in these roads means greater prosperity, raises the standard of living, and produces new wants which must be supplied.

There is no one thing, unless it be the public school, that is of such universal interest and importance to the whole people as the common road. The money spent in the proper improvement of it is an investment which will return large annual interest in reduced costs of transportation, greater freedom of traffic and travel, closer social intercourse between neighbor and neighbor, between town and country, and increased joy, comfort, and happiness.

CHAPTER II

ROAD LOCATION

THE laying out of a road, whether it be intended for wagon and horses, automobile or locomotive, is largely an engineering problem. In many of the Western States the roads have been "located by law" upon section lines. In doing so, no thought whatever was given to the road as a usable thing, as an agency for efficiency in marketing the products of the farm, as a means for rapid communication with neighbor, dealer, or consumer, as an instrumentality for hastily securing the services of the physician or spiritual adviser, as an aid to the education of the growing and incipient citizen, or as a means of pleasure and comfort to those who must perforce travel thereon. The section-line scheme of road location thought primarily of the convenient rectangular division of land and secondly of placing a road near every farm. The final result is that there is being wasted in unused and unnecessary roadways at least one-half of all the land set aside for road purposes.

In the Eastern and Southern States, on the other hand, many old trails have expanded into crooked and inconvenient roadways. The day is near when it will be deemed wise to relocate the principal highways leading to market and trading centers. Why not learn a lesson from nature? A stream flows along the path of least resistance, winding from side to side so that it will not unduly tear up its bed and destroy its banks, thus performing its business of transporting water with an economy worthy of imitation by the most skilled managers. The stream goes the most direct way possible, passing around hills and cutting away the soil until the grade is commensurate with the velocity. That is what should be done with the highways, streams of travel and commerce.

There are some general principles that will apply to the location or relocation of a road, but it must always be borne in mind that local conditions are largely the determining factors, that economic questions, frequently, must give way to other considerations such as pleasure and ease, or the vested rights of land owners. It might be well, also, if the locator " dipt into the future, far as human eye could see," and built for the many generations this road is expected to serve, ever remembering that future changes will continually increase in difficulty and expense.

General Principles of Location

Directness.—Undoubtedly the shortest line compatible with easy grades and proper drainage should be selected, for thus the interest on first cost and the annual charge for maintenance and operation will be least. While the value of directness is of prime importance, it may be overestimated. Often it is not much farther around a hill than over it. The bail of a bucket is no longer when lying horizontally than when standing vertically. A road may even vary considerably from a straight line and not materially increase its length. The statement of Gillespie, published as long ago as 1847, is often quoted: " If a road between two places 10 miles apart were made to curve so that the eye could nowhere see more than a quarter of a mile of it at once, its length would exceed that of a perfectly straight road between the same points by only about 150 yards."

The saving due to a difference in length can be computed only when the cost of hauling and the amount of traffic on that particular road are known. For example, suppose it is desired to find out whether it will pay to relocate a road now going along two sides of a quarter-section of land, diagonally through the section, the traffic being 3000 tons per year and the cost of hauling 20 cents per ton mile. (Fig. 7.)

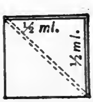


Fig. 7.

Annual cost of hauling along the two sides:

One mile ($3000 \times .20 \times 1$)	\$600
Diagonal distance ($\frac{1}{2} \times \sqrt{2}$) = .71 mile.	
Annual cost hauling through ($3000 \times .20 \times .71$)	426
Difference in cost	\$174

Assuming these roads to be 4 rods wide, they occupy 8 acres per mile.

	Acres
Around the field (8×1)	8.00
Through the field ($8 \times .71$)	5.68
Difference	2.32

If this land rents at \$5 per acre, there will be a saving of $2.32 \times \$5 = \$11.60$, which makes a total annual saving of	\$185.60
This is 5 per cent interest on	\$3,712.00

This amount could be expended by the community for the purpose of this improvement and still be no worse off financially than before. It should be remembered that all computations of this sort must be taken as approximations, but can be used in connection with local considerations to aid in reaching a decision.

Grades. Definition.—The grade of a road is the rate of rise or fall and is usually expressed in rise or fall per hundred or per cent. Everyone knows that it is easier to pull a load on the level than up a hill, therefore, other things being equal, grades should be reduced as much as possible. However, the first cost of a longer and flatter grade may offset any advantage, or drainage may be the determining factor. Each particular case must be studied by itself. There are some mechanical formulas that can be applied, but too much reliance must not be placed on them, for, while the mathematics is absolutely correct, the assumptions necessary for their application may be erroneous.

The load which a horse can pull up a hill is given by the formula

$$L=\frac{(t+g)W}{\mu+g}.$$

To demonstrate this,

Let T = tractive force of horse along the road;
W = weight of horse;
L = load pulled, including weight of vehicle;
μ = coefficient of road resistance;
α = angle of incline;
g = grade of incline $=\tan\alpha$;

$t=\frac{T}{W}$ = tractive force in terms of weight of horse.

Fig. 8.

The work of moving a load from O to B equals the work of moving it from O to A plus the work of lifting it from A to B. (Fig. 8.)

Work from O to $B=T(OB)$;

Work from O to $A=\mu L(OA)$;

Work from A to $B=(W+L)AB$;

$$\therefore \quad T(OB))=\mu L(OA)+(W+L)AB;$$

$$T=tW=\mu L\frac{OA}{OB}+(W+L)\frac{AB}{OB};$$

$$=\mu L\cos\alpha+(W+L)\sin\alpha.$$

Whence

$$L=\frac{\frac{t}{\cos\alpha}-\tan\alpha}{\mu+\tan\alpha}W,$$

or, since for small angles $\cos\alpha$ does not differ materially from unity

$$L=\frac{(t-g)}{\mu+g}W. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

It is generally asserted that a horse working day after day can, without injury to himself, exert a direct pull on the traces of about one-tenth his own weight, and that for a short space of time he is capable of doubling this amount. It has also been determined by experiment that the direct pull necessary to draw a load at slow speed on the level in well-lubricated wagons is approximately as follows:

	Lbs. Per Ton	μ = Coef. of Resist.
Upon Steel rails	10	$\frac{1}{200}$
Sheet asphalt	20	$\frac{1}{100}$
Asphaltic macadam	20	$\frac{1}{100}$
Concrete	20	$\frac{1}{100}$
Brick	20	$\frac{1}{100}$
Broken stone water-bound macadam	30	$\frac{3}{200}$
Earth, best condition	67	$\frac{1}{30}$
Earth, medium condition	100	$\frac{1}{20}$
Earth, poor condition	300	$\frac{3}{20}$

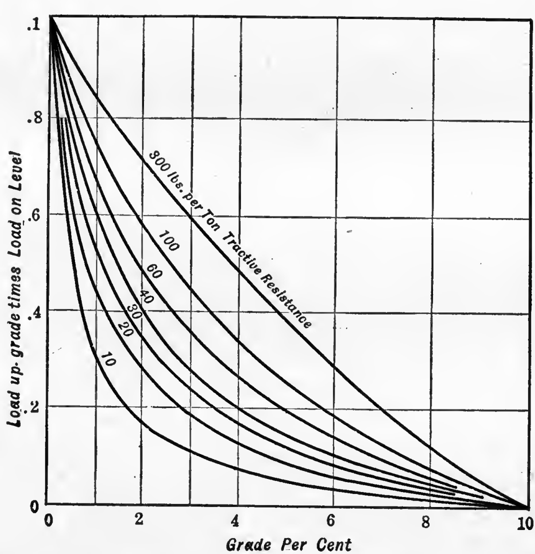


FIG. 9.—Showing the Load in Terms of W (the Weight of the Horse) that May be pulled Up-grade by Exerting a Force of $1/10$ W

Using these values and Equation (1), Tables I and II have been computed. Figs. 9 and 10 are graphs drawn from these tables. To one used to reading graphs it is immediately evident that the effect of grade is very much greater for a smooth than for a poor road, that is, the effect is much more for those roads having a small coefficient of resistance. The harder and smoother the roads, the greater need of reducing the grades.

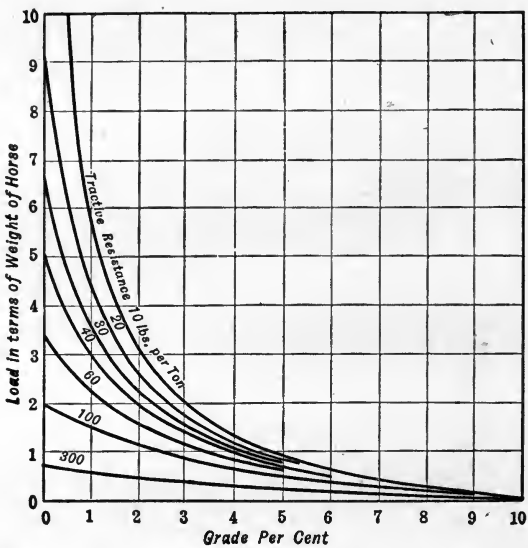


Fig. 10.—Showing the Load that a Horse Can Pull by Exerting a Force of 1/10 His Own Weight up a Grade in Terms of the Load He can Pull on a Level Road of the Same Condition

It will be noticed that the advantage on traction of a smooth road is not particularly manifest for grades greater than 4 per cent, but is very marked as the grades become smaller and smaller. It might be well to notice, however, that always for every grade a larger load may be pulled upon the smooth hard road than on the poor road. Again, the reader must be cautioned that all calculations such as this should be considered with judgment in the light of the particular case in hand.

TABLE I

Showing the load in terms of *W* (weight of horse) that may be pulled up-grade by exerting a force of 1/10 *W*.

Grade Per Cent	Tractive Resistance in Pounds per Ton						
	10	20	30	40	60	100	300
0	20.00	10.00	6.67	5.00	3.33	2.00	.67
1	6.00	4.50	3.60	3.00	2.25	1.50	.56
2	3.20	2.67	2.29	2.00	1.60	1.14	.47
3	2.00	1.75	1.56	1.40	1.17	.87	.39
4	1.33	1.20	1.09	1.00	.86	.67	.32
5	.91	.83	.79	.71	.62	.50	.25
6	.62	.57	.56	.50	.44	.36	.19
7	.40	.38	.35	.33	.30	.25	.14
8	.24	.22	.21	.20	.18	.16	.09
9	.15	.10	.10	.09	.08	.07	.04
10	.00	.00	.00	.00	.00	.00	.00

TABLE II

Showing the load that a horse can pull by exerting a force of 1/10 his own weight up a grade in terms of the load he can pull on a level road of the same condition.

Grade Per Cent	Tractive Resistance in Pounds per Ton						
	10	20	30	40	60	100	300
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1	.30	.45	.54	.60	.68	.75	.84
2	.16	.27	.34	.40	.48	.57	.71
3	.10	.18	.23	.28	.35	.44	.58
4	.07	.12	.16	.20	.26	.33	.47
5	.04	.08	.12	.14	.19	.25	.37
6	.03	.06	.08	.10	.13	.18	.28
7	.02	.04	.05	.07	.09	.12	.21
8	.01	.02	.03	.04	.05	.08	.13
9	.01	.01	.01	.02	.03	.04	.06
10	.00	.00	.00	.00	.00	.00	.00

Slipperiness or poor foot-hold might materially change these values, and this may depend upon the weather.

In Equation (1) no account was taken of increased work of moving the horse, that is the motive power, itself due to the condition of the road surface. Were a formula to be derived

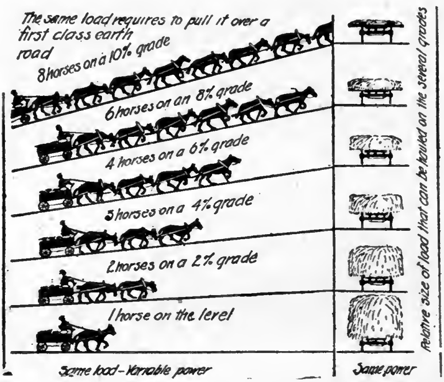


FIG. 11.—A Load that One Horse can Pull on the Level Requires Eight Horses on a 10 Per Cent Grade

for tractors or automobiles, this would enter and the formula be changed.

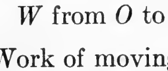


FIG. 8.

Using the same notation as on page 22 with the exception that W now = the weight of, and F = the force exerted by the tractor or automobile, there results:

Work of drawing load L with tractor weighing W from O to B . . . . $= F(OB)$

Work of moving along OA . . . . $= \mu(W+L)\overline{OA}$

Work of lifting along AB . . . . $= (W+L)AB$

$$\therefore \quad F\overline{OB} = \mu(W+L)\overline{OA} + (W+L)AB;$$

$$F = (\mu \cos \alpha + \sin \alpha)\,(W+L)$$

$$\doteq (\mu + g)\,(W+L) \text{ approximately;}$$

$$L = \frac{F}{\mu+g} - W. \qquad (2)$$

EXERCISES

What load can a gasoline tractor weighing 12 tons, exerting 20 H.P., traveling over a good earth road at a speed of 3 miles per hour, haul up an incline of 3 ft. in a hundred?

A H.P. is defined as doing work at the rate of 33,000 ft.-lb. per minute, or $33{,}000 \times 60$ ft.-lb. per hour.

20 H.P., therefore, is $33{,}000 \times 60 \times 20$ ft.-lb. per hour.

If the force exerted by the tractor is F, the work performed per hour is $3 \times 5280 \times F$ ft.-lb.

$$\therefore \quad 3 \times 5280 \times F = 33{,}000 \times 60 \times 20$$

$$F = \frac{33{,}000 \times 60 \times 20}{3 \times 5280} = \frac{20{,}000}{8} = 2500$$

Substituting in Equation (2),

$$L = \frac{2500}{\frac{100}{2000} + \frac{3}{100}} - 24{,}000 = 31{,}250 - 24{,}000$$

$$= 7250 \text{ lb.}$$

2. If the engine could continue to exert the same force, at what speed would it haul this same load over a level road? *Ans.* 11 miles per hour.

[NOTE: The above examples tacitly assume the coefficient of resistance remains constant. As a matter of fact, determined by experiment, the force necessary to project a body through a resisting medium varies approximately as the square of the velocity, so that 11 miles would be too large.]

It has been assumed above that a horse can exert for the period of a working day one-tenth his weight. For short periods of time this may be materially increased; for moderate periods it might be doubled, for very short periods quadrupled. Solving Equation (1) for g gives the grade up which any particular load can be hauled. Thus

$$g = \frac{tW - \mu L}{W + L}.$$

If the tractive force be increased n times,

$$g = \frac{ntW - \mu L}{W + L}. \qquad \qquad (3)$$

EXERCISES

1. On a level steel track (Table I) a load of 20 W can be hauled; up what grade can the same load be hauled if the tractive force be doubled?

Substituting in (3) $g = \frac{1}{210}$ or about $\frac{1}{2}$ of 1 per cent, which might be considered the limiting grade of a steel track if the load on the level is to be a maximum.

2. Under similar conditions what would be the limiting grade for an earth road in good condition? *Ans.* $g = 3\frac{1}{3}$ per cent.

3. What would be the limiting grades if the tractive force be quadrupled? *Ans.* Steel track, 1.4 per cent; earth, 10 per cent.

This last example shows why, if the hill is short and the rest of the road is comparatively level, it would pay to use a snatch team for the hill.

Rise and Fall.—By rise and fall is meant the vertical height through which the load must be lifted in traversing the road in either direction. If a road, otherwise level, passed over a hill 20 feet high, the rise and fall is defined as 20 feet. The minimum amount of rise and fall upon any particular stretch of road is the difference in elevation of its terminals. Any additional rise and fall may be considered avoidable and in the location of the road whether it will pay to avoid it will depend again upon local conditions. If the work necessary to raise the load vertically through the avoidable rise and fall be computed and that compared with the work necessary to move the load on the unavoidable gradient, the rise and fall may be expressed in terms of distance. For example, to raise 1 ton 1 foot high requires the expenditure of 2000 foot-pounds of work, and taking the tractive resistance on an ordinary earth road as 100 pounds per ton, there will be 100 foot-pounds of work expended in drawing a ton load 1 foot; therefore, to balance the work done in overcoming 1 foot of rise and fall the load must be drawn on the level a distance of $2000 \div 100 = 20$ feet. The better the road surface, the more it may be lengthened.

EXERCISES

1. Using the coefficients of resistance given on page 23, determine the distances level roads might be lengthened to avoid 1 foot of rise and fall.

Ans. Steel rails, 200 feet; asphalt, asphaltic macadam, concrete, brick, 100 feet; broken stone macadam, 67 feet; earth, best condition, 30 feet; earth, medium condition, 20 feet; earth, poor condition, 7 feet.

2. Two farms are each 5 miles from the market, as indicated on the map, but the road to one has a rise and fall of 132 feet, the other of 396 feet. What is the virtual distances of these farms from town?

Ans. ($\mu = 100$ lb. per ton) $5\frac{1}{2}$ and $6\frac{1}{2}$ miles.

Take the case heretofore referred to, page 20, of a diagonal road through a quarter section. If in going around as shown in the pen sketch, Fig. 12, the road goes up and down a hill of 50 feet, say, the work of going up that hill would be equivalent to traveling $50 \times 20 = 1000$ feet; and if the hill is so steep a brake must be applied, or the horses must hold the vehicle back, the descent furnishes practically the same work as the

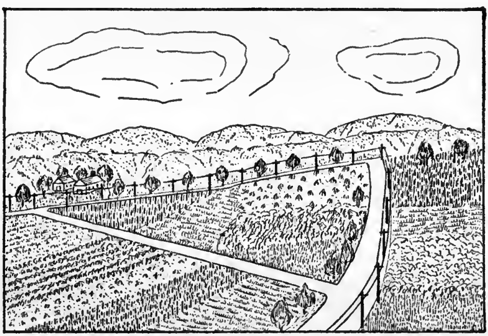


Fig. 12.—Frequently a Road May be Shortened and Two Hills and a Sharp Angle Eliminated by Cutting across a Corner

ascent and there must be added another 1000 feet, so, by eliminating, with the diagonal road, both hills, there is a saving of .38 mile. Add this to the .29 saved by cutting diagonally across and it gives a total saving of .67 or two-thirds of a mile on this one quarter-section of land. Put on a cash basis this means using the same assumption as before, a saving of 14 cents for each ton of traffic or $420 for 3000 tons annually. A total saving including the rental value of the land of $431.60. Therefore, there could be borrowed to make the improvement, at 5 per cent interest, the sum of $8600. Many a road following the section line crosses a series of foothills which could be avoided by moving it a short distance one way or the other to the comparative level land of the valley or the ridge, thus materially saving distance, time and money. Fig. 13 is a pen sketch, by the author, of a road that might have been made nearly level by moving it parallel to itself a quarter-mile either way.

Many roads in our plains country have steeper grades than do the mountainous roads of Switzerland. The roads of France are classified:

National roads (most important), not exceeding 3 per cent.
Department roads, not exceeding 4 per cent.
Subordinate roads, not exceeding 5 per cent.

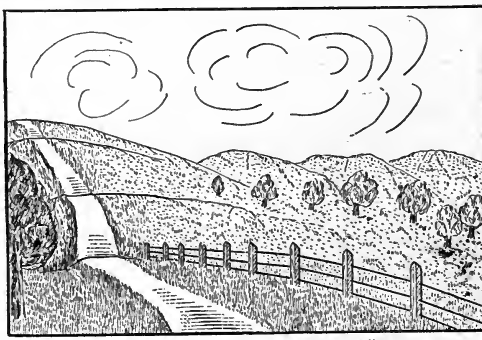


Fig. 13.—Some Roads Run Up and Down Hill When by Moving Them One Way or the Other They Might be Put on a Comparatively Level Grade.

Minimum Grade.—A perfectly level road, other things being equal, would be best to travel over, but for the purposes of drainage a small longitudinal grade is not only allowable but desirable. All road men know that a road going up a small hill is much easier to maintain than the level one across the bottom. Engineers pretty generally agree that the grade should never be less than three-fourths of 1 per cent.

In order to save expense, it is taken for granted that the center line of the road is made to conform as nearly as possible with the natural surface of the ground. To determine whether or not it is better to go around a hill or cut through, the interest on the difference in the cost of construction and right of way of the two lines must be compared with the difference in operating and maintenance expenses.

There are many roads leading out from the larger towns which it would pay to relocate, and very frequently more direct lines and easier grades could be obtained by locating roads in the general direction of water courses either in the valleys or upon the ridges between, thus avoiding unnecessary ascents and descents which waste power and energy. It is there, too, most easy to make the line conform to the original ground surface and save the expense of cuts and fills.

Obstacles.—New locations should strive to cross all obstacles right at angles; skew structures are expensive. On the other hand bridges and culverts not in line with the general trend of the road are dangerous. Likewise grade crossings of railroad and trolley lines should be avoided wherever possible.

Laying Out the Road

Reconnoissance.—Under this head may be placed the preliminary investigations necessary to familiarize the locator with the country and local conditions under which the work must proceed. A note book in which to keep full records is necessary. Some of the points to be considered are *amount and character of the traffic* in each direction; the general topographical and geological features of the country through which the road is to be run, foundation, and drainage; a knowledge of the desires and rights of the people living along the proposed line as to location and the material of which they desire the road to be constructed; materials at hand and those that must be shipped in, with freight rates and unloading facilities; and such other matters as the local conditions indicate.

Preliminary Survey.—Having in mind the general features of the country, including location and approximate elevation of all low passes; the trend of streams and ridges, conditions as to drainage, soil characteristics, bridge sites, railway crossings, and other determining features, a preliminary survey is run. Sometimes several such lines must be run before a definite location is decided upon. The better the advance knowledge the fewer preliminary surveys will be necessary. In the relocation of most roads slight changes only are necessary and these may be accomplished by a single survey. In locating new roads, however, methods developed in locating railroads can be resorted to advantageously.

The reconnoissance was for the purpose of gaining general knowledge of a considerable area through which a road is to be run. The preliminary survey is to furnish more accurate information of a narrow zone through which the road is to run. The preliminary transit line or traverse is the base line on which to tie the information obtained. Since the completed road is to occupy this zone the random transit line is a first

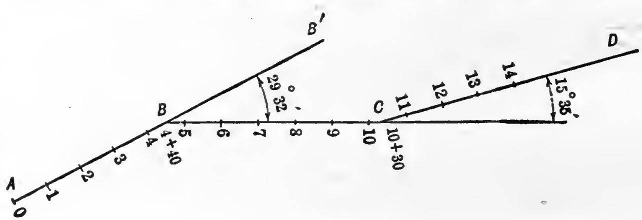


Fig. 14.

guess at the best location of the line, it being understood that final location is the last word regarding the best location under controlling local conditions. The last word will vary considerably from the first guess, but the nearer the first guess, the better the "land judgment" of the engineer, the less the expense for surveys.

Stationing.—The preliminary line generally consists of a series of straight lines, technically called tangents, *ABCD*. (Fig. 14.) Where the change in direction is considerable some locators run in curves to make the stationing better, but for preliminary surveys it is just as well to use several short tangents. Stakes are driven on the line every 100 feet apart, thus determining "stations." The stakes are numbered beginning at 0 and continuing 1, 2, 3, etc.; so that the number of the station indicates the distance from the beginning, station

4 being 400 feet; station 9, 900 feet, etc. A point between two stations is designated by the number of the last station plus the distance from that station to the point, thus 3+63 indicates a point 63 feet beyond station 3. At the point B the line changes direction, the *deflection angle* $B'BC$ being to the right and is recorded R 29° 32′. The point B being at 4+40, the next station 5 would be 60 feet from B on the line BC. The stationing is then continued in regular order to C, thence on the line CD, etc.

Stakes.—The stakes driven along the line of a preliminary survey need not be very substantial, carpenter's laths cut in three do very well. Hubs are short stakes driven nearly flush

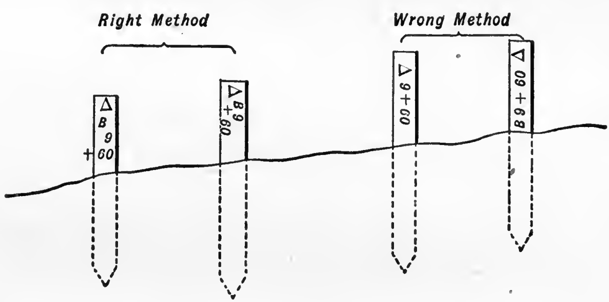


Fig. 15.

with the ground at points where the instrument is set up, and should present a top about 1½ inches square. A stake called the marker is always driven near the hub. The stakes are clearly marked near the top with the letter indicating the line and the station number. If a hub-marker, a △, indicating instrument point, is placed before the letter. The numbers should read from the top toward the bottom and be so near the top that there is no danger of their being covered up in the ground.

Grades or gradient is a term used to indicate the slope of the roadway and is usually expressed in per cent or the number of feet rise or fall per hundred feet horizontal. A rise of 24 feet in 600 feet $=\frac{24}{600}=\frac{4}{100}=4$ per cent grade. A fall is given the negative sign. Bringing a roadway to grade is called grading, and is a part of the work of constructing. The *ruling* or *limiting* grade is the steepest grade allowed on the particular road in hand. *Maximum grade* is the steepest grade used in the survey and may or may not be the limiting grade. Since it takes force to turn a vehicle, the grades on curves should always be less than the ruling grade; making them less is called compensating.

Party Organization.—The number of men in and the organization of the party will depend upon the character and magnitude of the work and may vary from thirty in large parties to two in small. In large parties separate sub-parties have charge of the several parts of the work—transit, level and topography, with draughtsmen, cooks, teamsters, and other camp followers. The transit party under its head officer will run in the preliminary line. He receives general directions as to location, controlling points, etc., from the chief over him, if there be one. Such directions should be explicitly noted on sketches or the best map of the region available. The transit man will, however, have plenty of opportunity to use his judgment in running the line.

Works on surveying give directions for the use of the instrument, but for handy reference here are given briefly the

Operations of Taking Preliminary Traverse

Transit Man.—The ordinary party will be in charge of the transit man, who will have sufficient assistants for the magnitude of the job.

Operation.—Set up the transit at *A*, Fig. 16; clamp the vernier at *O*; loosen the lower motion; sight upon *B*; tie in the point *A* (that is, relate it to a previous survey, U. S. government land system, the layout of a town, or to stones, trees, permanent features, or these failing, to solidly driven stakes and dug pits, so that it could be accurately relocated if the point should be lost. This can be done by taking the angles and bearings of the reference points and measuring their distances). Let the chainmen measure the distance *AB*; they may be lined in with transit if desired, but usually in preliminary surveys the rear chainman can do this by eye with sufficient accuracy; the axmen drive stakes properly marked at each station. The transit man will keep the notes as shown in Fig. 17.

Move the instrument to *B*; see that back flagman sets his flagstaff or ranging pole on the point *A*; with the vernier at *O* reverse the telescope on its horizontal axis and sight on back flag at *A*; check the magnetic bearing of *AB*. Meantime the front flagman goes forward and sets his flag at a place previously

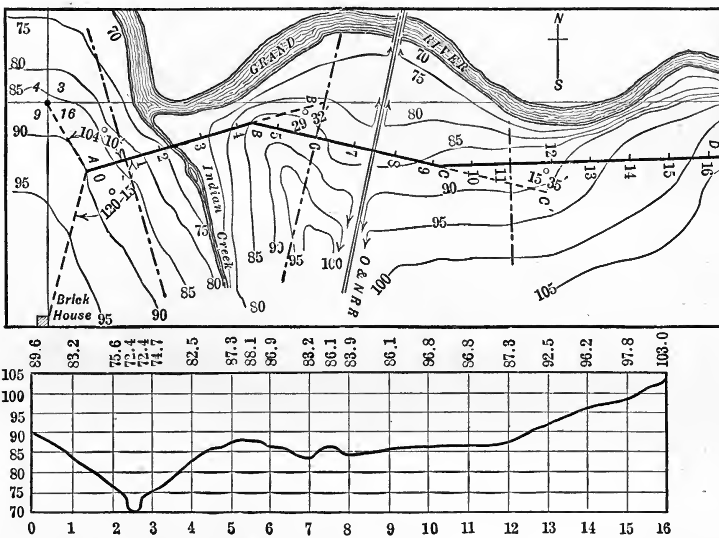


Fig. 16.—Map and Profile of Surveyed Road

decided upon from which he can easily see the instrument and in the direction wished to go next. Clamp the vernier on 0 and bring the telescope to bear on the back flag; reverse the telescope and sight on the front flag; read the angle *B′BC;* repeat the operation by clamping the vernier, loosening the lower motion and again reversing and sighting on the back flag; reverse and sight on front flag; the angle should now read double the first reading. Get the magnetic bearing of *BC* as a check on the angle. Chain *BC* and proceed to the next point *C*.

If a straight line is to be produced double sighting should be employed. This is done by sighting on the back flag; reverse the telescope on the horizontal axis; and set a range pole; unclamp the upper motion bring the telescope to bear on the back flag by reversing about the vertical axis; reverse and again set the pole. The true prolongation is half way between the two positions of the pole. Drive a hub there and repeat the operation with the range pole on the hub. Bisect the two

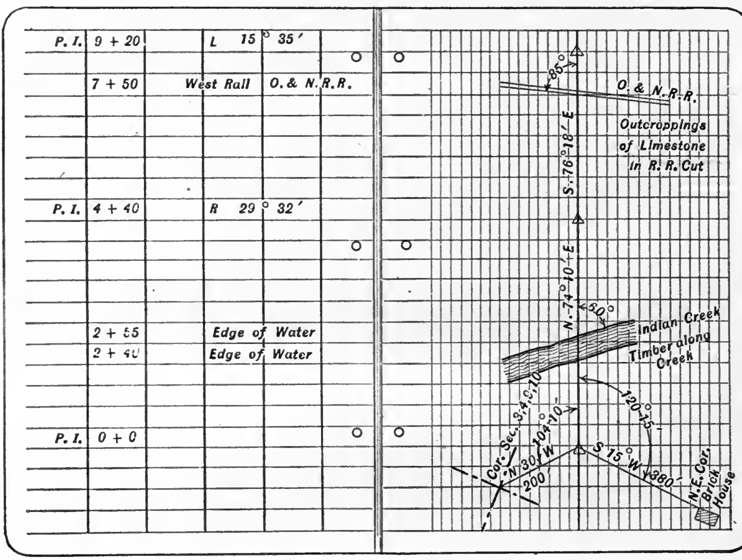


FIG. 17.—Sample Page of Transit Bote-book.

positions of the pole point and drive a tack over which to set the instrument for a continuation of the line.

Head Chainman.—After setting a stake and, if final location, testing it the head chainman must walk out briskly and be ready for the " halt " command as he reaches the next station. He should practice turning and walking in the direct line, occasionally, to assist him, sighting back over the two stakes behind; thus much time will be saved. In breaking chain on steep slopes it is generally best for the head chainman to pull out the entire chain and then come back to the necessary point to break; holding the tape at this point with the help of a plumb-bob or the pole, he draws the chain taut in a horizontal plane; the rear chainman comes up to the point of breaking and the head chainman goes on to break again if necessary. An axman or flagman standing off to one side can aid in getting the tape level.

Rear Chainman.—The rear chainman follows with the rear end of the tape, either holding it or following as it is being dragged along by the head chainman. He should see that the tape does not disturb the transit. He should see that it does not catch in rocks or bushes. He should walk and stand so as not to obscure the line of vision of the transit man. As he nears the stake last set, he calls a halt, holds the tape at the stake while the head chainman straightens it out and gets exact distance and direction. The rear chainman is responsible for the doing up and safeguarding of the tape. As a rule pluses should be read by the rear chainman. He should keep a record of pluses and topographic features when the transit man is not at hand. He should note that the station numbering is correct; as he reaches a stake he calls its number; the stakeman immediately calls the number of the stake he has just marked.

Stakeman.—Stakes are usually made up beforehand and a supply carried by the stakeman in a sack. Flat stakes are used for line and square stakes for hubs. The stakeman should keep up with the head chainman and be ready with marking crayon or keel to number the stake as soon as he hears the rear chainman call the number of the last stake; or the stakes may be numbered ahead and tied in bundles of ten to be deposited as called for. This furnishes a check on the numbering. The stakeman should assist in clearing the line and is under the direction of the head chainman.

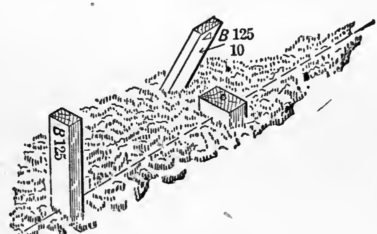


Fig. 18.—Method of Marking and Setting Stakes

Axman.—The axman carries an ax, tacks, and if desired an extra sack of stakes. He drives stakes, removes underbrush and other obstacles from the line of sight and the instrument station. In this work care must be taken to keep on the line and cut only as much as may be necessary that there may be no waste of time. Other members of the party of course, may assist in this work when not otherwise engaged. Line stakes should be driven crosswise of the line with the numbered face to the rear. Hubs are driven almost flush and witnessed by a flat guard stake driven about 10 inches to the left, marked face slanting toward the hub.

Front Flagman.—The front flagman goes ahead and under the direction of the chief and transit man establishes hub points. When he reaches a point for a hub he signals the transit man by holding his pole horizontally above his head. In establishing these points he should not only go in the general direction the line is to follow, but should select positions at proper distances from the transit and such that clearing for visibility will be a minimum for both fore and back sight. He carries with him a small supply of hubs, a hand-ax, tacks and large nails. Having selected his point if it is not the prolongation of the original line, he drives his hub and sets the tack, then lets the transit man get the angle. If it is a prolongation or a location point he must let the transit man line him in. He must watch the transit man and be ready instantly to plumb the pole which has its spike on the tack head by standing squarely behind it and holding it lightly with the tips of the fingers of both hands. When the head chainman is called back for other work he may plant his pole directly behind the hub. When crossing fences a piece of cloth tied to the wire or nailed to the top board will act as a check sight.

Rear Flagman.—The rear flagman holds a sight rod on the last instrument point behind that where the instrument is set up, for back sight. He records in a memorandum book, kept for that purpose, the numbers of the stations on which he gives back sight. If materials are at hand he may cut small saplings and set them behind the hub when signaled ahead. Splitting the tops and putting a small piece of paper in the split to make a " butterfly " renders them more visible and such pickets are frequently an aid to the transit man and chief in forming conclusions when looking back over the line.

Level Party.—The party consists of two members, the leveler and rodman, to which may be added an axman where necessary. They get the elevations of the stations and sufficient other points to make a profile or vertical section of the

Sta.	B. S.	F. S.	H. I.	Rod	Elev.	
B. M. (1)	0.70		100.70		100.00	Water Table, N. E. Cor. Brick House
0				11.1	89.6	
T. P. ⊙	0.52	11.11	90.11		89.59	Top of Stake Sta. 0
1				6.9	83.2	
T. P. ⊙	0.27	11.76	78.62		78.35	Root of Large Cottonwood Tree Right of Roadway
2				3.0	75.6	
2+40				6.2	72.4	Left Edge of Indian Ck. } Water about 4' deep
2+55				6.2	72.4	Left Edge of Indian Ck.
3				3.9	74.7	
T. P. ⊙	11.37	0.82	2 89.17		77.80	
4				6.7	82.5	
5				1.9	87.3	
5+40				1.1	88.1	Top of Hill
6				2.3	86.9	
7				6.0	83.2	
7+60				3.1	86.1	
T. P. ⊙		3.04			86.13	Top of West Rail
	12.86	26.73				

Fig. 19.—Sample Page of Level Notes.

line. They follow the transit party and should be on the alert to catch any errors that may have occurred.

A *bench mark* is a point selected or established for permanent reference. A *turning point* is a temporary reference point. A *back sight* is a rod reading taken to determine the *height of the instrument* above a bench mark and above the datum plane. A *fore sight* is a rod reading to determine the height of a point. In profile leveling back sights are upon established bench marks and turning points, fore sights on stations and points selected for turning points and bench marks. It is well to note that fore sights on stations not turning points or bench marks are termed *intermediate sights.* For profile work it is preferable to use a combination self reading and target rod, the one known as "Philadelphia" is a favorite. This allows the instrument man to read and record intermediate sights to the nearest tenth of a foot, turning points to the nearest hundredth and bench marks by the aid of the target to the nearest thousandth. The note book used is the standard "level book" ruled for six columns on the left-hand page and blank or ruled into squares, rectangles or columns on the right-hand page. (See Fig. 19.)

Operation.—The level man sets up his instrument at a convenient place where he can see four or five stations either way; lengths of fore and back sights should be approximately the same in order to equalize errors. Take a back sight on the established bench mark, the location and elevation of which should be fully set forth, and record the reading in the second column marked B. S., add this to the elevation of the bench mark to get the height of the instrument, and record in the fourth column marked H. I. Take a reading on station 0 to the nearest tenth of an inch and record the same in column five under heading "Rod." This is an intermediate sight but the calculations are exactly as for fore sights; subtract the rod reading from the B. M. elevation to get the elevation of the station. And so on until it is necessary to move the instrument forward when a turning point must be established. This may be a stake or boulder or other point sufficiently solid and determinate to repeat the reading if necessary. Take a fore sight on the T. P. and record the rod reading to the nearest hundredth in the third column under F. S., subtract from H. I. for the elevation of T. P. Move the instrument and take a back sight on T. P. and record; add this to the elevation for the new H.I.; continue to the end of the survey. As a check find the sum of the back sights and the fore sights separately. Take their difference or algebraic sum considering back sights, which are additive, positive and fore sights, which are subtractive, negative; this difference algebraically added to the elevation at the bench mark should equal the elevation of the last turning point, or stated another way, the arithmetic difference in the sums of back and fore sights over any portion of the line equals the difference in elevation of the ends of this portion, remembering that the first sight is a back sight and the last a fore sight. Expressed algebraically:

$$\sum_x^y BS - \sum_x^y FS \doteq \text{Elevation } y - \text{elevation } x.$$

It is better, however, to use only turning point and bench mark rod readings in checking a page, comparing the difference of their summation with the difference of the elevations or heights of instrument of first and last on that page. Permanent bench marks should be established about every quarter of a mile. These should be upon something that is likely to be permanent and not disturbed during the process of construction; the water table of a building, a large spike driven into a telephone post or a tree or a flat rock, all of which can be definitely determined and recorded. If the target is used on turning points the leveler will first read the rod and make a temporary note of the reading, then signal for the target. After this is set and clamped the rod should be again set up and waved back and forth. It is correctly set if the center in the process of waving just comes up to the cross hair and then recedes. The rod man will read and inform the leveler. He compares the reading with his check reading and if sufficiently close makes the record.

Rodman.—The rodman holds his rod on the points whose elevation is to be determined, which will be all stations and enough intermediate points to make a profile on a scale of 40 to 100 feet per inch horizontal and 10 to 20 feet per inch vertical (Plate A, profile paper). Elevations may, therefore, be plotted to the nearest tenth of a foot and horizontal distances about 5 feet. Observations closer than this will not only not be necessary but will be a waste of time. The rodman should select determinable positions for turning points and bench marks. Should hold his rod plumb, which can best be accomplished by standing directly behind it and holding it lightly with the fingers of both hands. In taking turning points and bench marks he should gently wave the rod. The rod man will keep a "peg book" and record turning points and make the necessary calculations, thus checking the leveler. He will assist the leveler in plotting his notes, and check the computations of the level book.

Topographer.—As the preliminary survey is of a zone the topographical features should be delineated upon the map in order that a location can be intelligently projected. The topographer, in the language of S. Whinery, "must possess a keen eye and a good judgment for locality, distance and elevation. . . . Particularly must he have the ability, natural or acquired, from experience to judge of the relative importance of the topography he sketches. He must know at a glance from the general lay of the country that the final location will hug this hillside closely, and its topography, therefore, must be taken accurately, while the other will not be touched, and therefore may be sketched with less care."

The topographer may have a tape man to assist in getting distances or he may work alone, stepping off distances and getting elevations with a hand level held at the known height of his eye.

His note book (or pad) should be ruled in squares like ordinary cross-section paper, the center line of the page being the traverse line. Topography should be taken for about 300 feet each side and contours and other features plotted in the field where everything is under the eye.

The topographer works about a day behind the leveler and should take from the level book the elevations of the several stations, these he will write along one edge of his book (Fig. 20), numbering the stations along the other. With the elevation of the stations known and the hand level he can determine contour elevations on each side of the station at convenient distances along the line and sketch in connections as he goes along.

These will be permanently transferred to the map by the draftsman later.

Draftsman.—The number of maps required for any road will, of course, vary with the importance of the scheme. The following will be, perhaps, more than sufficient. A comprehensive map of the entire project, which may be as small as 1000 feet to the inch.

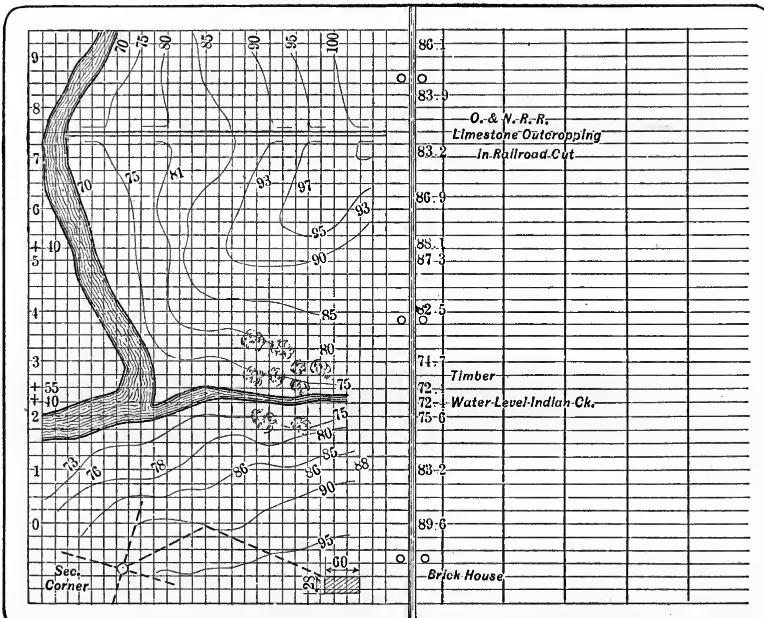


FIG. 20.—Sample Page of Topography Note-book.

A detail or working map on a scale of 40 to 100 feet per inch.

Profiles of preliminary lines platted by the leveler to a scale of 40 to 100 feet per inch horizontal and 10 to 20 feet per inch vertical.

Profiles of projected locations with tracings and estimates of quantities.

Maps and profiles of final location, if not previously shown.

The comprehensive map is compiled from the best local map at hand. The maps of the U. S. Geological Survey when available are valuable as they give contours and frequently character of soil, condition as to woodlands, etc. These maps may be obtained from the government at a low price and in sufficient quantities to preclude, frequently, the making of other maps—details being drawn in upon them. A tracing may then be made, if duplications are required. The detail map shows contours for each 5 feet and from it a road may, if desired, be accurately fitted to the ground surface.

Several methods of platting a traverse survey are in vogue. In one the transit line is laid down to scale and the deflection angles turned by means of a protractor. This may do for rough quick work but is not particularly accurate unless a protractor with vernier attachment is at hand. Even then any error tends to accumulate.

Another method, which is similar to this and offers much

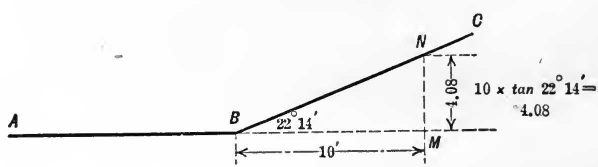


Fig. 21.

the same objections is to turn the angles by means of tangents. Here is measured out beyond the intersection point on the last line drawn, AB, Fig. 21, some definite distance, say 10′, to M. From M is measured on the perpendicular to right or left, $MN = BM$ times the tangent of the deflection angle. This determines a point, N, through which the next section of the traverse line, BC, is to be drawn.

The method of platting by latitudes and departures, coordinate method, avoids the carrying through of accumulative error. The method is somewhat longer, hence more expensive than the others; but is theoretically perfect. A base line is taken parallel to the edge of the paper. If the draftsman uses judgment in the selection of the base line, he may be able to get all the map on the paper without making breaks in it.

MN, Fig. 22, is the base line and MA, the tangent along that line. The angles $\alpha\beta\gamma\delta$ are calculated. The abscissa or departure $HB = AB \cos\alpha$, the ordinate $HA = AB \sin\alpha$, the point B is located and AB platted. Similarly $BJ = BC \cos\beta$ and $CJ = BC \sin\beta$. If the signs of the angles be taken into account, the summations of the departures and the latitudes will equal the total departure and the total latitude from the beginning point. The northernmost side of the map should be the top.

Profile.—For a small project the profile may be platted on the bottom of the same sheet upon which the map is drawn. For more extensive projects regular profile paper should be provided, as the labor of platting is thereby much simplified,

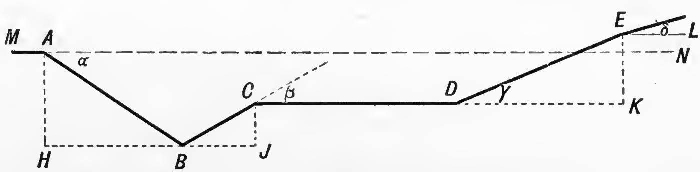


FIG. 22.

and if on a separate sheet it can be shifted along from place to place for study. See Fig. 16.

The stations are marked off along the lower margin, in the same direction as on the map. These will not be on vertical lines below the stations on the map. A line, freehand or straight segments, drawn through the plotted points, gives the profile of the ground surface.

The elevations are plotted above their respective stations, care being taken that the scale is such that all points fall above the lower margin of the profile plot. The horizontal scale should be the same as the scale of the detail map, but the vertical scale is magnified and is usually made 5, 10 or 20 feet per inch. The profile should show the location and elevations of culverts, bridges, car rails at crossings or adjacent to the line, curbs, and other objects that may be of use in final location.

Topographical Map.—The detail map upon which the traverse has been drawn should be filled in from the notes of the topographer. Of especial importance are the contour lines.

Establishing Grade Line

Having the maps thus far completed a temporary grade line should be laid down on the profile. A black silk thread or the edge of a transparent triangle will be of assistance in balancing cuts and fills. For, while the finished road must conform as near as may be with the surface of the land, necessary cuts and fills should be made to balance, or if this cannot be done the fill should be slightly in excess as the extra earth may usually be obtained from the side of the road thus avoiding overhaul. By comparing the contour map and the profile, a line may be projected with least grades and least grading. A compromise must usually be made between directness and grades. If the ruling grade is 4 per cent, that is, a rise or fall of 4 feet in a 100, or 1 foot in 25, set the dividers with the points exactly 25 feet apart, measured on the scale of the contour map, if the contours are drawn in for each foot of elevation. Then it is only necessary to note that the projected line shall not be shorter than the distance set between any two consecutive contours. Stepping over the contour map in this manner, several tentative lines may usually be run between controlling points. This line is made up of a succession of tangents and curves; each point of curvature (P. C.) and point of tangency (P. T.) should be marked as well as centers of curves, degree of curvature, and angle turned. Profiles should be drawn for these lines, by interpolating elevations from the contour map.

The grade lines having been laid down on these profiles, two or three, may be selected "as the best probable location." With a table of quantities for level cross-sections, estimates for cut and fill will be made and routes eliminated until a single line best adapted to the local conditions decided upon.

TABLE III.—EARTHWORK COMPUTATION

Level Sections, Slope 1:3, Cu. Yds. for 50 Ft. in Length

Height or Depth (*h*) in ft.	Width of Roadway (*b*) in Feet														
	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
1	28	32	35	39	43	46	50	54	57	61	65	69	72	76	80
2	67	74	81	89	96	104	111	118	126	133	141	148	155	163	171
3	117	128	139	150	161	172	183	194	205	217	228	239	250	261	272
4	179	193	207	222	237	252	267	281	296	311	326	341	356	370	385
5	232	250	269	287	256	324	343	361	380	398	417	435	454	472	490

TABLE IV.—EARTHWORK COMPUTATION

Level Section, Slope 1:1½, Cu. Yds. for 50 Ft. Length

Height or Depth (h) in ft.	Width of Roadway (b) in Feet														
	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
1	25	28	32	36	40	44	47	51	55	58	62	66	70	73	77
2	56	63	70	78	85	92	100	108	115	122	130	137	144	152	160
3	92	103	114	125	136	147	158	169	180	192	203	214	225	236	247
4	134	148	163	178	192	207	222	237	252	266	281	296	311	326	340
5	180	199	218	236	254	273	292	310	328	347	366	384	403	422	440
6	234	256	278	300	322	344	366	389	411	434	456	478	500	522	544
7	292	318	344	370	396	422	447	473	499	525	551	577	603	628	654
8	356	385	415	444	474	504	534	563	592	622	652	682	711	740	770
9	425	458	492	525	558	592	625	658	692	725	758	792	825	858	892
10	500	537	574	611	648	685	722	759	796	833	870	907	944	981	1018
11	581	622	662	703	744	784	825	865	906	947	988	1028	1069	1110	1151
12	666	711	756	800	844	889	934	978	1022	1066	1111	1156	1200	1244	1289
13	758	806	854	903	951	999	1047	1096	1144	1192	1240	1288	1336	1384	1432
14	856	908	959	1011	1063	1115	1166	1218	1270	1322	1374	1426	1478	1530	1582
15	958	1014	1070	1125	1180	1236	1292	1347	1403	1458	1514	1569	1625	1680	1736

Crown Corrections.—The quantities in Tables III and IV were computed for trapezoidal sections. (Fig. 23.) To get the true cross-section there should be added to the fill and subtracted from the cut the area of the crown. When the slope is given in the ratio $1 : n$, $c : \frac{1}{2}b = 1 : n$, that is $c = \frac{b}{2n}$, therefore the area of

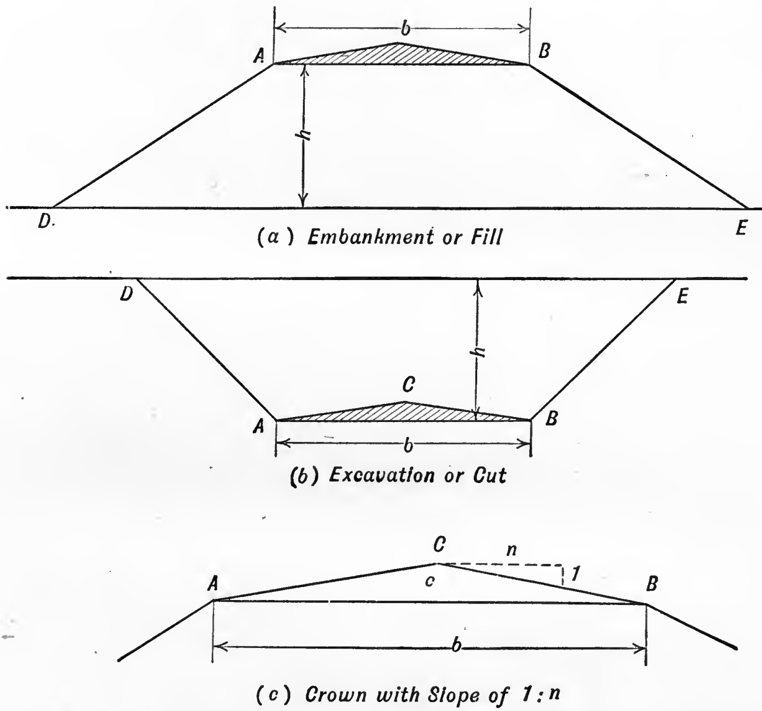


FIG. 23.—Cross-section in Fill and Cut Showing Addition and Subtraction of the Crown Necessary for Complete End Area.

the crown triangle, ABC, equals $\frac{1}{2}bc = \frac{b^2}{4n}$. The volume of a prism l feet long, with breadth of base, b, expressed in cubic yards is

$$v = \frac{b^2 l}{108n}.$$

TABLE V.—CROWN CORRECTIONS

To be added to quantities in fill and subtracted from quantities in cut. Cubic yards per 50 feet length

Slope 1 : *n*	Width of Roadway (*b*) in Feet														
	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
1 : 10 = $\frac{5}{6}$ in. per ft.	7	9	12	15	18	22	26	31	36	41	47	53	60	67	74
1 : 12 = 1 in. per ft.	6	8	10	13	16	19	22	26	30	35	40	45	50	56	62
1 : 16 = $\frac{3}{4}$ in. per ft.	4	5	7	9	11	14	17	20	23	26	29	33	37	41	46
1 : 24 = $\frac{1}{2}$ in. per ft.	3	4	5	6	7	9	11	13	15	17	19	22	25	28	31
1 : 48 = $\frac{1}{4}$ in. per ft	1	2	2	3	4	5	6	7	8	9	10	11	12	14	15

Table V gives the corrections to be used with the tables for the more common crowns. Since cuts and fills very nearly balance each other this refinement will ordinarily not be necessary. This table can, however, be used in the final calculations of the quantities, if the crown has not already been taken into account.

LOCATION

The line of the selected route should be inked upon the map and then located upon the ground. The stakes of the located line will all be marked *L* and are of a more permanent nature

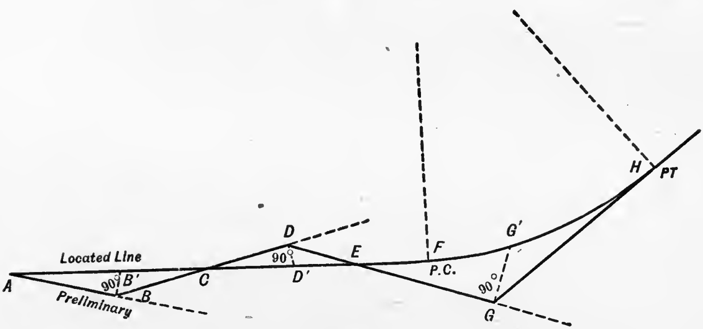


FIG. 24.

and more accurately set than those of the preliminary survey. In projecting the "paper location" upon the ground, it must not be thought that it will "fit" exactly. Numerous changes will be necessary. The preliminary traverse line, already staked out, is the base line and measurements scaled off the map are made with reference to it and not to the final location.

For example distances *BB′*, *DD′*, *GG′*, etc., are at right angles to the preliminary. Several points along a tangent *A*, *B′*, *C*, *D′*, *E*, *F*, should be located on the ground from the scaled distances. These points will not usually be found in an exact straight line, so the line staked out must be an average of these, of course, taking into account controlling local conditions.

In order to locate this finally accepted line on the ground or even to do the necessary preliminary surveying, a knowledge of curve surveying will be required. Likewise the surveyor should know how to keep his instruments in adjustment. Brief discussions of these subjects follow:

CURVES

Circular curves are usually employed to unite straight reaches, or tangents, of the road.

A simple curve is the arc of a circle; *a compound curve* is a combination of two simple curves of different radii on the same side of a common tangent. *A reversed curve* is a combination of two curves with centers on opposite sides of a common tangent.

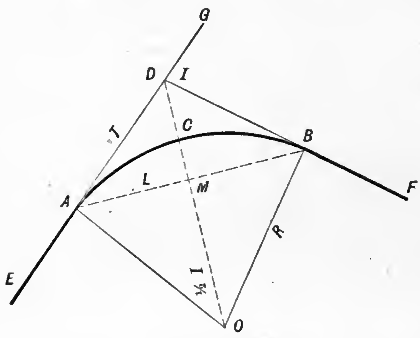


FIG. 25.

In Fig. 25, ACB is a simple curve uniting the tangents EAD and DBF. The angle GDB is the intersection angle usually denoted by I; it is equal to the central angle AOB. If the stationing on the line is from A toward B then A is called the P. C., point of curve, and B the P. T., point of tangent; the point of intersections of the tangents the P. I.; the point of compound curve, P. C. C. (Fig. 26); the point of reversed curve, P. R. C. (Fig. 27.)

By geometry and trigonometry a number of formulas may be derived for the properties of these curves. A few, only, are given below for simple curves:

Draw the broken lines DO and AB (Fig. 25) then from the right triangles thus formed.

$$AM = AO \sin AOM,$$

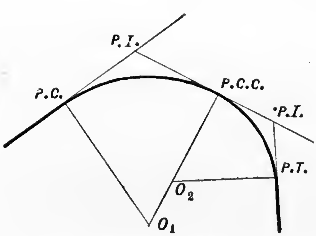
$$L = AB = 2R \sin \tfrac{1}{2}I, \quad \ldots \ldots \quad (1)$$

$$T = AD = AO \tan AOM = R \tan \tfrac{1}{2}I. \quad \ldots \quad (2)$$

The degree of a curve is defined as the angle which an arc of 100 feet will subtend at the center. If this angle is denoted by D and s is the corresponding arc then,

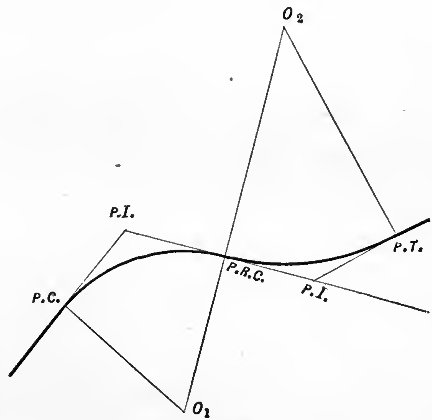
$$\frac{D}{360}=\frac{s}{2\pi R},$$

$$R=\frac{18000}{\pi D}=\frac{5729.58}{D} \qquad (\pi=3.14159).$$



Compound Curve

FIG. 26.



Reserved Curve

FIG. 27.

Since there is no easy method of measuring around the curve, measurement is made by unit chords. In the United States the unit chord is 100 feet. Works on railroad surveying define the degree of curvature as the angle at the center subtended by a 100-foot chord. The radius of the circle determined by this definition would be (Equation 1):

$$R=\frac{100}{2 \sin \frac{1}{2}D}=50 \csc \tfrac{1}{2}D.$$

For a 1° curve, therefore, the radius is 5729.65, while by the former equation it is 5729.58. It is customary to use 5730, and since R varies inversely as D the radius of any other curve is found from that of the 1°-curve by dividing by the degree of curvature. (This rule also applies for long chords, tangents, externals, mid-ordinates, and other functions of the curve which depend directly upon R for their values.)

The error incurred by using chords instead of the actual length of the arc is inconsiderable providing 100-foot chords are used on curvatures not greater than 7°, 50-foot chords from 7 to 14°, 25-foot chords from 14 to 28°, and 10-foot chords for larger curvatures. If the radius does not exceed 100 feet the curve can be easily struck in from the center.

Simple Curve Formulas

$$R=5730/D \qquad (1)$$

$R=50/\sin\frac{1}{2}D$, $25/\sin\frac{1}{4}D$, $12.5/\sin\frac{1}{8}D$, $5/\sin\frac{1}{20}D$, for chords of 100, 50, 25, and 10 feet respectively . . . (2)

$$R=T\cot\tfrac{1}{2}I \qquad (3)$$

$$T=R\tan\tfrac{1}{2}I \qquad (4)$$

$$T=E\cot\tfrac{1}{4}I \qquad (5)$$

$$E=R\,(\sec\tfrac{1}{2}I-1) \qquad (6)$$

$$E=T\tan\tfrac{1}{4}I \qquad (7)$$

$$M=R\,(1-\cos\tfrac{1}{2}I) \qquad (8)$$

$$M=T\cot\tfrac{1}{2}I(1-\cos\tfrac{1}{2}I) \qquad (9)$$

$$M=E\cos\tfrac{1}{2}I \qquad (10)$$

$$S=100I/D \qquad (11)$$

$$S=2\pi RI/360 \qquad (12)$$

$$C=2R\sin\tfrac{1}{2}I \qquad (13)$$

$$C=2T\cos\tfrac{1}{2}I \qquad (14)$$

$$C=2E\sin\tfrac{1}{2}I/(\sec\tfrac{1}{2}I-1) \qquad (15)$$

If the long chord C is divided by a point into two parts, s_1 and s_2, the ordinate at the point is, $m=\frac{7}{8}\cdot\frac{s_1}{100}\cdot\frac{s_2}{100}\cdot D$ (approximately).

In the above formulæ R stands for radius $=OA$, Fig. 25; T for tangent, AD; E for external, DC: M for mid-ordinate, CM; S for length of arc, ACB; C for long chord, AB; I, inflection angle; D, angle subtending a chord of 100 feet.

Laying Out the Curve

With Transit and Tape.—The method may be illustrated by a particular case. Suppose there are two tangents meeting at an angle of 70° 14′ to be united by a simple curve. (Fig. 28.) The P. C. may be arbitrarily selected, the tangent distance measured, and the radius and degree of curvature calculated by Equations (3) and (1). Or the degree of curvature may be arbitrarily selected and the tangent length computed by (4) and (1). Suppose the latter method to be adopted and D be taken as 12°.

$$T = R \tan \tfrac{1}{2} I = \frac{5730}{12} \tan 35° \, 07' = 335.8.$$

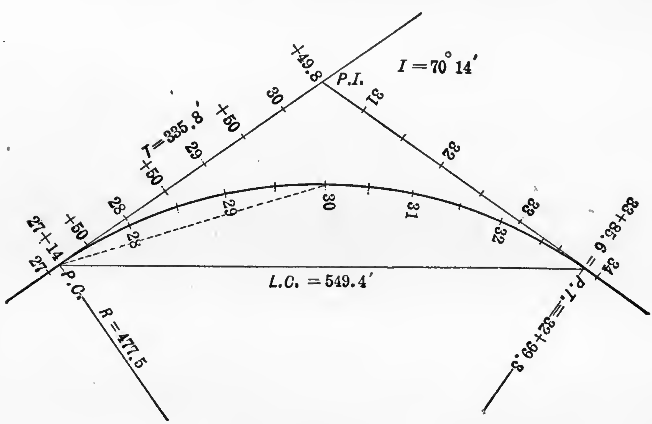


Fig. 28.

The chainmen will measure or count back this distance from the intersection point and set a stake marking it P. C. (If the P. C. has been chosen arbitrarily it may be necessary to measure forward and set P. I.) The transit is set up at P. C. and with verniers on 0° directed along the tangent line either by sighting at (P. I.) or to a backward station. It is not likely that P. C. will fall exactly at a station point; suppose it to be at 27+14. Then the distance to the first station on the curve will be 36 feet. This is sometimes called a *sub-chord*. Since the degree of curvature is 12, the length of chord used in laying out the curve should be 50 feet, and this will subtend an angle at the center of $\frac{1}{2}D=6°$; the deflection angle for a chord of 50 feet will be one-half of this which is $\frac{1}{4}D=3°$. The sub-deflection, therefore, for 36 feet will be $\frac{36}{50}$ of $3°=2°\ 9.6'$. This angle is turned off, deflected, on the transit in the direction, right or left, which the curve is to take. The rear chainman holds 36 feet on the P. C., the transit man lines in the head chainman who keeps the tape taut. The point being located a stake is marked 27+50 and driven. The transit man now deflects an additional angle of $\frac{1}{4}D=3°$, making the total vernier reading now $5°\ 9.6'$; this is the index angle for Station 28. A stake is set for Station 28 with a full 50-foot chord. Succeeding stations are set in the same manner, deflecting 3° for each station. If it becomes necessary to move the transit, and railroad engineers advise this when the index angle reaches 15° to 18°, even though the stations are visible, the transit man will signal for a hub. When the hub is checked he goes forward and sets his transit on it. If he desires to get the tangent line he would clamp his verniers on 0° and sight back to the P. C. then deflect the index angle of the station on which the instrument is now setting. Suppose the resetting to be at station 30 then the index angle would be

$$2°\ 9.6'+(5\times 3°)=17°\ 9.6'.$$

The telescope is now plunged and it points along the tangent. Further stationing can be located as before. Note that if the tangent line is not required the transit man will save time by deflecting after the back sight the index angle of the next station, namely 20° 9.6′. The index angle is always the sum of the deflection angles from the P. C. The transit notes would be kept something like the form shown on page 57.

The transit is put " in tangent " over a second or other hub by the following operations: (1) clamping the plates upon the index angle of a previous hub which is to be used as a back sight; (2) backsighting on the hub; (3) clamping the lower and loosening the upper plate and deflecting the transit until the index

FORM OF TRANSIT NOTES FOR CURVES

Station			Deflection Angle	Index Reading	Total Angle	Calculated Course	Magnetic Course	Remarks
32	+99.3	⊙P. T. (Set)	2° 57.4′	35° 7′	70° 14′	N 49° 38′ E	N 39° 26′ E	
	+50			32° 9.6′				
32				29° 9.6′				
	+50			26° 9.6′				
31				23° 9.6′				
	+50			20° 9.6′				
30		⊙		17° 9.6′				
	+50			14° 9.6′				
29				11° 9.6′				
	+50			8° 9.6′				
28			3° 0′	5° 9.6′				12° Curve, R
	+50		2° 9.6′	2° 9.6′				$I = 70° 14′$
	+14	⊙P. I. (Set)	0° 0′					$T = 335.8$
27						N 20° 36′ W	N 30° 48′ W	

angle of the hub over which it now stands has been reached; (4) plunging; this brings the telescope in line with the tangent forward. It must be noticed that this is equivalent to turning off from the chord between the hubs an angle equal to half the subtended central angle. To apply this to the particular example at hand: When the P. T. has been located, a hub set, and the transit moved to that point, it is clamped on 17° 9.6′, the index reading for station 30, backsighted and deflected 35° 7′, the index reading for P. T. The telescope is now directed along the tangent toward P. I., and if that point can be seen it furnishes a check upon the work.

To Locate the Curve by Chord Offsets.—The length of the mid-ordinate, AB, is calculated by the formula

$$M = R(1 - \cos \tfrac{1}{2}I),$$

or by the approximate formula

$$M = \frac{C^2}{8R}.$$

The ordinates of other points are given by

$$y = \frac{ab}{2R} = \frac{7}{8} \cdot \frac{a}{100} \cdot \frac{b}{100} \cdot D.$$

EXERCISE

Suppose I, Fig. 29, to be 42°, $D = 6°$, and that P. C. is at station 4+25. The angle D_1 then would be 75/100 of 6° = 4.5° = 4° 30′ and the angles

$$BOL = \tfrac{1}{2}I - D_1 = 21° - 4° 30' = 16° 30'.$$

$$BOG = 16° 30' - 6° \qquad = 10° 30'.$$

$$BOE = 10° 30' - 6° \qquad = 4° 30'.$$

and

$BA = R(1 - \cos 21°) = \frac{5730}{6}(1 - .9336) = 63.4$; $AJ = R \sin 21° = 342.3$;

$BP = R(1 - \cos 16° 30') = 39.7$; $LM = 63.4 - 39.7 = 23.7$; $PL = R \sin 16° 30'$ $= 271.2$; $JM = 342.3 - 271.2 =$ ——; $BQ = R(1 - \cos 10° 30' =$ ——; $GF =$ ——; $QG = R \sin 10° 30' =$ ——; $SE =$ ——; $CE =$ ——;

with the coordinates of the curve determined it may be readily staked out.

To Locate the Curve by Tangent Offsets.—The angle between the tangent at P. C. and the chord ac_1, Fig. 30, is one-half the

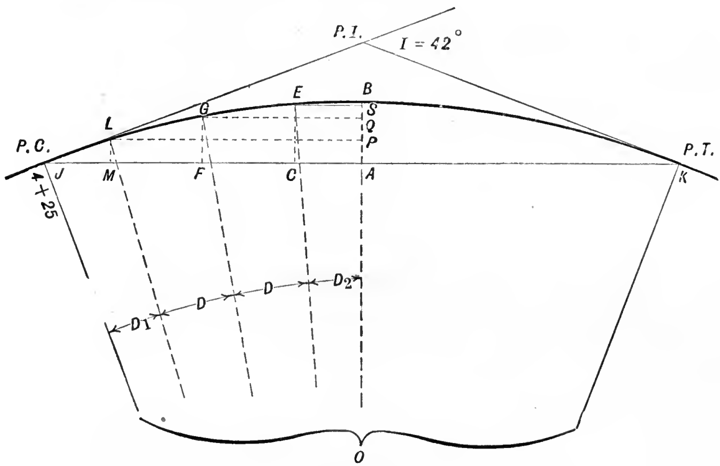


FIG. 29.

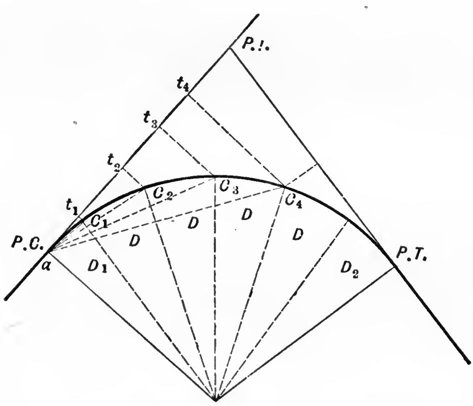


FIG. 30.

central angle D_1, therefore $at_1 = ac_1 \cos \frac{1}{2}D_1$; similarly, $at_2 = ac_2 \cos \frac{1}{2}(D_1+D)$, etc. Also, $t_1c_1 = ac_1 \sin \frac{1}{2}D_1$; $t_2c_2 = ac_2 \sin \frac{1}{2}(D_1+D)$, etc. But $ac_1 = 2R \sin \frac{1}{2}D_1$; $ac_2 = 2R \sin \frac{1}{2}(D_1+D)$, etc. Therefore $at_1 = R \sin D_1$ $at_2 = R \sin (D_1 + D)$, etc. And $t_1c_1 = 2R \sin^2 \frac{1}{2}D$, $t_2c_2 = 2r \sin^2 \frac{1}{2}(D_1 + D)$, etc. The method of procedure is clearly to measure at_1 then turn a right angle, either with transit or tape, and measure t_1c_1. The method is valuable for locating stations whose view from P. C. is obstructed and the transit deflection cannot be used.

The tangent offsets could have been calculated by the approximate formula

$$tc = \frac{7}{8}\left(\frac{at}{100}\right)^2 D.$$

EXERCISE

Find six offsets to a 4°-curve at points 50 feet apart, measured around the curve. By successive applications of the above rule the offsets are 0.88, 3.50, 7.88, 14.00, 21.88, and 31.50 feet.

NOTE: These values are approximate only and are more nearly correct when measured toward the center of the curve, O, but when the degree of curvature is small and the offsets are short the error is not great.

Instead of measuring the offset from the tangent every time, the second offset may be measured from the chord through a and c produced. In this exercise the first offset from the tangent will be as before, 0.88 foot. The second, third, fourth, etc., will be double that or 1.66 feet. An 0.88 foot offset will at any time determine the tangent.

Striking in the Curve.—If the radius of curvature is 100 feet or less and the center is accessible the easiest way is to hold one end of the tape at the center and with the desired radius mark as many points on the curve as necessary.

Locating by Eye.—Sometimes a short curve may be located by sticking pegs or marking pins along its course and by looking over them determine whether or not the curve is smooth. Where a record of the survey has to be kept other methods should be employed.

Parabolic Curves.—Let AEB, Fig. 31, be a parabola, AC and BC its tangents, AB the chord uniting the tangent points and D the mid-point of AB. According to analytic geometry:

(a) CD is the principal axis or diameter of the parabola and the curve bisects CD in E.

(*b*) If lines are drawn from points t_1, t_2, t_3 . . . on the tangent, parallel to the diameter CD, the tangent offsets t_1m_1, t_2m_2, t_3m_3 . . ., are proportional to the square of the distances At_1, At_2, At_3 . . ., from the point of tangency A.

(*c*) A tangent to the curve at the extremity of a middle ordinate, as at E, is parallel to the chord of that ordinate, AB.

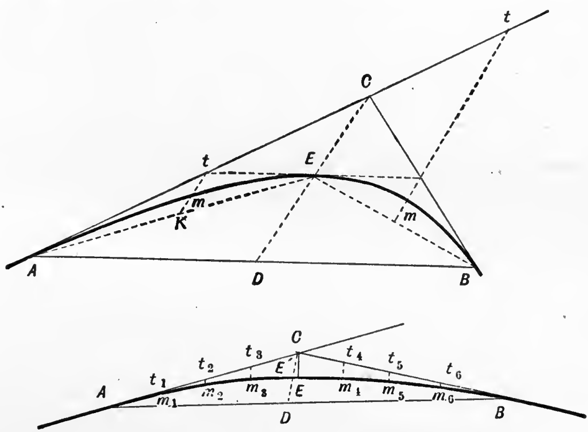


FIG. 31.

These properties give several methods for laying out the curve. For example:

Locate D, the mid-point of AB; locate E, the mid-point of CD; then any tangent offset $tm : CE :: \overline{At}^2 : \overline{AC}^2$).

$$tm = \left(\frac{At}{AC}\right)^2 CE.$$

Substituting At, AC and CE, found by measurement in the formula tm is determined and the point m may be staked out.

Or, draw a tangent through E, suppose it meets the tangent through A at t, draw the chord AE, the mid-point of tK is m, a point on the curve. Continued application of this operation will give any number of points. After the curve has been determined it may be stationed by using 50-foot chords from A.

Vertical Curves.—The parabolic curve lends itself very readily as a vertical curve for rounding out the intersection of two grade lines. If $g_1 = 3$ per cent is the gradient of AC, and $g_2 = -2$ per cent is the gradient of CB the algebraic difference is the change in grade at C; $g_1 - g_2 = 3 - (-2) = 5$ per cent. Experience shows that for a difference of less than 3 per cent, a 100-foot curve, 50 feet each side of C, will be ample for easy transition; from 3 to 6 per cent, 200 feet; above 6 per cent, 300 feet. In this example, therefore, 200 feet will be taken.

Let the elevation of C be 110, then the elevation of A will be $110 - (3 \text{ per cent of } 100) = 107$; of B, 108; of D, $(107+108)/2 = 107.5$; of E, $(107.5+110)/2 = 108.75$. Note that the elevation of E is taken the same as that of E^1, the mid-point of CD.

Divide the tangents AC and BC each into four 25-foot lengths then the tangent offset

$$t_1m_1 = \left(\frac{At_1}{AG}\right)^2 CE = \frac{1}{16}(1.25) = .078125,$$

and the grade at m_1 is the grade at A + the rise in At_1 − the tangent offset—$107 + .75 - .078 = 107.67$. Similarly, $t_2m_2 = \frac{4}{16}(1.25) = .31$, grade at $m_2 = 108.19$; $t_3m_3 = 9(.078125) = .703$, grade at $m = 108.54$; in general the offset at the nth station from the tangent point A will be n^2 times the offset at the first station. The offsets for points beyond C may be calculated in the same manner but it is easier to notice that $t_6m_6 = t_1m_1$, $t_5m_5 = t_2m_2$, $t_4m_4 = t_3m_3$. Thus the elevation at m_4 = elevation at C − the fall in $Ct - tm = 110 - .5 - .703 = 108.8$.

If the line station should fall between t_2 and t_3, say, its elevation could be found by the offset at that point or by interpolation.

Adjustments of the Transit and Level

The Important Adjustments of the Transit Are.—(1) To make the plane of the plate bubbles perpendicular to the vertical axis; (2) to make the line of sight (collimation) perpendicular to the horizontal axis; (3) to make the horizontal axis perpendicular to the vertical axis; (4) to make the attached level and line of collimation parallel to each other.

1. *The Plate Bubble.*—Unclamp the plates and level the instrument with the bubbles on line with the two pairs of leveling screws; turn the instrument half way around (180° in azimuth). Half the apparent error is the real error; bring the bubble half way back by turning the small nuts at the ends of the levels with the adjusting pin. Again level the instrument and repeat the operation until the bubbles will remain in the middle through the entire revolution of the instrument.

2. *Line of Collimation.*—Set up and level the instrument; focus on some well-defined point; clamp; elevate and depress the telescope by turning about its horizontal axis. If the point does not appear to travel along the vertical wire, the ring screws must be loosened and the ring turned by gently tapping one of the screw-heads until the condition is fulfilled. Tighten the screws and test. Now direct the intersection of the cross wires on an object 200 or 300 feet distant; clamp; transit; set a point in the line of sight about the same distance in the opposite direction; unclamp and turn the plates in azimuth half way around and direct again to the first object; transit and set another point beside the first. The two points should coincide; correct the error by turning the capstan headed screws, loosening one and tightening the other thus moving the vertical cross-hair until the line of sight has been moved over a distance equal to one-fourth the apparent error. Test results.

3. *The Standards.*—Set up and level the transit; sight to some high point as the top of a house or spire; lower the telescope and set a point in line of sight slightly below the level of the instrument; turn the instrument half around in azimuth; reverse the telescope and sight on the lower point; clamp and elevate the telescope until the first point comes into view. If the wires do not bisect it the adjustment necessary is made by raising or lowering one end of the horizontal axis. The apparent error is double the actual error. The final adjustment should be made by a right-handed turn of the adjusting screw.

Tighten the cap screws just enough to take up all looseness in the bearing.

4. *Attached Level.*—Construct a level line and adjust the instrument to agree with it (see adjustment of level, page 65).

The Important Adjustments of the Y-Level are: (1) To make the line of sight coincide with the axis of the clips or parallel to it; (2) to make the line of sight and the bubble tube parallel; (3) to make the axis of the bubble tube perpendicular to the vertical axis of the instrument.

1. *Line of Collimation.*—Make the horizontal cross-hair level by turning the ring until the cross-hair coincides with a level surface, or, as the telescope is turned in azimuth a point will appear to travel along the wire, the instrument being set up as nearly level as possible. Next loosen the clips by removing the Y-pins clamp the instrument on the leveling head, and by the leveling and tangent screws bring the wires on a clearly marked point; carefully rotate the telescope in its Y's one-half round and see if the intersection now coincides with the point. Correct one-half the apparent error by moving the cross-hair ring by means of the capstan-head screws. Repeat the operation if necessary.

2. *Level Viol.*—Clamp the instrument over a pair of leveling screws and bring the bubble to the middle of the tube. Rotate the telescope in the Y's so as to bring the bubble tube out of vertical with the telescope axis. Should the bubble run toward the end of the tube it shows that the vertical plane passing through the axis of the telescope is not parallel to that through the axis of the bubble. Correct the error by means of the capstan-head screws on each side of the viol holder. Test the adjustment. This adjustment is preparatory to making the level-tube parallel with the axis of the Y's. Bring the bubble to the middle of the viol with the leveling screws; without jarring the instrument lift the telescope out and reverse it in the Y's. Should the bubble run to either end lower that end or raise the opposite end until half the error is corrected. Level up the instrument and test.

3. *The Y's.*—The bubble tube must now be set at right

angles to the axis of the instrument. Bring the bubble to the middle of the tube directly over a pair of leveling screws; turn the instrument about its vertical axis 180°. If the bubble runs to one end of the tube bring it half way back by the Y-nuts. Test.

The Important Adjustments for the Dumpy Level are: (1) To make the bubble line perpendicular to the vertical axis; (2) to make the line of sight parallel to the bubble line.

1. *Bubble.*—Bring the bubble to the center over a pair of leveling screws; revolve about the vertical axis through 180°. If the bubble moves bring it back half way by the screws at the end of the tube. Test. The bubble should remain in the middle through the complete revolution.

2. *Line of Collimation.*—Construct a level line by driving two pegs at equal distances in opposite directions from the instrument and taking careful reading on them with the bubble in the middle of its tube. The pegs may be driven to the same rod reading then if the distances are equal they will be level. If ground cannot be found for this the difference in the level of the two pegs must be taken into consideration. Set up the instrument so near one peg that the height of the eye-piece can be measured directly by holding the rod vertically on the peg. Sight to the same " height of instrument " at the other peg (or at the calculated height of instrument if the pegs are not level). The axis of the telescope will now be a level line. If the bubble is not in the middle of its tube, bring it half way to the middle and adjust the horizontal cross-hair to the " height of instrument " reading at the farther peg. Test by repetitions.

Cross-sectioning

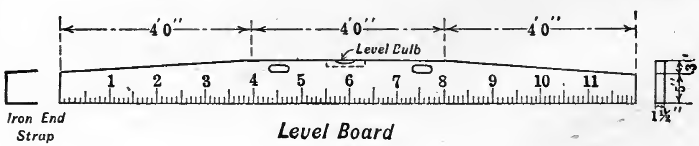
Having located the road by setting the center line stakes cross-sectioning is necessary. By cross-sectioning is here meant the several combined operations of (*a*) taking levels of the lay of the land at right angles to the center line of location, (*b*) the setting of marked grade and slope stakes, and (*c*) the recording of the notes in such a manner that the true shape of the area of a transverse section of the road at that place may be plotted and its area computed; also, from the stakes set, the road may be constructed in true form, grade and position.

Cross-sections (transverse sections) are taken at each station and at intermediate points where the longitudinal slope changes, considerably.

Slope Stakes are set to mark the points on cross-sections where the side slope meets the ground surface.

Grade Stake.—All stakes which indicate cuts or fills are generally known as grade stakes. The term is sometimes, in counterdistinction to slope stakes, used to indicate a stake at a station on the center line of location on which has been marked the cut or fill at that station.

Grade Point.—A point in the intersection of the plane of



Level Board
FIG. 32.

the roadbed with the surface of the ground. Three are usually set across the roadway; they are driven flush with the ground and witnessed by a stake bearing the inscription 0. 0. The point is best found by trial such that the rod reading equals the difference between the height of instrument and elevation of grade.

Leveling.—This may be done with a hand level, a level-board, or the Y-level. When the hand level is used, the height of the eye of the observer must be accurately known and proper corrections made in the rod-reading. A staff, of such length that the line of sight of the hand level when placed on top of it is exactly 5 feet from the ground, may be used.

With the Level Board.—A level board is a long straight-edge, Fig. 32, graduated to feet and inches (12 feet is a convenient length), made of light straight-grained lumber, such as white pine, spruce, or fir, 8 inches wide at the middle and tapered to 4 inches at the ends, and about $1\frac{1}{2}$ inches thick. Iron straps at the ends will prevent wear and splitting. A few hand-holds, cut into the board, will be found convenient. Two men are necessary to handle a level board efficiently. It is well adapted to rough country where the slopes are such that several set-ups of the Y-level might be necessary for a single cross-section.

With the Y-*level* cross-section leveling may be done and the center line elevations taken or checked at the same time.

Grade stakes are set for the convenience of the "grader." On the center stake, on the opposite side from the location or station number is marked the cut or fill at that point: Thus C 4.2 means a cut of 4.2 feet; F 0.3 means a fill of 0.3 feet.

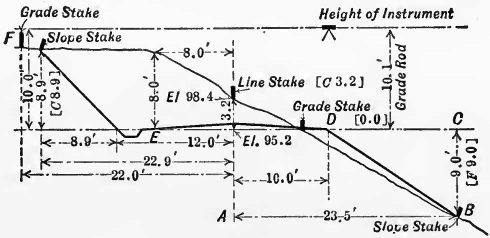


Fig. 33.

Slope stakes are set at the "toe of the slope" with top inclined inward for cuts and outward for fills, and marked with *C* or *F* followed by the vertical distance to the grade plane of the road.

Setting Stakes.—The slope of the fill and cut will vary with the material but for ordinary earth a common slope for fill is 1 vertical to $1\frac{1}{2}$ horizontal and cuts 1 : 1. Referring to Fig. 33, having obtained the elevation of the center stake, say 98.4, just as in leveling for the preliminary survey the grade elevation which has previously been taken off the profile and recorded is looked up, suppose it to be 95.2; this indicates that the ground is there 3.2 feet higher than the grade, hence the stake is marked *C* 3.2. Suppose the width of the roadway in fill to be 20 feet, in cut to be 24 feet, the extra width to allow for side ditches. If the H. I. at this time is, say, 105.3, a rod on grade at this station would read H. I. − grade = 105.3 − 95.2 = 10.1 = grade rod or station constant. Since upon holding the rod at the edge of the grade the reading is found to be greater than that, it will be necessary to fill on the lower side of this cross-section. The rod man comes back, trying at various places until he finds a place the reading of which is 10.1 (grade rod); a stake is placed here and marked 0. 0., that is, grade. The rod man keeps setting his rod out from the center until he finds a point where the rod reads, 10.1 (grade reading) + (distance − out − 10) × $1\frac{1}{2}$. In this case at 23.5 out the rod reads 19.1. The rod man and leveler will compute thus, 19.1 − 10.1 = 9.0 (B. C., Fig. 33), one and one-half times 9.0 = 9.0 + 4.5 = 13.5 (C. D.); 13.5 + 10 (half-width of road bed) = 23.5 (*AB*). So that the distance-out and the road reading check. A stake is driven at the toe of the slope and marked *F* 9.0.

Going out on the other side it is noticed that there is a marked change in slope 8 feet from the center. A rod reading is therefore taken at this point and the cut recorded, but no stake driven. Suppose the reading here to be 2.1, subtract this from the "grade rod" (10.1 − 2.1 = 8.0) and the cut is seen to be 8.0. Going on out, suppose a trial reading is made at 20 feet, and the rod reading is 1.2. The computation is 10.1 − 1.2 = 8.9; 8.9 + 12 (half width of road in cut) = 20.9; but the distance out is 20.0, therefore, another trial is made farther out, say 22 feet with a reading of 0.7 feet, 10.1 − 0.7 = 9.4 (cut); 9.4 × 1 (slope) + 12 = 21.4; which being less than the distance out, 22, shows the distance out to be too great. A trial is then made farther in, say at 21.0 and a rod reading of 1.2; 10.1 − 1.2 = 8.9; 8.9 + 12 = 20.9, which agrees well enough with the distance-out so a stake is driven here and marked *C* 8.9.

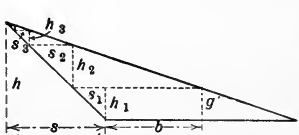


Fig. 34.

This is a practical method of finding slope stake positions by trial. A course of reasoning on the part of the rod man, similar to this might be followed which would also be mathematically correct. If the ground were level the distance-out would be $b+s_1$, where $s_1=g$ tan slope. But in going out this distance the ground has risen an amount h_2, Fig. 34, add therefore to the distance-out, $s_2=h_2$ tan slope, continue this until distance-out and change in height are inconsiderable, say less than 0.1 foot. The algebraic equation then is

$$d=b+s_1+s_2+s_3+s_4\ldots$$

$$=b+(h_1+h_2+h_3+h_4\ldots)\text{ tan slope.}$$

Some engineers, instead of marking the slope stakes, set grade stakes just back of them, F_1, Fig. 33, having an even or integral cut or fill and an integral offset. In the figure the stake is shown with an offset of 22 feet and a cut of 10 feet. By setting another stake on the other side of the road, say with an offset of 25 feet and a fill of 10 feet, a string may be attached to the top of the upper stake and held at the required height above the lower one, pulled taut and measurements made downward from it to the road surface. A small allowance should be made for the sag in the string.

Slope stakes may be set by using a level plane, *DE*, Fig. 33, as a basis through the edges of the roadway, or a plane through the crown, or one-half way between. Whichever plane is taken corrections should be made for the crowning of the roadway in the marking of the center stake and in calculating the quantities.

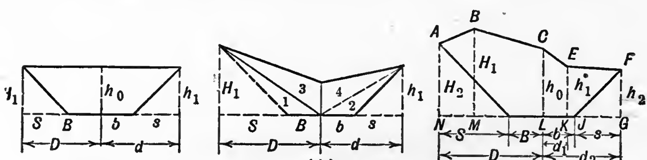
In practice the quantity in the parentheses is guessed at and the rod reading taken, the cut (or fill) is obtained by comparison with the grade rod of the station, this multiplied by the slope tangent (usually $1\frac{1}{2}$ for fill and 1 for cut), and added to half the road bed; the sum is then compared with the distance out.

Recording Cross-section Notes

An ordinary level book with a column for grade elevations for the profile record of the center line of stakes is suitable. The right-hand page, Fig. 35, can be used for cross-sections. In the middle is written the cut (+) or fill (−) at the center stake, on either side the numerator of the fraction is the cut or fill at a distance-out (offset) indicated by the denominator.

CROSS-SECTION NOTES

Sta.	B. S.	F. S.	H. I.	Elevation Ground	Elevation Grade			Cut or Fill.		
327			105.3	98.4	95.2	$\frac{8.9}{20.8}$	$\frac{8.0}{8.0}$	3.2	$\frac{0}{7}$	$\frac{-9.0}{23.5}$
328										
329			94.6		99.2		$\frac{-4.6}{19.9}$	−4.6	$\frac{-4.0}{16.0}$	



(a) Level Section (b) Three Level Section (c) Five Level Section

Fig. 35.—Cross-sections.

Calculating Quantities

Each portion of the roadway between stations may be considered to be a prismoid and the areas of the ends may be determined and the prismoidal formula applied. But this refinement will not usually be necessary. The calculations are simpler for the approximate method, of averaging end areas and when bids are based upon it, they will be reasonably close and fair. If A_1 and A_2 are the end areas, and l the length, the volume

$$V=\frac{A_1+A_2}{2}\cdot l.$$

Stated in words.

To get the volume: Multiply the half-sum of the end areas by the axial length of the prismoid.

If areas are in square feet and length in feet, the volume will be in cubic feet; it may be reduced to cubic yards by dividing by 27. To apply this rule the end areas will have to be calculated.

End Areas.—When the center and side heights of a cross-sectional area are the same it is a one-level section; when the center and side heights differ it is a three-level section; when the height is found at five places it is a five-level section, and so on. (See Fig. 35.)

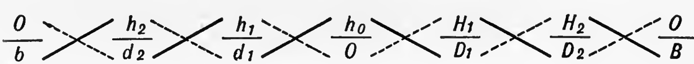
In any case the section may be divided into triangles and trapezoids and the areas found. The following rules may be easily verified by geometry.

Area of a three-level section: Multiply the half-sum of the side heights by the half-base and to this add the product of the center height by the half-sum of the distances-out.

EXERCISES

1. Express this rule for a one-level section.
2. Verify the rule by dividing the section into four triangles as indicated in Fig. 35 (*b*).
3. Verify the rule by considering the section made up of two trapezoids minus two end triangles.

For a section having more than three levels, the method can



be best illustrated by a diagram. The notes are written in the fractional form with the addition of $\frac{0}{b}$ at each end, and 0 under the central h_0. Beginning at the center, multiply heights by distances-out in pairs as indicated by the sloping lines. Call those products connected by the full lines positive, those connected by the dotted lines negative. All distances-out are positive, heights are positive for cuts and negative for fills. The area then is

$$A=\tfrac{1}{2}\left[\begin{Bmatrix} h_0d_1+h_1d_2+h_2b \\ +h_0D_1+H_1D_2+H_2B \end{Bmatrix} - \begin{Bmatrix} 0h_1+d_1h_2+d_20 \\ +0H_1+D_1H_2+D_20 \end{Bmatrix}\right] \quad (1)$$

Applying this to Fig. 35 (*c*), consider the figure made up of four trapezoids less two end triangles.

Area of trapezoid $EFGK = \frac{1}{2}(h_1+h_2)(d_2-d_1)$.

Area of trapezoid $CEKL = \frac{1}{2}(h_0+h_1)d_1$.

Area of triangle $FJG \quad = \frac{1}{2}h_2(d_2-b)$.

Hence the area of the section on the right of the center line

$$CEFGL = \frac{1}{2}[(h_1+h_2)(d_2-d_1)+(h_0+h_1)d_1-h_2(d_2-b)]$$
$$= \frac{1}{2}[h_1d_2-h_1d_1+h_2d_2-h_2d_1+h_0d_1+h_1d_1-h_2d_2+h_2d]$$
$$= \frac{1}{2}[h_0d_1+h_1d_2+h_2b-h_2d_1].$$

The area on the right may be found in exactly the same manner. Added together, the result is the same as found above (1).

Mr. E. U. Bryan, Modesto, Cal., applies an old rule thus:[1]

$$A = \frac{1}{2}[y_0(x_1-x_u)+y_1(x_2-x_0)+y_2(x_3-x_1)+y_3(x_4-x_2) \\ +y_5(x_6-x_4)+y_6(x_7-x_5)+y_7(x_u-x_6)+y_u(x_6-x_7)].$$

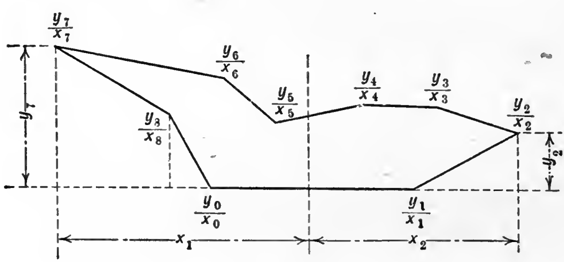


Fig. 36.

Stated in words: "Begin at any point on the section and proceed in either direction (clockwise or counter-clockwise), multiplying each cut (or fill) in its order by the horizontal distance between the point just preceding and the point just succeeding. In cases where one passes to the right in measuring the horizontal distance from the preceding to the succeeding point the product obtained by multiplying this distance by the cut (or fill) at intermediate point is of one sign and in cases

[1] Eng. Record, p. 470, Oct. 24, 1914.

where one passes to the left the product is of the opposite sign. Take one-half of the difference between the sums of products of opposite signs and the result is the area of the section."

EXERCISES

1. Find the area of the cross-section station 327, level notes, p. 70 for a 20-foot roadway in fill and 24 feet in cut. *Ans.* 111.5 sq. ft.

2. Find the area of the cross-section station 329 same page.

NOTE: Part of section 327 is in fill and part in cut. As it is usual to pay for either cuts or fills and not for both it is customary to compute each part separately and record in columns set apart for "cut" and "fill" in the quantity book. The same rules will apply by considering the section as two sections with readings thus:

$$\frac{8.9}{20.8}\quad\frac{8.0}{8.0}\quad\frac{3.2}{}\quad\frac{0.0}{7.0}$$

$$0.0\quad\frac{0.0}{7.0}\quad\frac{-9.0}{23.5}$$

Ans. Cut 125.0 square feet.
Fill 13.5 square feet.

As a check on the work each cross-section may be, and by some engineers is always, plotted on squared paper, and the area obtained by a planimeter or the number of squares counted.

MISCELLANEOUS

Crown.—In road work where the quantities have been determined by the foregoing methods there must be added to the quantities in fills and subtracted from those in cuts the amount necessary for the crown. With plane surfaces the end section is a triangle with area, $\frac{1}{2}bc$, where b is the base width of the crown and c the mid-height. With the parabolic form of crown the end area is $\frac{1}{3}bc$. The quantities given in Table V, p. 50, which is for plane surface, must be multiplied by $\frac{2}{3}$ to get the corresponding quantities for a parabolic surface.

Blade Grader Work.—Where the excavations and embankments are not large and the grading can be done with a blade grader, it is often better to pay for the work on a time basis, or some other method of compensation, thus saving the expense of earth computation.

Shrinkage.—Earth taken from a hole and piled loosely will occupy more space than when in its original position, varying from 10 to 20 per cent for earth, and from 50 to 70 per cent for solid rock. But when the earth is placed in an embankment or tamped into a ditch it will occupy less space. The amount of shrinkage depends upon the character of the earth, on the method of depositing, upon its state of moisture, and upon the height of embankment. Loamy and light sandy earth will shrink about 12 per cent; clay and clayey earth, 10 per cent; gravel, 8 per cent; while solid rock will expand from 50 to 70 per cent. As to the method of depositing the shrinkage from pit measurements is probably greatest when the embankment is made by drag scrapers where the horses and drivers are continually walking over the deposited earth. Earth spread in shallow layers and compacted by thorough harrowing and rolling may come next. Then, perhaps, without rolling, wheel scrapers, wagons, cars, and wheelbarrows. Damp earth will compact better than dry earth, embankments laid up during rainy weather show more shrinkage from pit measurements and less settlement than those laid in dry weather. The higher the embankment the greater the weight on, and consequently the compaction of the lower layers.

Settlement.—The shrinkage mentioned in the preceding paragraph takes place during construction. In time the embankment will shrink further due to settlement, a slow rearrangement of the particles composing it into more stable positions under the weight of the super load and jarring of vehicles. The greater the shrinkage during construction the less will be the settlement. Consequently the settlement of earth will be in inverse order of that given above for the shrinkage from pit measurements; likewise, the percentage of settlement of low embankments will be greater than that of high.

To compensate for settlement it is customary to set the grade stakes (on low grades only the finishing stakes) about 10 per cent higher than the calculated values, for example, instead of setting the finishing stake for a fill of 2.1 it is set for a fill of 2.3. Iowa Highway specifications for depth of fill up to 5 feet allow 15 per cent; from 5 to 12 feet, 12 per cent; from 12 to 18 feet, 10 per cent. With rock it is not customary to allow for settlement, but the amount will depend upon the size and shape of the stones used, varying from nothing for large angular stones to 8 per cent for gravel.

Borrow Pits.—Where the cuts and fills do not balance, or where the haul is long, it is advantageous to "borrow" earth from excavations alongside the road. Borrow pits should be regular in form, so they can be measured easily. They should always be a little distance from the toe of the slope, leaving a *berm* increasing from 6 feet, say, with height of embankment.

Wasted Earth.—Sometimes earth from cuts must be wasted. This can be done frequently by widening the embankment at the foot of the cut. Otherwise it may be necessary to secure permission to place it on adjacent land.

Existing Road Layouts

The matter of surveying has been gone into with considerable detail. Such refinement will seldom be necessary. For example, the preliminary survey and the final location can be combined into a single operation and done by two men. Even the leveling, if not omitted, can be run by the transit and the curves and grades staked in by eye. But as populations become denser and traffic increases more money will be spent in higher-priced roads, there will be a demand for straighter roads with easier grades. Calf-path trails and section-line roads will have to give way for scientifically located and constructed highways.

Relocations along Existing Lines.—Where the relocation is not along existing lines it becomes a new location and some of the methods given, or some modification of them may be applied. However, when the road is to be relocated approximately along existing lines the surveyor can do little but eliminate short crooks and bends, smooth out and better the grades by cuts and fills, and perfect the drainage by proper use of ditches, tiling, culverts, and bridges. Where possible the true location of the right of way should be determined by finding government corners, if these still exist, or others established by reliable authority if this can be done without expending too much time. Some State highway departments locate and tie out these marks if easily obtainable; if not, they assume the proper location of the highway to be outlined by long-established fence rows. The right of way having been determined or assumed the relocation is made within these limits as far as practicable. Occasionally to avoid a swamp, bad angle, steep hill, or other feature there must be new locations for short distances.

A party for relocation work may consist of as few as three men; an instrument man, who is also chief of party; and two assistants who act as chainmen, rodmen, axmen, and so forth, as occasion may require. They will ordinarily have an automobile or other conveyance to take them to and from the work and to haul instruments, stakes, and other supplies. The outfit required will be one combined transit and level, one leveling rod, two flag poles, one set of 11 steel marking pins, one 100-foot steel tape, one 50-foot metallic tape, one ax, a supply of stakes, nails of various sizes, tacks, red cloth for patches, and note books and pencils. If the country is rough a level board for cross-sectioning will be found handy. A corn knife for cutting corn stalks and high weeds will be convenient at times. If the party is to establish grade lines profile and drafting paper and instruments will be required. A small chest or trunk in which to keep such articles as tapes, note books, pencils, drawing instruments, and other supplies safe from rain storms or marauding hands is highly desirable.

Surveying Operations.—A traverse line is run near the center of the right of way. Twenty-penny wire nails driven through a patch of red cloth flush with the ground will serve to mark the stations. Ordinarily these will not be disturbed by the traffic. Hubs should be set flush with the ground and tied out in the ordinary manner. After a short line of traverse has been surveyed the same party can run levels over it and get cross-sections at each station and sudden break in ground.

The notes will usually be sent to headquarters for plotting and computations; but in some cases the party may do this work, establish a grade line and set grade stakes.

Office Work.—After the grade stakes have been set the cross-sections are plotted, end areas measured by a planimeter or computed by methods heretofore given. Cross-sections should be plotted on cross-section (squared) paper so that by counting the squares there may be a rough check on the planimeter computation. Or, an accurate measure of the cross-section may be made by adding together the average height of each foot space across the section, the sum being the area in square feet. As these sections are small and irregular the use of the planimeter is the only practical method of obtaining the areas with speed and accuracy. The planimeter should be run around the area

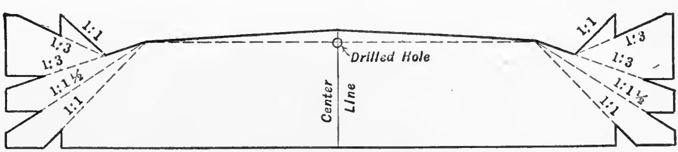


Fig. 37.—Template for Plotting the Crown of a Road

twice, the readings noted at the end of each run, the second reading should be twice the first. Harger and Bonney [1] state that a satisfactory rule is to allow a difference of 0.4 square foot for areas up to 50 square feet and 1.0 square foot error above 50 square feet. Also that it is best to have two men work independently with separate planimeters and check the one against the other. To assist in plotting, standard templates of the crown of the roadway for cuts, low fills and high fills may be made from transparent celluloid, Fig. 37. Broken triangles can be thus utilized.

Field Procedure.—During the process of construction the survey party will keep the road surveyed and staked ahead of the graders, from time to time check the work of the con-

[1] "Highway Engineers' Handbook," by Harger and Bonney, McGraw-Hill Book Co., New York.

struction gang, stake out culvert and bridge openings, as may be required, measure borrow pits, make estimates on the amount of work done, at the end of each month, set finishing grade stakes in the center of the graded way just before its completion, and do such other work as may be required by those in authority even, perhaps, to the acceptance of the finished work.

Stadia Surveying.—Stadia surveys for maps or traverses may be made with either transit, or plane table equipped with telescopic alidade. The Plane Table, since details and natural features are sketched in the field, furnishes a convenient instrument for preliminary work. By means of a stadia-rod distances to any desired point may be quickly found and the elevation of the point calculated trigonometrically or with reduction tables. The Beaman Stadia Arc is advantageous for finding these elevations. If contour lines are desired the plane table may be set so that H. I. is approximately on a contour, or at a known distance above or below, and as many points as needed shot in and sketched on the map. By resetting the table as many contours as wanted may be determined. In running traverses the table is oriented by back-sighting on the previous table station and another station ahead located by stadia shot. Side shots to points visible from more than one station will furnish convenient checks upon the work.[1]

[1] For fuller details of stadia methods see standard works on surveying, such as, Breed and Hosmer's "Surveying," Vols. I. and II., Wiley & Sons, New York; also "A Treatise on the Plane Table," by D. B. Wainwright, U. S. Coast Survey Report, 1905.

CHAPTER III

TYPES AND ADAPTATION OF ROADS

To secure the kind of road best adapted to any particular place is not an easy task. While economic and other engineering principles should be involved, the real determining factor will usually be some local consideration. The wishes and opinions of the people who live along, use and pay for any road improvement, even though they have never studied the scientific principles of transportation and road making, should have much weight. The final test of success will be the satisfaction of these people. The tactful engineer will present facts and strongly advocate good materials and good construction, well suited to the conditions, but will nevertheless bend to constraining influences and do the very best he can with the means and materials at hand.

The main points to be considered in the selection of a type of road are:

1. The amount and character of the traffic.
2. The character of the location as to drainage, grades, and soil.
3. Climatic and weather conditions.
4. Available building materials.
5. First cost and annual charges.
6. Cost of maintenance.
7. Durability.
8. Smoothness, hardness, tractive resistance.
9. Slipperiness—animals, pedestrians, motors.
10. Sanitariness—healthfulness, noisiness, mud, dust.
11. Acceptability—esthetics, heat, light, comfort, desires of the users.

While these items may be considered individually with respect to any particular road, they must also be considered collectively. Likewise they are not absolutely independent of each other. Durability is a function of climate, character and amount of traffic, hardness and smoothness, drainage, cleanliness, and possibly other items. Smoothness and hardness increases slipperiness. Cost depends upon availability of materials, and so on.

Types of Roads

Earth Road.—By far the most common is the ordinary earth road. Of the more than two and a quarter million miles of roads in the United States, about 90 per cent are earth roads, and many have not even been graded. This indicates the importance of the earth road, and while the surfacing of roads will continue indefinitely, it is not expected or desirable that a very large percentage of the earth roads ever will be surfaced with harder materials. In many of our Prairie States every section line is made by law a road. Suppose the north and south and the east and west roads meeting at the center of each township were surfaced. While this would be as unscientific as the laying out of these roads was, every farmer would be within three miles of a surfaced road and only $16\frac{2}{3}$ per cent of all roads would be surfaced. If 10 per cent of the roads were surfaced and these selected with judgment they would amply accommodate 90 per cent of the traffic.

The earth road when it can be graded with the blade road grader and a traction engine can be very cheaply constructed, costing from $35 to $100 per mile, exclusive of culverts and bridges. These perhaps double the cost. The road can be maintained by the road drag at a cost of $10 to $25 per mile per year. The annual cost of maintaining bridges and culverts will depend upon the character of those structures as well as the weather conditions, floods and soil, assuming this to amount to as much as dragging, there results:

First cost of earth roads including culverts...	$70 to $200
Maintenance of earth roads including culverts	20 to 50

The good qualities of an earth road are:

Low first cost.

Not slippery.

Noiseless.

Easy on horses' feet.

Comfortable when in first-class condition.

The poor qualities are:

High tractive resistance.

Not durable. High cost of maintenance needing constant attention.

Difficult, practically impossible to clean.

Muddy in wet weather.

When the dust blows away is left choppy.

Ruts easily.

Wears down rapidly under heavy traffic in windy localities.

Uncomfortable except when in prime condition.

The road is satisfactory if well drained and maintained, under light or moderate traffic. As soon as the traffic becomes heavy, ruts and pockets form and it is practically impossible to keep it in good condition or repair.

The character of the soil has much to do with the condition of the road surface. Clay soils become soft and sticky in wet weather and hard and choppy in dry weather. Gumbo soils are very sticky in wet weather and rut badly. They dry up rough and are a long while wearing smooth. Sandy soils are best in wet weather, as sand itself has no cementing power, depending on the water for that property. When dry, therefore, sand roads are in their poorest condition. Some soils, like field soils, are a sandy loam; such soil makes good earth roads for all kinds of weather.

Sand-clay Roads.—Sand being best in wet weather and poorest in dry, while clay is the opposite, a right proportion of the two makes a fairly good road surface. This type is very appropriate for roads having a light or moderate traffic over sandy stretches or over clay and gumbo soils. The cost will depend upon the availability of materials. Roads actually constructed range in price from $500 to $1500 per mile. Maintenance cost will be about the same as for earth roads.

Gravel Roads.—Where gravel of good quality can be readily obtained, this may be spread over the road surface and when compacted by the traffic forms a smooth, non-slippery, non-muddy, noiseless, comfortable, driveway. Gravel roads get dusty and rutted in dry weather, especially under heavy traffic. They are to be commended for park drives, house drives or rural roads where there is a moderate amount of traffic.

Macadam Roads.—These are roads made of broken stone thoroughly compacted by roller or traffic. They are cemented by fine particles of stone or clay and when in good condition form an excellent road for horse and iron-tired vehicle traffic. The horses' shoes and the iron tires wear away enough dust from the stone to keep the top surface thoroughly cemented. With tough stone and not too heavy a traffic, they remain smooth and hard under such conditions, and never become slippery. Motor traffic, however, due to the shearing effect of the drive wheels, has a tendency to loosen the stones and start raveling. Most of the famous good roads of Europe are of this type. Until the advent of the automobile, they were thought to be almost ideal for rural roads.

Bituminous Macadam Roads.—Because " waterbound macadam " roads deteriorated under the action of automobile traffic, as has been stated on account of the shearing effect of the drive wheels and also because the rubber tires failed to furnish the stone dust to re-cement continually the road surface, experiments were made in cementing the stone pieces with tar and asphalt-bitumens. These roads have proven quite popular for all except extremely heavy traffic. They are smooth, easy riding, of small tractive resistance and comfortable. They must be placed upon a concrete or macadam foundation, as the bituminous material is plastic and the surface will conform to any depression in the subgrade below. The concrete foundation furnishes the required stiffness. For roads with moderately heavy traffic leading into the larger cities they are well adapted.

Brick Roads.—Vitrified paving brick make a hard and durable surface having a low tractive resistance; the surface is reasonably smooth and non-slippery. It is noisy, although the noise is somewhat reduced by filling the joints with bituminous filler. It is sanitary and can be cleaned by flushing or sweeping. It is well adapted to places where there is heavy traffic either with teams, tractors or motor trucks. Brick has been found to be thoroughly serviceable for country roads leading into large cities. The first cost is considerable, but annual maintenance is not great. Just what the life of such roads may be is not known; roads thirty years old are still in good condition. So much depends upon the quality of the brick—no two clays giving exactly the same results, upon the manner of laying, upon the character of the foundation, and upon climatic conditions, that it is not safe to make specific statements regarding durability.

Concrete Roads.—This type of road is comparatively new and it can hardly be asserted that it is more or less durable than other roads. Concrete roads seem to be well adapted for automobile traffic; under such traffic they remain smooth, have easy traction and are not slippery. Under heavy teaming with iron wheels it is doubtful if they would prove as durable as some other types. The cost is a little less than brick, and when made in two or three courses, about the same as bituminous macadam.

Asphalt Blocks.—Blocks about 5 inches wide, 12 inches long and 2 inches deep are manufactured of crushed rock and asphalt in a central plant under uniformity of mixture and pressure. These are laid on a concrete or macadam base as bricks and soon cement together under traffic into a smooth surface looking much like asphaltic macadam or sheet asphalt. They have been successfully used for country roads under a variety of traffic. Being in the form of blocks special equipment for laying is not necessary. The first cost is about the same as a brick road.

Sheet Asphalt.—This type of road while very popular for street paving has not yet been used greatly for rural roads. It is at its best where it receives a moderate traffic sufficient to keep it packed hard. The asphalt and sand surface has a property of swelling and cracking if not used. It therefore should never be put where any part of it will lie idle a great share of the time.

Wheelways.—Stone, concrete, and steel have been utilized to form parallel tracks upon which the wheels of vehicles travel, the center being filled with various other materials. Telford built a road having wheelways of stone: " The blocks were of granite, 12 inches deep, 14 inches wide, and not less than 4 feet long." He used under this a telford-gravel foundation, and between the wheelways broken stone.

A number of forms of steel wheelways have been proposed and in some instances successfully used. From Valencia to Gras, Spain, is a noted steel wheelway over which many tons of freight are annually hauled. The traffic is said to be over 3000 vehicles daily. This is a particular case, adapted to particular conditions and cannot be followed generally.

A few years ago General Dodge, formerly Director of the U. S. Office of Public Roads, used his influence to popularize steel trackways. And while it is conceded that they have some advantages they have not been even moderately adopted by road builders. In a place like that in Spain, where there is an extremely heavy freight traffic for a short distance, no doubt they would prove economical.

Burned Clay Roads.—For many years the railroads have burned clay and gumbo for ballast. A trench is dug in the clay soil, in the bottom wood is piled, over this coal, over this is thrown a layer of clay, then other layers of coal and clay are piled on this, each a little nearer the bank from which the clay is thrown. Thus as the fire burns the pile is moved sidewise a little. The clay burns into angular, reddish lumps about as hard as ordinary brick. The material is too porous for a good road, but on account of its reddish color is a valuable covering for ground in parks which traffic occasionally passes and in contrast with gray stone drives and paths may be formed into pleasing figures.

Shell Roads.—Along the Atlantic and Gulf of Mexico sea-boards oyster shells being abundant have been utilized in road making. For light driving they make a fairly acceptable roadway. The shells are not sufficiently tough to withstand heavy traffic, hence soon become ground into powder, forming dust and mud.

Furnace Slag has been used to a limited extent for roads. It lacks toughness but is applicable for light traffic.

Coal Slack.—Near coal mines waste coal slack has been used on the roadways. It does not make as good a road as gravel.

Cinders.—Cinders are frequently used for park drives where heavy teaming, of course, is not allowed, being porous, the rain soon sinks away, leaving no mud. Cinder roads are better than earth roads and can be utilized advantageously in the several drives about the farmstead.

Plank Roads.—Years ago plank roads were common and even yet in the lumbering regions of the Northwest, where rain is plentiful and plank cheap, roads of this sort are still constructed. Two stringers are laid lengthwise upon which are spiked crosswise the planks about 8 feet long. The writer has read in an old paper an article asking the town council not to allow railroads to enter Chicago because they would destroy the plank-road industry.

Corduroy Roads.—Small logs or poles are laid down across the roadway. They are makeshifts used to cross muddy places in timbered country. They were quite common during the Civil War to transport army supplies to unsettled locations.

Hay Roads.—Just before the rainy season in the Northwest hay or straw is often strewn upon the roads. This prevents them from becoming muddy during the long wet season. The straw is only a temporary palliative, just as brush is sometimes, used in a timbered country, crushed sugar cane in the South, and other waste products everywhere.

Strawing roads in the sand hills of western Nebraska and neighboring States may be considered something more than temporary improvement. The straw is spread upon the sand with a manure spreader. It mixes with the sand, decays and after a series of years a loam is formed, and the road becomes similar to any other earth road.

Comparison of Roads

A comparison of several roads for a particular place can be made by the forming of a table in which the essentials are written along the left-hand side with their weighted values and the roads to be compared along the top, thus:

	Ideal Road for this Particular Location	Best Earth Road	Sand Clay Road	Gravel Road	Macadam Road	Brick Road	Concrete Road	Asphalt Block	Creosoted Wood Block	Bituminous Concrete
Low first cost	20	20	16	16	15	10	12	10	8	14
Low cost of maintenance	20	15	15	10	8	9	8	8	10	8
Ease of traction	10	1	4	6	8	10	10	9	9	9
Non-slipperiness	10	9	9	9	9	8	5	5	5	5
Noiselessness	5	5	5	5	4	1	1	2	4	2
Healthfulness	10	5	5	6	8	9	9	9	8	9
Freedom from dust and mud	10	1	2	3	4	9	9	9	9	9
Comfortable to use	10	3	4	5	6	8	8	9	9	9
Appearance	5	2	3	3	4	5	4	5	5	5
Total	100	61	63	63	66	69	66	66	67	70

It must be remembered that a table such as this applies only to an individual road. *No two will be exactly alike.* First cost may be a large determining factor; it may be ranked at 50 or more, while healthfulness might be 0. Local conditions, as has been frequently stated, are always to be taken into account.

CHAPTER IV

DRAINAGE

Drainage is, perhaps, the most important element connected with road making. If the road be of sand the drainage should be such as to keep it continually moist, if of clay, continually dry. Extreme drying out is bad for a waterbound macadam, but a wet foundation is worse. Roads upon level ridges and valleys are harder to maintain in good condition than those on slightly rolling land, primarily because of bad drainage. The effect of the water is the same whether it soaks in from the top or seeps up from the bottom. Therefore, drainage must look after the water from both directions. Usually, therefore, the subject is discussed under the two heads of surface drainage and sub-drainage. Drainage, also, has to do with the taking care of all surplus water that may come near the roadway; bridges and culverts might very properly be a sub-heading of this subject.

Surface Drainage

On all roads the surface is inclined, generally away from the center, occasionally toward the center, to allow the rainwater to run off the road into longitudinal ditches or gutters in which it is carried to some convenient point of egress.

Crown.—The raising or rounding up of the center is the crown of the road. The amount of crowning depends upon the character of the road, being greater for road surfaces of a porous nature like earth, than for those which are impervious like asphaltic macadam. Too great crowning will make traffic seek the center, it being uncomfortable to ride on the incline. The more tracks may be done away with and the whole road surface used, the better. The crown of an earth road may be as much as 1 inch to the foot. An impervious roadway may be half as much. Sometimes the crown is made up of plane surfaces. It is argued that a curved surface is preferable because it tends to distribute more uniformly the traffic causing the surface to wear more evenly, but the tendency seems to be toward the plane surface. With the plane surface the fall is directly proportional to the distance-out from the center. Thus in Fig. 38

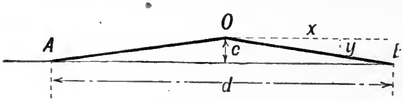


FIG. 38.

$$y : x :: c : \tfrac{1}{2}d;$$

whence,

$$y = \frac{2cx}{d},$$

where y = the distance of the surface below the center,

c = the crown of the road;

x = the distance-out from the center;

d = the road width.

Curved surfaces are most easily made the arc of a parabola, Fig. 39. This can be obtained from the parabolic formula,

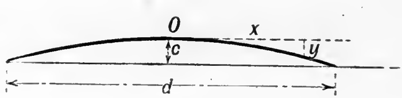


FIG. 39.

$$y = \frac{4c}{d^2} \cdot x^2,$$

where the letters have the same signification as above. A simpler method is to consider x an aliquot part of the half road width; that is, suppose $x = \frac{1}{n}$ of $\frac{d}{2} = \frac{d}{2n}$, substituting in the formula,

$$y = \frac{4c}{d^2} \cdot \frac{d^2}{4n^2} = \frac{c}{n^2}.$$

If the depression at $\frac{1}{6}$ the distance from O to N is wanted, $y=\frac{c}{36}$; at $\frac{1}{4}$ the distance, $\frac{c}{16}$; at $\frac{1}{2}$, $\frac{c}{4}$; at $\frac{3}{4}$, $\frac{9c}{16}$; at $\frac{5}{6}$, $\frac{25}{36}c$; at any fractional distance, $\frac{k}{l}$ of the half road width, $y=\frac{k^2}{l^2}c$. These distances may be measured downward from a line stretched across the roadway from N to M or a wooden template can be made by rounding out the underside or nailing strips to a board with ends projecting below it, Fig. 40 (*e*). With the center height known the side stakes may be obtained by using a spirit level on the top of the board. If side grade stakes are set, the center and intermediate stakes can be quickly set, by sight rods. Three are required. They are shown in Fig. 40.

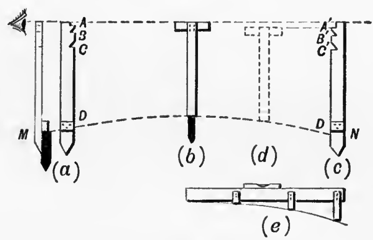


FIG. 40.—Sight Roads.

Rods are placed upright behind the stakes at M and N with the blocks D resting on their top. The "T" is of constant height and the stake upon which it is held is driven until the line of sight from A to A' coincides with its top. Several notches are cut in the rods A, B, and C to facilitate setting intermediate stakes. The top is used for center stake, notches A for one-fourth distance-out; B, for one-half; and C for three-fourths. It is easier to sight these rods if the farthest one is painted white and the middle one a different color.

Side Ditches.—The water having been shed from the road surface by the crown must be further taken care of. For this purpose side-ditches parallel to the center line of the roadway are constructed. These must have sufficient longitudinal grade to allow the water to flow along them until a place is reached where the natural formation of the land will allow it to flow away from the right of way. Every opportunity for this should be provided. A small amount of water flowing on to a field will do no damage but a large quantity might be troublesome. Natural drainage and water courses should be utilized wherever possible. It is not generally a wise plan so to change

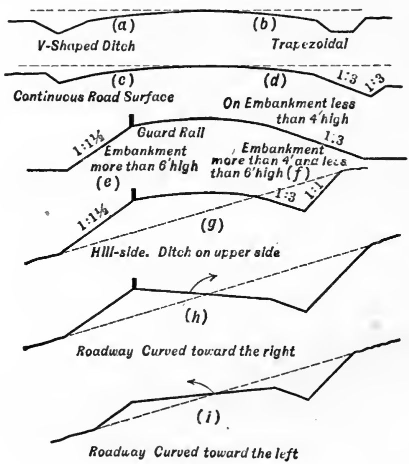


FIG. 41.

the grade of the road that water from one natural drainage area will be carried over into another. Let each area take care of its own water and thus avoid damage suits.

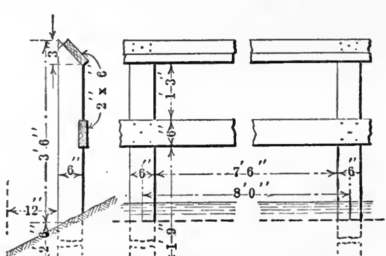


FIG. 42.—Wooden Guard Rail.

Broad and shallow ditches are better than deep and narrow ones. They are not so dangerous nor are they so liable to become clogged; they are also easier to keep clear. Three principal forms are in use; the V-shaped, the trapezoidal, and that in which the ditch is a continuation of the road surface, Fig. 41, (*a*), (*b*), (*c*).

Ditches such as these offer but little obstruction to the passage of vehicles over them whenever necessary or to the use of a mower to cut the grass and weeds. Where the roadway is on an embankment less than 5 or 6 feet high, Fig. 41, (*d*), (*f*), the slopes, preferably, should not be steeper than 1 : 3. The ordinary vehicle could go on this without tipping over. If the embankment is more than 6 feet high a guard rail should be pro-

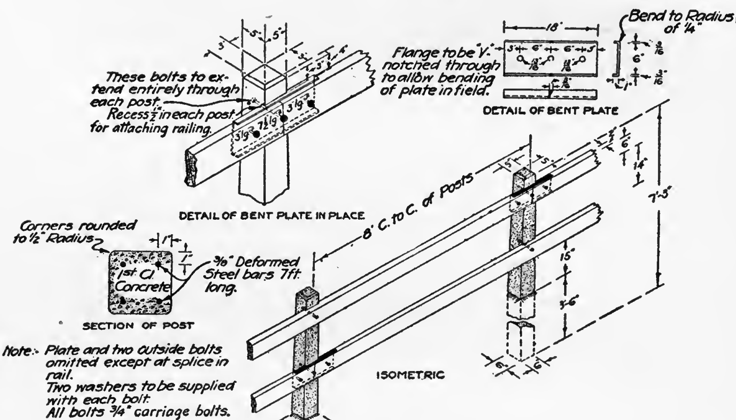


Fig. 43.—Concrete Posts, Wooden Rails.

vided for the safety of the traffic, Figs. 42, 43, 44. Frequently it will not be necessary to have a ditch at the foot of the embankment, Fig. 41, (*e*), (*f*). In a cut ditches are placed on the sides the same as on level ground. On a side-hill the ditch is on the upper side, Fig. 41, (*g*), (*h*), (*i*). Where the road curves the crown should be brought to or toward the outer side of the curve, Fig. 41, (*h*), (*i*). Side ditches on slopes can be paved in the bottom to prevent washing. Concrete, brick and cobble stones will be found acceptable.

Guard rails, mentioned above may be made of wood, concrete or iron. They should preferably be wide enough to be easily seen and strong enough to prevent a vehicle from going over if it should strike them at reasonable speed. Fig. 42 shows details for a wooden guard rail; Fig. 43, a combined wood and

FIG. 44*a*.—Concrete Guard Rail.

cement; and Figs. 44*a* and 44*b*, a cement. Steel pipes with wooden posts, and steel lattice with steel posts are also used.

SUB-DRAINAGE

Where the subsoil is wet, mucky and yielding, due to an excess of water, provision must be made for under-drainage, else the "roof" of the road will soon give way with consequent rutting and destruction of the surface.

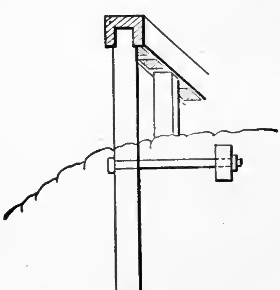


FIG. 44*b*.—Concrete Guard Rail.

The methods for accomplishing this, are usually, deepening the side ditches, using a blind drain, or laying farm drain tile.

Deep side ditches are usually of the trapezoidal form, Fig. 35 (*a*). With these open ditches there is always danger of accident; and they are liable to become clogged with debris, thus forming dams which hold the water where it is not wanted. Open deep ditches should be avoided if possible.

Blind drains are made in a variety of ways—from a mere opening through the soil to the cylindrical farm tile.

A blind drain plow having an acorn-shaped piece of steel at the bottom of an extension piece is drawn through the ground to be drained. It leaves a small round opening in the soil through which the water is supposed to find its escape. Since this opening may soon be filled with earth, it is not to be used except for temporary effect.

Better results are obtained by digging trenches and partially filling them with field stones, boulders, broken rock, or gravel, the coarsest at the bottom and covered over with earth Fig. 45 (*b*). In timbered country logs have been used in the same manner.

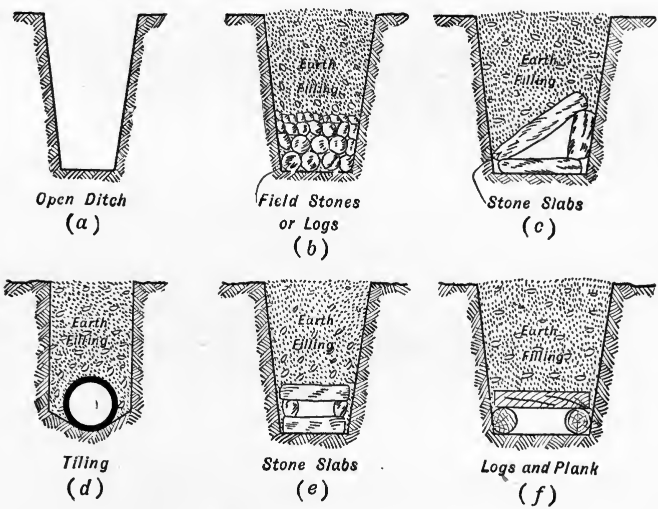


Fig. 45.—Open and Blind Ditches.

Drain Tile.—Probably the best form of under-drain is that made of clay or cement drain tile. These may be placed under the middle or side of the road. Under the side ditch is considered better for the reason that the road surface needs not to be disturbed for laying or repairing the drain. Some good engineers prefer to have the drain about 3 feet inside the gutter in order that there may be no danger of its being washed out by surface water running down the gutter. Tiling will " draw " the water for a considerable distance on either side—the ordinary estimate being 50 feet if the soil is reasonably porous. Tile must be set carefully to grade and alignment and deep enough to avoid the effect of frost upon it. In the Northern States 5 feet is considered sufficiently deep. In the Southern States it should be covered at least its own diameter to prevent accidental breakage. In any instance, the pipe should be laid deep enough to lower the water table sufficiently that there will be no danger of the road being broken through under the weight of the traffic. Often deepening the pipe on one side will do away with the necessity of tiling the other side of the road and the expense may be much less.

Size of Tile.—The judgment of experience is perhaps the best guide. The amount of water which a pipe will carry depends upon its size and grade; also on internal friction and head or pressure. Size and grade are all that need to be considered here. Several formulas have been propounded for the flow of water from a drainage pipe. Baker [1] gives the following:

$$A=1.9\sqrt{\frac{f}{l}d^5},$$

in which A is the number of acres for which a tile having a diameter of d inches and a fall of f feet in a length of l feet will remove 1 inch in depth of water in twenty-four hours.

The Poncelot formula is

$$v=48\sqrt{\frac{df}{L+54d}},$$

in which d is the diameter of the tile in feet,

f, the total fall of the line in feet;
L, the length of the line in feet, and
v, the velocity in feet per second.

[1] " Roads and Pavements," p. 76, First Edition, 5th thousand. Wiley & Sons.

The Chézy-Kutter formula, much used, is,

$$V = c\sqrt{rs},$$

in which V = velocity in feet per second;
c = a coefficient found by Kutter's formula;
r = the hydraulic mean radius;
s = slope, or fall in feet divided by length in feet;

The simplified Kutter's formula for obtaining c is

$$c = \frac{41.6 + \frac{1.811}{n}}{1 + \left(\frac{41.6n}{\sqrt{r}}\right)}.$$

Spalding's Table for capacity of tile drains in cubic feet per minute based on the above formula with a coefficient of roughness, $n = .013$ follows:[1]

Slope per 100 Feet in Inches	Size of Pipe				
	4 in.	6 in.	8 in.	10 in.	12 in.
2	4.0	12.0	27.0	49.5	81
4	5.5	16.5	38.0	70.0	114
6	6.5	21.0	46.5	86.5	143
9	8.0	25.5	57.5	106.5	176
12	9.5	29.5	66.0	122.5	204
24	13.5	41.5	92.0	173.0	288
36	16.5	51.0	114.0	212.0	353
48	19.0	59.0	132.0	245.0	408
60	21.0	66.0	148.0	275.0	456

Iowa Highway Commission table:[2]

[1] "A Text-book on Roads and Pavements," by F. P. Spalding, Wiley & Sons.

[2] Manual for Iowa Highway Officers, 1906, p. 48.

NUMBER OF ACRES DRAINED BY TILES REMOVING ¼-INCH DEPTH OF WATER IN 24 HOURS

Grades		Diameters of Tile Drains											Grades	
Per Cent	Inches Per Rod	3-Inch	4-Inch	6-Inch	8-Inch	10-Inch	12-Inch	15-Inch	18-Inch	20-Inch	22-Inch	24-Inch	Inches Per Rod	Per Cent
0.03	1/16	....	....	....	....	37	59	109	159	205	254	319	1/16	0.03
0.05	3/32	....	5	13	28	49	75	131	219	264	332	411	3/32	0.05
0.10	3/16	4	7	19	40	69	109	186	289	373	471	582	3/16	0.10
0.15	9/32	4	9	24	49	85	132	232	355	458	577	713	9/32	0.15
0.25	3/8	5	10	28	56	97	153	264	410	529	667	823	3/8	0.20
0.30	9/16	6	12	33	69	119	188	322	502	648	808	1008	9/16	0.30
0.40	13/16	7	14	39	79	138	216	371	580	748	942	1165	13/16	0.40
0.50	1	8	16	44	89	154	246	416	648	838	1050	1300	1	0.50
0.60	1 3/16	9	17	48	97	169	266	457	710	911	1154	1422	1 3/16	0.60
0.70	1 3/8	10	19	50	105	182	287	488	768	988	1242	1549	1 3/8	0.70
0.80	1 9/16	10	20	55	114	195	307	526	822	1059	1332	1645	1 9/16	0.80
0.90	1 3/4	10	21	59	119	207	326	558	872	1123	1414	1747	1 3/4	0.90
1.00	2	11	22	62	126	218	343	589	917	1176	1495	1838	2	1.00
1.50	3	13	28	75	153	267	419	722	1123	1450	1824	2256	3	1.50
2.00	4	15	31	88	178	309	485	832	1297	1676	2110	2594	4	2.00
3.00	5 15/16	19	39	107	216	377	593	1020	1589	1957	2592	....	5 15/16	3.00
4.00	7 15/16	22	45	123	253	437	683	1176	....	....	....	....	7 15/16	4.00
5.00	9 7/8	25	50	138	280	486	765	....	....	....	....	....	9 7/8	5.00
7.50	14 7/8	30	61	169	344	....	....	....	....	....	....	....	14 7/8	7.50
10.00	19 13/16	35	71	195	....	....	....	....	....	....	....	....	19 13/16	10.00

Roughly speaking tile smaller than 4 inches should not be used; it is difficult to determine just what size will remove surplus water and lower the line of saturation sufficiently below the road surface to prevent trouble. It is better to use tiling too large than too small. In farm drain practice it is said,[1] " with the dark-silt-loam soils of Illinois and Iowa, where the rainfall approximates 36 inches a year, an 8-inch tile with a fall of 2 inches to 100 feet will furnish an outlet for the complete drainage of 40 acres, a 7-inch for 30 acres, a 6-inch for 19 acres,

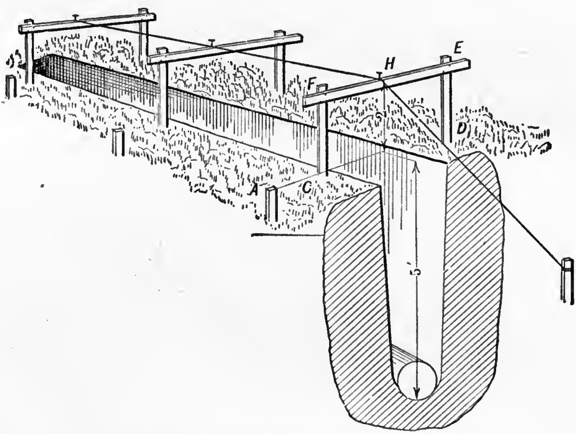


Fig. 46.—Staking Out and Laying Tile.

a 5-inch for 10 acres, and a 4-inch for 6 acres. On stiff soils with equal rainfall the same-sized outlets will be found adequate, but on the level soils of the South Atlantic and Gulf States, where the rainfall is heavier, only about three-fourths of the area can be drained with the same sized tile."

Laying the Tile.—To be of service the tile should be true to line and grade. Therefore, the line of the ditch should be carefully staked and the grade established. As much fall as possible should be given; the faster the flow of water the less likely is the pipe to silt up. A fall of less than 3 inches to 100

[1] A. G. Smith, Farmers' Bulletin 524, U. S. Dept. of Agri.

feet will require very careful leveling. A fall of 3 inches to 100 feet for tile 4 inches or larger will clear itself of silt or fine sand. Short sections of tile with frequent outlets, if possible, will be found better and cheaper than long sections, as smaller tile set shallower may be used.

Having staked the line and definitely marked the grade (which may be done a little to one side of where the actual digging is to take place) cross-bars should be erected opposite the stakes over the line of the ditch about every 50 feet.

To do this, drive uprights *CF* and *DE*, Fig. 46. With a spirit level mark a line at *C* on a level with the grade mark on

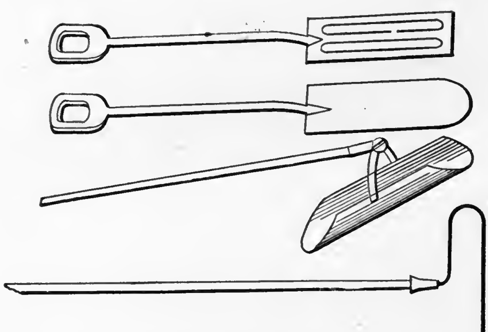


FIG. 47.—Tools Used for Laying Tile.

A, usually the top. Measure up to a point *F*, such that *FC* plus the cut marked on the stake will be exactly 7 feet when the tile is to be laid 5 feet deep. Tack the cross-bar *FE* at this point, level it and nail at *E*; locate *H*, the center line of pipe, by hanging a plumb-bob along the bar until its line is the right distance from the tack in *A*. Drive a nail at *H*.

Unless much ditching is to be done, when a machine may be used, the excavating will be performed with tiling spades. These are from $5\frac{1}{2}$ to 6 inches wide and about 18 inches long. A careful digger can so use this spade if the soil has the right moisture, neither too wet nor too dry, that there will be little crumbling and the ditch dug will be about 16 inches deep. An ordinary shovel can be used to remove the crumbs. A second spading will double the depth. Sometimes the last spade used has a round end, the spader finishing his ditch to within 1 or 2 inches of the required depth. The last earth is removed with a tiling scoop, leaving the bottom round and true for laying the tile, Fig. 47. A light pole or rod is used by the workman for measuring down from a line stretched over the cross-bars held from slipping sideways by the nails and fastened to stakes at the side of the ditch, Fig. 46. The scoop is attached to the handle, at an angle so that it can be used without standing in the ditch. Standing or walking in the finished ditch is to be avoided. Small tile are placed in position by means of a hook.

Both digging and laying the tile should begin at the outlet.

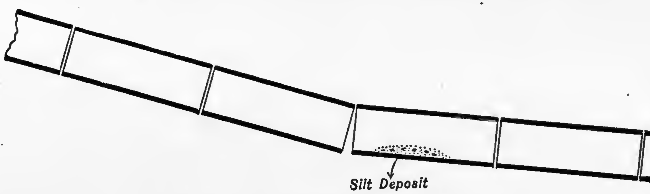


Fig. 48.—Effect of Changing Grade

The laying done as soon as practicable after the digging. Extra work of cleaning the ditch is thus avoided. The tile should be turned until the joint is close at the top; large cracks should be covered with broken tile or canvas; misshaped and cracked tile should be discarded; sharp turns and angles should be avoided; and connections made with "Y's" and not "T's." Change from a steep to a less steep grade should be avoided because the swifter water on the steep grade will carry particles which will be deposited on the less steep grade, Fig. 48.

After the tile are laid and inspected, they are "primed" by cutting off a little earth from the ditch side with a spade and tamping it gently about the tile so they will not get out of line. The upper end of a line of tile should be plugged to prevent its filling with earth.

Filling the Ditch.—The earth is usually filled in directly upon the tile, but if the soil is close-grained or compact drainage may be assisted by putting in first some porous material, such as broken rock, brick or gravel. However, in most soils this will not be necessary as the water will eventually carve out runways for itself; the drainage of a line of tile improves with age.

A plow attached to a long evener so that one horse may walk each side of the ditch can be efficiently used. The ditch

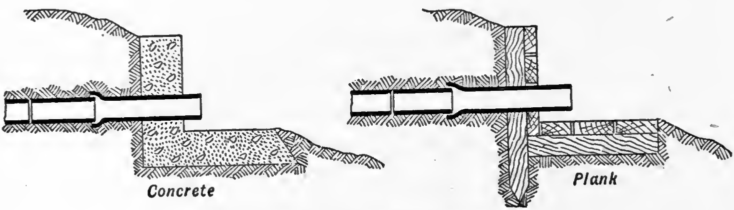


FIG. 49.—Outlet Protection.

can be filled with a team and scraper. Filling by hand is, of course, possible, but much more expensive.

Outlets.—The outlet of a line of pipe should always be protected, Fig. 49. A concrete wall makes the best comparatively cheap protection. Stone, brick and timber may also be used. Or a long section of corrugated galvanized iron pipe will stick out far enough to prevent caving under. Wire netting can be

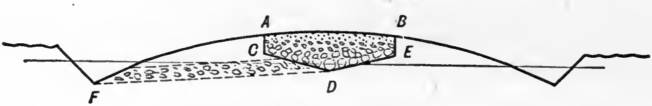


FIG. 50.—V-Drain

used to prevent small animals from entering. If the mouth becomes submerged a valve may be provided to prevent the water and silt from backing into the drain.

V-Drains.—Sometimes V-drains are constructed under the center of a road by excavating a V-shaped trench *ABCDE*, Fig. 50, and partially filling it with boulders, field stones, broken rock, or gravel. The earth may be pushed over to the shoulders of the road, by loosening with a plow and using the blade grader. Stones not exceeding 12 inches in diameter are placed in the bottom of the excavation, with the largest stones under the center, diminishing toward the sides. These are rolled and the drain completed by smaller stones and coarse gravel on top, the surface being parallel to the finished roadway. Before final surface material is applied suitable outlets *DF*, Fig. 50, should be built through the shoulders at intervals of not more than 200 feet, and especially to low points where the water may drain from the right of way. These outlets are filled with stone and gravel about 3 feet wide and deep enough to permit the escape of the water from the V-drain.

Where stones suitable for building V-drains are not available coarse clean gravel may be used and a 4-inch land-tile pipe placed at the bottom. Outlets are made by using Y's and the same sized tile. Outlets should preferably not be at right angles to the roadway but diagonally down to the grade. The joints of drain-tile thus used should be wrapped with canvas or burlap to prevent the entrance of fine sand or silt.

Draining Ponds.—Lines of tiling placed in the pond give best results. Wells bored in the pond through the impervious bottom to porous subsoil have been found to be temporarily effective.

Water Courses.—It will sometimes be advisable to turn a water course to save the building of a bridge or bring it to a safer or more convenient position. The size of such ditch can ordinarily be judged by the size of the original water course, remembering that if the stream be straightened the grade will be steeper and the water run faster. If the area of the land drained through this ditch is known the table heretofore given in this chapter will assist in ascertaining the size.

The quantity of earth excavated from such ditches may be calculated by averaging end sections just as is done in figuring quantities in embankment and in excavations.

Résumé.—It must be remembered that the object of drainage is to remove the water from the roadway so quickly that it will not soften the surface. This is accomplished by crown and side ditches. The water plane beneath the roadway must be so far from the surface that the " roof " of the road will not break in. In most places this will be so naturally and no special under-drainage will be necessary. If the natural condition of the subsoil is not sufficiently dry provision must be made for sub-drainage, or for raising the surface by grading above the waterplane. An embankment thrown up through a short valley will in addition to accomplishing this object often reduce the gradient of the road. Good judgment based upon local conditions surrounding the particular case in hand must always be exercised.

CHAPTER V

CULVERTS AND BRIDGES

Most of the States have highway departments which prepare standard plans and specifications for culverts and bridges. Where these are obtainable they should be used. In this chapter, therefore, only a few plans will be submitted; nor is it the intention to go into detail of methods of calculating stresses in such structures.

Definition.—Originally the word culvert was applied to a small covered drain or water way under a road, street or canal, while bridges were structures built over streams, streets, or canals. Now the term culvert seems to be applied to the smaller of such structures, and bridges to the larger; where one ends and the other begins is not very definitely defined. The Colorado Highway Commission says, "Clear spans of 10 feet and over are referred to as bridges; all under 10 feet, as culverts."[1] The Wisconsin Highway Commission classifies all waterway structures 6 feet and under as culverts. It might be well to make 16 feet the dividing line.

Size of Waterway.—The size of the opening under a bridge or through a culvert is usually spoken of as the area of the waterway. In determining this, first, existing openings, if there are other bridges upon the same stream, should be observed; second, evidences of high water such as drift, and the testimony of residents should be taken; third, formulas for openings may be applied "as a guide to judgment" after noting the character of the topography of the country, area drained, heaviest rainfall, and peculiar local conditions. Sometimes, though not considered the best practice, the water may be allowed to dam

[1] Bulletin No. 4, Colorado State Highway Commission.

up back of a culvert, the increased pressure thus obtained hastening the flow of the water. Care must be taken that this will not damage the highway or surrounding property. It may not always be wise to provide for extreme cases of high water that have occurred only once in a generation; it may be cheaper to risk the washing out of a road or culvert.

Fig. 51 is a plot of Talbot's formula for the area of waterways, which is

Area in square feet $= C\sqrt[4]{(\text{drainage area in acres})^3}$ in which C is a constant depending on the slope, varying from $\frac{1}{6}$ to 2.

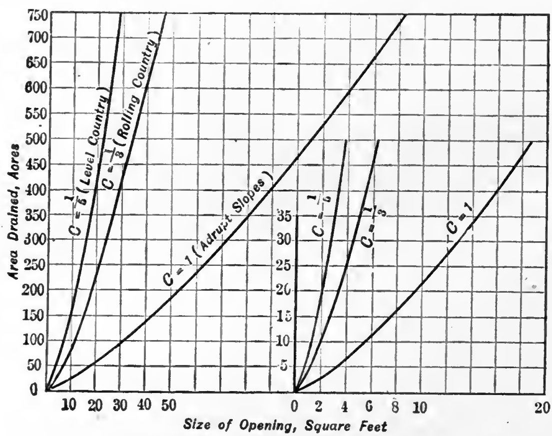


FIG. 51.—Talbot's Formula for Waterway Openings.

The Burlington railway for the so-called Prairie States uses the McMath formula in this form:

Area in square feet $= 0.20625\sqrt[5]{15\ (\text{drainage area in acres})^4}$ for a drainage area of less than 640 acres; when the area is more than 640 acres the formula.

$$\text{Area in square feet} = \frac{300\ (\text{drainage area in sq. mi.})}{3+2(\sqrt{\text{drainage area in sq. mi.}})}.$$ [1]

Design.—The design of the bridge or culvert must be suit-

[1] For a digest of this subject see Proceedings Am. Ry. Eng. Assn., Vol. XII, Part 3, page 470.

able for the location and its character will depend upon local conditions as to traffic, desires of users and other considerations. For very large bridges a competent engineer should be consulted. It is not the intention here to enter into the discussion of such structures.

Temporary and Emergency Structures

Where traffic will not warrant, nor time permit, where materials are not available for more permanent structures, temporary culverts and bridges must be built.

Wooden Box Culverts.—Two plans for these are sketched.

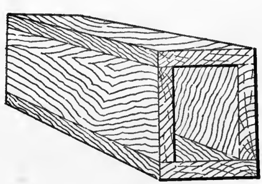


Fig. 52.—Plank Culvert.

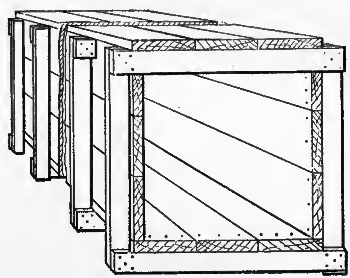


Fig. 53.—Wooden Box Culvert. Up to 4′ Square, 2″×4″ Stiffening Forms and 2″×12″ Plank are Suitable.

Fig. 52. Made of 2×12-in. plank nailed together, giving a 10×12 opening.

Fig. 53. This box culvert can be made any size by using a proper number of stiffening forms. As illustrated it is built of 2×12-inch plank and 2×4-inch forms. The forms should be spaced from 2 to 3 feet apart and the planks well nailed that the pressure of the earth may not push them off.

High-water Low Bridge.—Sometimes when a bridge is out of commission it is necessary to put in a temporary bridge to accommodate traffic until the regular bridge can be repaired. A low bridge under which all the water cannot pass in case of a hard rain can quickly and easily be made by throwing two or more stringers across the stream and nailing some plank on them. If the up-stream side of the bridge be made about 6 or 8 inches lower than the down-stream side the pressure of the water when it flows over the bridge will prevent it from going out. As a precautionary measure, solid stakes should be driven at the ends of the stringers and these securely wired or nailed to them. If long stakes are set to show the position of the roadway, this bridge may be used as a ford in case of high water.

Pile and Stringer Bridge.—This is a common type of bridge in the Middle West. The trestles are made by driving four

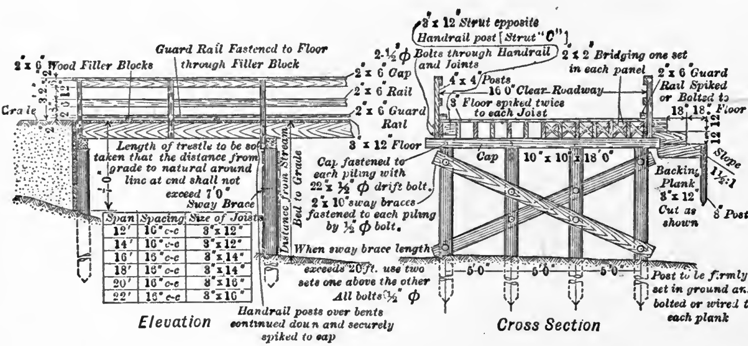


Fig. 54.—Pile Highway Bridge after Plan by Iowa Highway Commission.

piles in line across the road space, sawing them off at exact elevation, and fastening on a cap of heavy timber with driftbolts. Joists are then placed from trestle to trestle and the planks nailed thereto. This is finished with a guard rail. When the piling are exposed for a distance of 8 feet or more they should be sway-braced by bolting two 2×10-inch planks to the piles. If the diagonal distance from cap to ground is more than 18 feet, two or more sets of sway-bracing should be used, Fig. 54.

The bearing power of piling may be obtained by the common formula

$$\text{Safe load in pounds} = \frac{2Wh}{S+1}.$$

in which W represents the weight of pile driver hammer in pounds;

h, the fall of the hammer in feet;

s, the average penetration of the pile in inches the last three or four blows.

EXERCISE

Find the safe load of a pile which is lowered $\frac{1}{2}$ inch by a 20-foot fall of a 1500-pound hammer. *Ans.* 20 tons.

White oak and red cedar piling are considered to be best; for floors, oak or fir; other parts, fir, spruce, or yellow pine. Timber should be uniform in quality, sound, free from large season checks, heart shakes, or large loose knots. When such bridges are more than 30 feet high the cost of the necessary long piling becomes excessive.

More Permanent Structures

Cast-iron, wrought-iron, "ingot iron" and low-carbon low-manganese steel are used for road culverts.

Cast-iron is made up in different forms. Fig. 55 shows four kinds of cast-iron culverts. Cast-iron makes a very durable culvert and were it not for high cost of freight due to its weight would be much more extensively used.

Corrugated Iron and Steel Plate.—Many culverts such as shown in Fig. 56 are now in use. Corrugating the plate stiffens it so that if covered with earth to the depth of the diameter of the pipe it will sustain any ordinary load. Where these are made up of wrought iron, "ingot iron" or low-carbon low-manganese steel, they will last indefinitely. Should one ever show signs of rusting through, it may be used as a form for building a concrete pipe over and around it. Steel which has a high percentage of carbon, manganese or any other impurity should not be used as a culvert, for it will soon corrode. Corrugated iron culverts are comparatively light, so by making them up in sections and nesting them a great many feet may be placed in a car load. Fig. 56 shows various kinds.

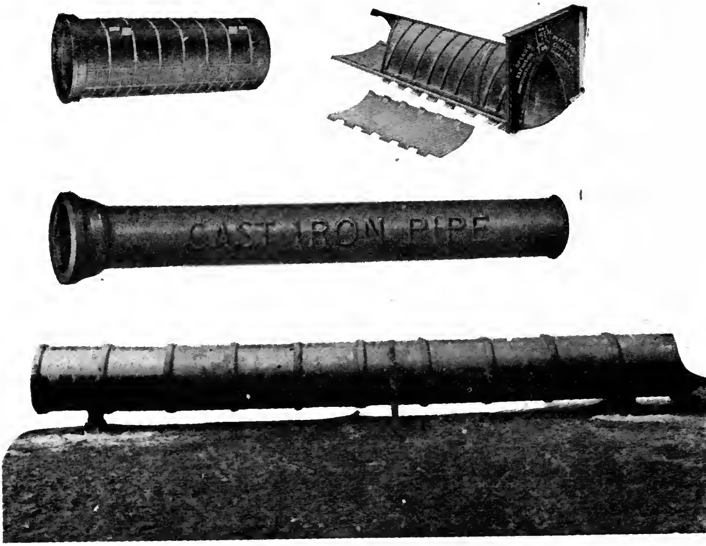


FIG. 55.—Cast-iron Culverts.

FIG. 56.—Sheet-metal Culverts.

The outlet end of all pipe culverts should be carefully protected if there is any likelihood of washing. Boulders, logs, planks, concrete are some of the means of protection.

Vitrified Clay Pipe.—The formula given by the Iowa State College [1] for the weight of the filling on a drain tile and the specifications of drain tile by the American Society for Testing Materials [2] may be used for pipe culverts. Fig. 57 shows the ordinary supporting strengths of drain tile necessary for the

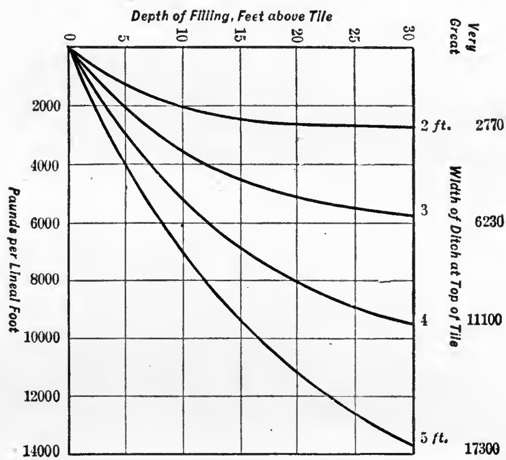


Fig. 57.—Standard Ordinary Supporting Strength of Drain Tile Wet Clay Filling Material.

depths and widths of ditches given. The seller of pipe should guarantee that they will comply with A. S. T. M. specifications.

In laying the pipe the socket end is toward the inlet and the bell toward the outlet. The joints may be cement filled to prevent water leaking through and softening the foundation.

Cement Pipe.—These are used the same as clay or cast iron and of course must stand the same loads. Large-sized cement pipes usually have their ends beveled so they will fit into each

[1] Iowa State College Engineering Experiment Station Bulletins Nos. 31 and 34.

[2] A. S. T. M. Standards, 1916, p. 452.

other, the better to maintain alignment. The larger sizes should be reinforced with steel bars. Several kinds of forms for making cement pipes are on the market. Some counties are employing their indigent men to manufacture the pipes during the winter months. By summer the pipes have cured and are ready to be hauled to place and set in the roadway. Concrete pipe should not be used where there are large quantities of alkaline salts that have a tendency to disintegrate Portland cement concrete.

Twin Pipe Culvert.—When one pipe is not large enough to convey all the water another may be installed beside it making a twin pipe culvert, the end protection being lengthened accordingly.

Foundation.—It is essential that all types of culverts have

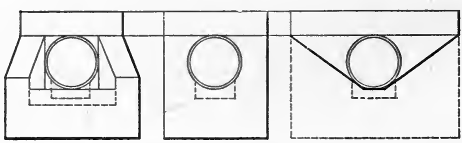


Fig. 58.—Culvert End Protection.

good foundations. Where the soil is mucky or soft a concrete bed extending about one-fourth the height of the pipe is recommended. Back-filling should be carefully tamped in about the pipe to prevent undue settlement.

End Protection.—Head walls are more important with jointed clay and concrete pipes than with long corrugated or cast-iron pipes. Fig. 58 shows forms of head and wing wall protection.

Where the embankment above a culvert is not great the head wall may be built parallel to the line of the road. Where there is an embankment, the length of the culvert may be cut down by building wing walls. Economy and space for water will often determine which should be used. Concrete lends itself well to the building of such protection heads; brick, stone or wood may also be used with success.

Intake Drop.—Where it is difficult to get sufficient depth of roadway over the culvert, or the conformation of the ground demands the culvert is sometimes dropped and an intake constructed on the upper end. This is an open box of concrete or masonry and is not difficult to make, Fig. 59.

Box-culverts.—A small culvert having a rectangular opening

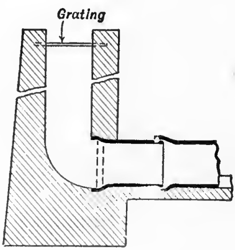


FIG. 59.—Intake Drop.

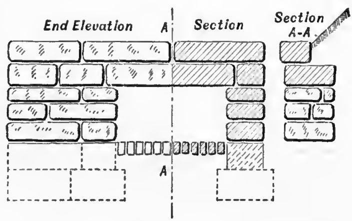


FIG. 60.—Stone Box Culvert.

is called a box-culvert. Most any material or combinations of materials may be used for such culverts. Already wooden types have been shown, Figs. 52 and 53.

Where stone of suitable kind is plentiful, small culverts may be built as shown in Fig. 60. Masonry walls are built

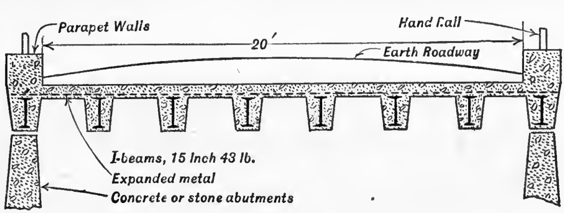


FIG. 61.

I-beam Culvert. Eight 15-inch 43-lb. I-beams, 27 ft long, will be needed for a 24 ft. span. Expanded metal reinforcing to be used above the beams.

upon each side and capped by large flat stones. The thickness of the cap stones should not be less than 12 inches for openings of 4 feet. Since large cap-stones are often difficult to obtain, reinforced concrete slabs have been used for this purpose. Rubble masonry or concrete walls may be spanned by steel

I-beams to support a thin concrete slab for floor, Fig. 61. In New York State such slabs are made 6 inches thick. The weight of the roof and load is carried by the I-beams.[1]

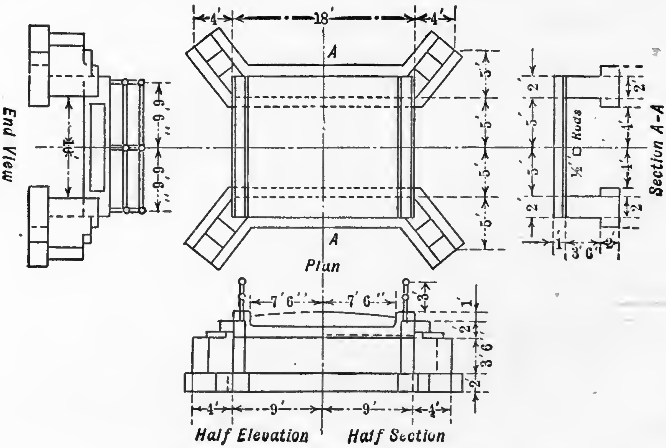


Fig. 62.—Concrete Box Culvert.

Concrete Box Culverts.—Nearly every State has its standard forms for concrete box culverts. Fig. 62 shows a typical form after a plan prepared by the U. S. Office of Public Roads.

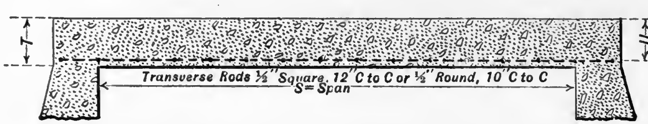


Fig. 63.—Reinforced Concrete Slab Culvert, Floor Dimensions.

Fig. 63 and table following show the thicknesses and other dimensions of floor slabs. The data and calculations are from the publications of the office of Public Roads, U. S. Department of Agriculture.

[1] For descriptions of I-beam and other culverts, see U. S. Department of Agriculture Bulletins: No. 43, "Highway Bridges and Culverts"; No. 45, "Data for Use in Designing Culverts and Shorts-pan Bridges."

Reinforced Concrete Floor Slab Dimensions

Assumed Data: 1 : 2 : 4 Concrete; Deadload 700, Live Load 470 lb. per Sq. In., Modulus of Elasticity: Concrete, 900,000, Steel, 30,000,-000 lb. Per Sq. In.

Span, feet	Thickness, Inches		Lengthwise Reinforcing Rods, Inches			
	T	*U*	Square	Spacing	Round	Spacing
2	6	4½	½	8	½	6
3	7	5½	½	6	½	5
4	7½	6	½	5½	⅜	7
5	8	6½	½	5	⅜	6
6	9	7½	⅝	7	¾	8
7	9½	8	⅝	6½	¾	7
8	10½	9	⅝	5¾	¾	6½
9	11½	10	⅝	5¼	¾	5¾
10	12	10½	⅝	5	¾	5¼
11	12½	11	¾	6¾	⅞	7¼
12	13½	12	¾	6¼	⅞	6¾
13	14½	12½	¾	6	⅞	6¼
14	15½	13½	¾	5½	⅞	6
15	16	14	¾	5¼	⅞	5¾
16	17	15	¾	5	⅞	5¼

Detailed Method of Constructing Concrete Culvert

These culverts are especially adapted to flat country where the head room for arches cannot easily be obtained.

The wooden forms for their construction are simple, Fig. 64. Two-inch lumber dressed on the face side and edges should be used for the sides and top. If a small trench is dug the earth may be used for the outside form, otherwise boards may be set up and braced to position. These may be given a batter if desired.

The bents may be made of 2×4's nailed firmly together and placed 3 feet c. to c.; 2×6's are well adapted for sides and cover. Only a few nails and these in small sizes should be used in the boards on the sides. Tops will need none whatever. Centering, of course, should be made strong. The wedges should be of hard lumber, smoothed. After the forms are braced and blocked in position, they may be painted with oil or greased with soap or hard-oil; this will prevent the concrete from sticking, facilitate the removal of the forms and give a smoother and better appearance to the work.

The concrete should be deposited with care, so that the aggregate and mortar will not separate, and spaded thoroughly

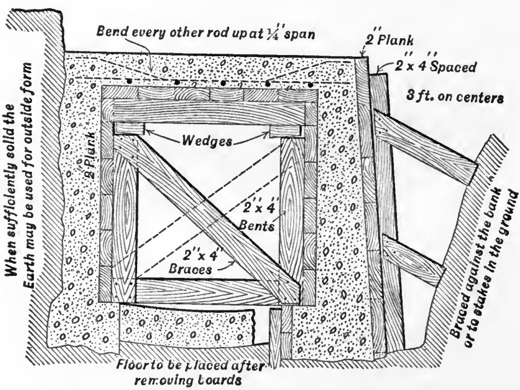


Fig. 64.—Box Culvert Forms.

against the forms. A flattened shovel or a broad sharpened chisel shaped on one side may be used for this by pushing it down next the plank and prying the coarse aggregate away from the form. The concrete should be plastic and tamped until it quakes. Some engineers prefer a slushy mixture so that it will flow to place, especially is this true if reinforcing rods are to be used. This is not recommended because excess water weakens concrete. In placing the concrete it is well to carry it up equally at all parts in order that the water will not drain off and take with it the cement, and that stresses may be equalized. If it is impossible to do this the work should be divided into sections and each section completed without interruption.

Vertical joints which will key into each other should be provided at the ends of the sections. This may be done by inserting a piece of 4-inch timber 6 or 8 inches wide against the end wall and withdrawing it after the concrete has set and before beginning the next section. Whenever the depositing of concrete has been interrupted the surface of the old concrete should be thoroughly wetted and a grout of water and cement mixed to a creamy consistency applied just before depositing the new concrete. Any "laitance," a whitish or yellowish deposit of fine particles of cement or silt separated from the concrete of the previous work, must be removed in order to secure a proper bond.

To remove the forms the wedges can be loosened; the centering, roof and sides will easily slip out. Forms should be left in until the concrete has hardened sufficiently to carry the loads that may come upon it. Twenty-eight days is considered a reasonable time for structures of considerable size. The forms may be removed from small culverts at a shorter period. In removing forms great care should be exercised not to break off corners or projecting parts. Tapping or slipping the boards endwise, where that may be done, will prevent sticking and scaling or slabbing off. In panel work and other irregular surfaces extreme care should be exercised in greasing the forms before depositing the concrete.

Head and Wing Walls.—For small culverts a protecting wall is usually erected parallel to the roadway of such length as may be thought necessary. The length will depend upon the height and character of the embankment, as well as the size of the culvert.

Slab-bridges.—When the span is lengthened on such culverts as last mentioned they become slab-bridges. For spans up to 20 feet the flat type of slabs is applicable. They are economical to construct and furnish a bridge well adapted to the more or less level country of the Prairie States. The waterways are adequate and the horizontal lines blend in with such landscapes admirably. The side walls of the bridge besides forming parapets, also are used as girders to strengthen it.

Fig. 65 shows the standard designs for slab culverts and bridges adopted by the Virginia State Highway Commission. The accompanying table gives the amount of reinforcement used in these bridges.

Arch Culverts.—The arch furnishes a type of bridge or culvert which is extremely attractive; when properly made is strong and durable and has a large opening for the discharge of water. It is especially appropriate in deep depressions or

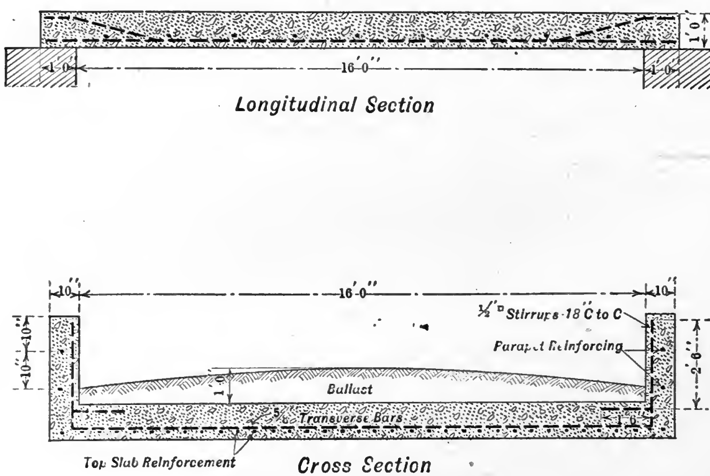


Fig. 65.—Typical Reinforced Concrete Slabs for Highway Culverts, Office of State Highway Commission, Richmond, Va.

ravines or under high fills on account of abundance of head room. Here, too, it harmonizes well with the landscape. The arch culvert should only be erected on the best of foundations for any yielding there will loosen the parts and destroy the arch. Stone and brick have long been used for such culverts. Of late years concrete has largely superseded these materials on account of its conformability to local conditions, its comparative cheapness and, in the reinforced variety, its ability to withstand tensile as well as compressive stresses.

TABLE SHOWING REINFORCEMENT OF THE VIRGINIA STATE HIGHWAY COMMISSION'S STANDARD CULVERT SLABS

Span	Thickness	Top Slab Reinforcement				Transverse Reinforcement			Parapet Reinforcement				Stirrups				Quantities	
		Size	Space	Length	No.	Size	Length	No.	Size	Space	Length	No.	Size	Space	Length	No.	Concrete Cu. Yds.	Steel Lbs.
2	5″	⅝″	8″	4′ 6″	26	⅝″	21′ 3″	2	½″	10″	9′ 6″	4	½″	18″	4′ 0″	6	1.70	247.5
4	6″	¾″	8″	6′ 6″	26	⅝″	21′ 3″	3	½″	10″	6′ 6″	4	½″	18″	4′ 0″	8	2.88	456.8
6	7″	¾″	6″	8′ 6″	35	⅝″	21′ 3″	4	½″	10″	8′ 6″	4	½″	18″	4′ 0″	10	4.26	744.0
8	8″	⅞″	7″	10′ 6″	30	⅝″	21′ 3″	5	½″	10″	10′ 6″	4	½″	18″	4′ 0″	12	5.99	1036.6
10	9″	⅞″	6″	12″ 6″	35	⅝″	21′ 3″	6	½″	10″	12′ 6″	4	½″	18″	4′ 0″	16	7.73	1403.7
12	10″	⅞″	6″	14′ 6″	35	⅝″	21′ 3″	7	½″	10″	14′ 6″	4	½″	18″	4′ 0″	18	9.75	1627.5
14	11″	1 ″	7″	16′ 6″	30	⅝″	21′ 3″	8	½″	10″	16′ 6″	4	½″	18″	4′ 0″	20	11.99	2032.9
16	12″	1 ″	6″	18′ 6″	35	⅝″	21′ 3″	9	½″	10″	18′ 6″	4	½″	18″	4′ 0″	24	14.51	2600.0
18	13″	1 ″	6″	20′ 6″	35	⅝″	21′ 3″	10	½″	10″	20′ 6″	4	½″	18″	4′ 0″	26	17.25	2889.8
20	14″	1⅛″	6″	22′ 6″	35	⅝″	21′ 3″	11	½″	10″	22′ 6″	4	½″	18″	4′ 0″	30	20.22	3875.2

All concrete 1 part No. 1 Portland cement, 2 parts sharp, clean sand and 4 parts of broken stone, sizes ¼″ to 1″. Reinforcement of structural steel square bars of sizes shown. Every alternate bar bent up as shown. All bars except Stirrups and Transverse bars to be bent 3-inch at each end in addition to bending of alternate bars. All Transverse Bars to be bent up 2 feet 5 inches at each end and into Parapet as shown. Specifications, Virginia State Highway Commission, 1909. Capacity: 12-ton Roller.

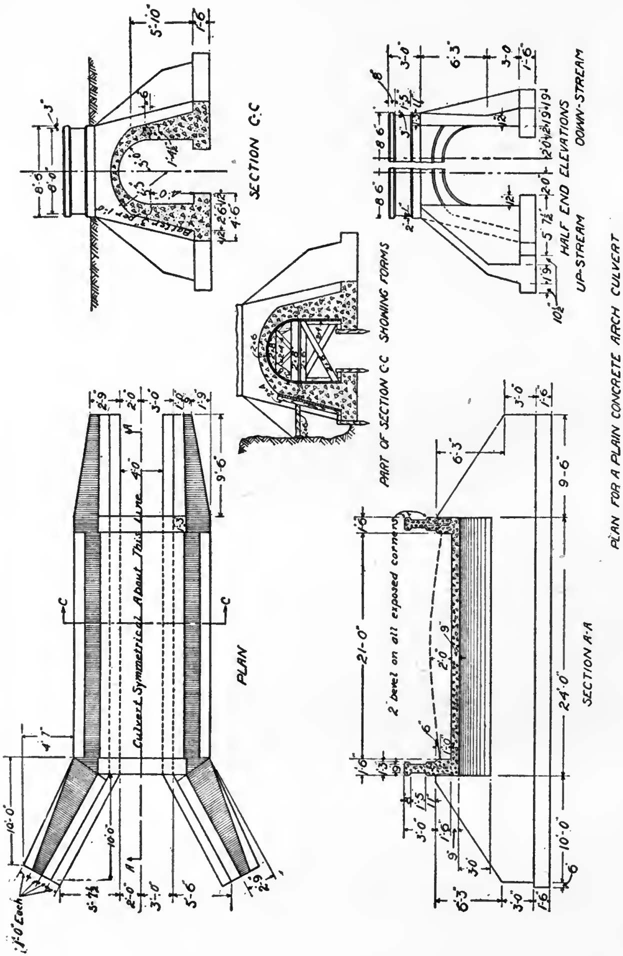


Fig. 66.

Plan for a Plain Concrete Arch Culvert. Span 6 feet. Office of Public Roads. U. S. Department of Agriculture.

Fig. 66 shows a form of arch culvert designed by the U. S. Office of Public Roads, Bulletins Nos. 39 and 43. For this culvert the following quantities will be required:

Concrete, arch and parapets (1 : 2 : 4)	12.9 cu. yds.
Concrete, side, end and wing walls (1 : $2\frac{1}{2}$: 5)	39.8 cu. yds.
Concrete, footing (1 : 3 : 6)	20.1 cu. yds.

This will take

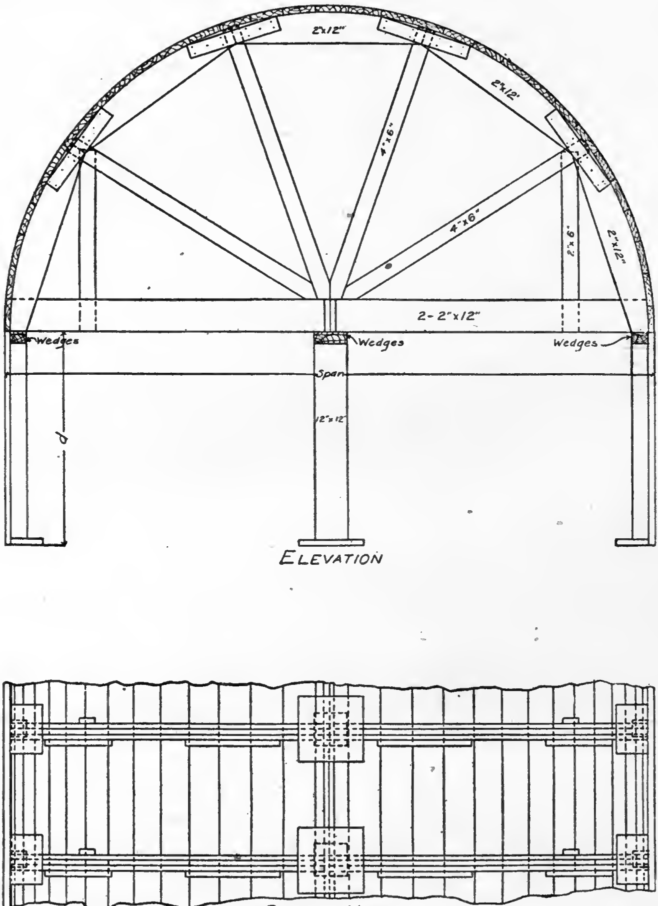
102 barrels cement.
33 cubic yards sand.
66 cubic yards stone or gravel.

If a floor is wanted below the waterway the material for this must be added, and mixed the same as the footings. The footing and floor concrete should be deposited first and the forms for the arch erected on this.

Forms.—Fig. 67 shows a method of placing the centering for a concrete arch bridge. This must be well and strongly made for much weight will come on it while the concrete is green. The ribs in Fig. 67 are spaced every 4 feet, supporting 2×6-inch lagging, and rest upon wooden posts. The wedges are hard wood and smooth. Safe removal of the centering depends upon the proper driving of the wedges. Spandrel and guard rail forms may be built at the same time that the arch ring centering is placed. To prevent the concrete sticking to the forms they should be treated with a coating of soap or grease.

Removing Forms.—In striking the centers, the wedges under the crown should be removed first, in order that the strains may be equalized under the two sides of the arch. The arch centers should be left in place until the concrete is sufficiently hard to hold its weight and that of the superimposed roadway and will not chip or crumble in removing the forms. The Iowa Highway Commission requires a minimum time of three weeks. The Portland Cement manufacturers think it should not be less than four weeks in good drying weather, and longer in cold or wet weather, the latter being unfavorable to the hardening of the concrete.

Fig. 68 shows a plain culvert, somewhat between an arch and a box, designed by the Minnesota Highway Commission. There is an accompanying table of dimensions.



CENTERING FOR CONCRETE SEMICIRCULAR BRIDGE

FIG. 67.—Cross-section.

Guard Rails and Parapets.—It is becoming quite popular to run the concrete sidewall above the culvert far enough to

TABLE OF DIMENSIONS FOR PLAIN MINNESOTA (ARCH) CONCRETE CULVERTS.

Sizes 2×2 Feet, to 4×4 Feet.

W	*H*	*A*	*B*	*C*	*D*	*E*	*F*	*I*	*K*	*M*	*N*	*T*
2′ 0″	2′ 0″	1′ 0″	0′ 8½″	1′ 2″	5′ 5″	3′ 0″	1′ 2″	0′ 6″	0′ 6″	0′ 8″	0′ 8″	0′ 8″
2′ 0″	2′ 6″	1′ 0″	0′ 8½″	1′ 2″	5′ 3″	3′ 6″	1′ 4″	0′ 6″	0′ 7″	0′ 8″	0′ 8″	0′ 8″
2′ 6″	2′ 6″	1′ 2″	0′ 9½″	1′ 3″	6′ 5″	3′ 6″	1′ 5″	0′ 6″	0′ 7″	0′ 8″	0′ 8″	0′ 9″
2′ 6″	3′ 0″	1′ 2″	0′ 9½″	1′ 3″	6′ 5″	4′ 0″	1′ 7″	0′ 6″	0′ 8″	0′ 8″	1′ 0″	0′ 9″
3′ 0″	3′ 0″	1′ 4″	0′ 10½″	1′ 4″	7′ 5″	4′ 0″	1′ 8″	0′ 7″	0′ 8″	1′ 2″	1′ 0″	0′ 10″
3′ 0″	3′ 6″	1′ 4″	0′ 10½″	1′ 4″	7′ 5″	4′ 6″	1′ 10″	0′ 7″	0′ 9″	1′ 2″	1′ 0″	0′ 10″
3, 6″	3′ 6″	1′ 6″	0′ 11½″	1′ 5″	8′ 5″	4′ 6″	1′ 11″	0′ 7″	0′ 9″	1′ 2″	1′ 4″	0′ 11″
3′ 6″	4′ 0″	1′ 6″	0′ 11½″	1′ 5″	8′ 5″	5′ 0″	2′ 1″	0′ 7″	0′ 10″	1′ 2″	1′ 2″	0′ 11″
4′ 0″	4′ 0″	1′ 8″	1′ 0½″	1′ 6″	9′ 5″	5′ 0″	2′ 2″	0′ 8″	0′ 10″	1′ 2″	1′ 8″	1′ 0″

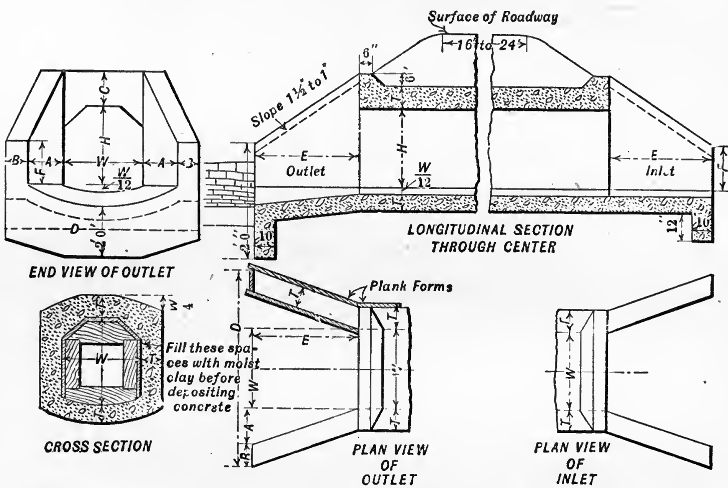


Fig. 68.—Concrete Culverts Designed by the Minnesota State Highway Commission.

furnish a guard rail. Some of the plans show this. Paneling these parapets helps the esthetic features of the bridge. The parapets also serve in flat slab construction as girders.

Gas-pipe guard rails are also used. These are made up, set in the forms and cast into the concrete of the side walls. Objection is made to pipe rails on account of weakness and lack of visibility.

For larger bridges the services of a competent bridge engineer should be secured.

Fords.—Where streams, irrigation canals, or other water channels are shallow, or only occasionally carry water, the bridge is sometimes omitted and the crossing made by wading. This requires a hard bottom such as gravel or sand. Where the bottom is muddy, as in some of the Western States, the roadway has been paved with concrete. The slab of concrete

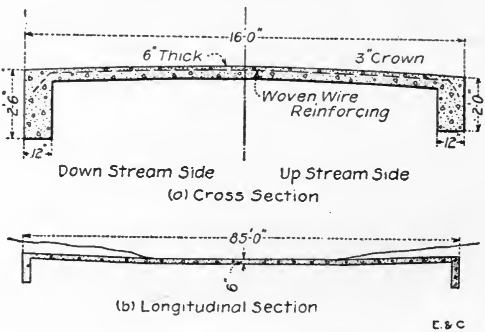


Fig. 69.—Concrete Ford.

about 6 in. thick is laid directly on the bottom and protected from washing beneath by sheet piling, or by extending the concrete downward, a foot or so, on the sides, Fig. 69. In other cases planks lashed together with wires have been anchored so that under a light load they will float on the water, thus allowing a foot passenger or a small animal to cross without wetting the feet, and under a heavy load sink to the bottom, forming a solid and secure roadway. Fords are now frequently used in parks to create variety in the road scenery.

CHAPTER VI

EARTH ROADS

It has already been stated that a large percentage of all our roads are of the type known as earth roads. And since this must perforce remain so for many, many years it is well to study the construction and maintenance of such roads. "Earth," the natural soil, consists of a mixture of clay, sand, and organic matter. It absorbs water readily and when moistened has little power to withstand pressure, but when drained to the proper consistency, will bear loads of 1 to 4 tons per square foot of surface area without very great depression.

The kinds of "earth" vary from almost pure clay to pure sand. But for the purposes of classification, roads which are practically all clay or all sand are spoken of as clay or sand roads respectively. And those composed of loam, which is a mixture of these elements with organic matter, as earth roads.

Clay is decomposed and hydrated rock. The particles are extremely small and have great affinity for water. When moistened to just the right consistency, clay is almost perfectly plastic,[1] with less water it becomes sticky, stiff and finally loses its plasticity, becomes brittle, easily breaking up into a fine dust. By increasing the water the particles move freely, upon each other, as though lubricated, having little or no power to withstand an applied force.

Sand is a water worn detritus finer than, although similar to gravel. The main difference between sand and gravel is one of size of particles. While clay comes largely from those rocks which in the breaking down processes of nature change their chemical composition, sand is usually a more or less finely

[1] Flint clays do not have the property of plasticity.

divided rock which has not changed its chemical composition. Granites, gneisses, and other feldspathic varieties are the principal clay-forming rocks, while quartz bears the same relation to sand. Though the particles of sand have an affinity for water, they are also so much thicker than the film of water which covers them, that there is no slipping or flowing as with clay whose particles are much smaller than the thickness of the water film. A little water tends to bind particles of sand together. A committee of the American Society for Testing Materials has proposed the following definitions:

Clay.—Finely divided earth, generally silicious and albuminous which will pass a 200-mesh sieve.

Loam.—Finely divided earthy material containing a considerable proportion of organic matter.

Sand.—Finely divided rock detritus, the particles of which will pass a 10-mesh sieve and be retained on a 200-mesh sieve.

Silt.—Naturally deposited fine, earthy material, which will pass a 200-mesh sieve.

Gravel.—Small stones or pebbles which will not pass a 10-mesh sieve. The differentiation between gravel, sand, silt and clay should be made on the following basis:

Sizes of Particles.	*Name.*
Retained on a 10-mesh sieve	Gravel
Passing a 10-mesh and held on a 200-mesh sieve	Sand
Passing a 200-mesh sieve	Silt or Clay

Drainage.—Just what effect the organic matter and other impurities may have on the road-making qualities of the soil is not known. Some of them, no doubt, unite with the clay to form a slippery soapy mixture which prevents good bonding, others assist in the formation of a hardened surface. There is need of more study along these lines. But, according to present knowledge, the chief element which affects an earth road is water. With too much water, the road is soft and unable to bear up even a light load, "tracks" easily, then dries rough; with too little water, the soil on top pulverizes into a powdery dust under the action of the wheels, blows away leaving the road uneven or "choppy"; with just the right amount of water the road is reasonably hard, remains smooth, is dustless and comfortable to travel. Water, therefore, can be at once the enemy and the friend of the road. It is better to have too little than too much water. The general principles of drainage enunciated in Chapter IV apply with especial forcefulness to earth roads, and should at this time be reviewed carefully. It makes no difference whether in a valley or on a hill, an undrained earth road is always a poor road.

Alignment and Grades.—In laying out earth roads care should be taken to place them in the best location. While the effect of grades is not so noticeable on an earth road as upon a hard, smooth-surfaced road it, nevertheless, is noticeable and rise and fall should be avoided as much as good judgment will warrant. A road should always be built for the future as well as the present. A little extra work may remedy a bad place in the road which, if allowed to remain, would be a source of inconvenience and expense indefinitely.

Width.—The right of way in the Prairie States is usually 4 rods or 66 feet. There are, of course, many places where this amount is not needed. Likewise, there are many other places where it is all needed. Then it is never certain what demands the future may make. Many valuable pieces of public property have been given away only to be bought back at high prices subsequently. If the right of way is not needed and can be farmed by adjacent farmers to advantage, let the public officials lease definite portions of the land to the farmers at nominal rental prices but not give up the right to its future use should it be needed. Where farmers have been allowed to plant and crop the right of way without a definite contract there is a tendency to encroach too much, leaving the traveled roadway too narrow. In some localities, actions in court have been necessary to regain such ground, the owners of adjacent land claiming the roadway by right of adverse possession.

Any road having moderate travel should have at least 50 feet right of way; main roads having considerable travel as much as the traffic justifies even 100 or more feet. "In the Middle Atlantic States, the regulation width is 49½ feet for important roads and 33 feet for secondary roads. In recent years there is a tendency to increase the width, a minimum of 60 feet being preferred."[1]

According to the authority just quoted, Massachusetts' State-aid roads have a minimum of 50 feet, where there is no likelihood of an electric traction line, and with a trolley line 60 feet. Texas divided its roads into three classes having widths of 60, 30, and 20 feet. Nearly all Mississippi Valley States have either 60 or 66 feet. A few Western States have a right of way of 100 to 165 feet. In New Jersey the narrowest State-aid roads are 33 feet. In France roads are divided into four classes: National, 66 feet wide, the surface improved not less than 22 feet; departmental, 40 feet wide, improved surface, 20 feet; provincial, 33 feet wide, improved surface 20 feet; neighborhood roads, 26 feet wide, improved surface 16 feet. Main roads in England are 66 feet wide, improved surface 22 to 30 feet. On the whole 66 feet seems an admirable width. A road 66 feet wide contains 8 acres per mile of 5280 feet.

Clearing.—If brush or trees are upon the right of way, they must be cleared off and the roots grubbed out. The entire right of way is generally cleared and, if done by contract, at a certain fixed price per acre; $30 to $50 are average prices. Several kinds of stump pullers are on the market, but blasting is probably as cheap as any method of removing stumps. Small stumps and brush roots are removed by hand labor. Grubbing is usually paid for by the square of 100 square feet. For removing hedges or rows of trees along the road, the contractor is paid a specified price per rod. Stumps and roots need not be removed under fills, but trunks or branches of trees, brush or other debris should never be used in them.

Staking Out.—The staking out of a road varies greatly with the road. Some may require all that has been given in Chapter II. The minimum number will probably be two lines of temporary stakes set at each edge of the roadway to be graded. Others such as center line, slope stakes, bridge openings, reference stakes and so on may be added as required. The traveled roadway should, unless there are very good reasons for

[1] George D. Steel in "Better Roads and Streets," March, 1914.

changing, be staked out in the middle of the right of way. Care in this, having the edges straight, and other minor details add greatly to the attractiveness of the highway.

Width and Cross-section of Roadway.—The width across the ordinary road vehicle from center to center of tire, or gauge of the vehicle, in the Northern and Western States is 4 feet 8 inches; the width over all varies from 5½ to 7 feet. Vans, trucks and loaded hay-racks are from 7 to 10 feet wide. In a few of the Southern States a gauge of 5 feet is still in use. The maximum width and commonly traveled width of roadways measured in Massachusetts and printed in the report of the Massachusetts Highway Commission for 1900 is shown in tabular form below:

Width of road in feet...............	7	8	9	10	11	12	13
Number of roads found with above traveled width as maximum........	..	..	2	6	2	28	8
Number of roads found with above traveled width commonly used.....	12	17	25	32	10	30	3

Width of road in feet...............	14	15	16	17	18	19	20
Number of roads found with above traveled width as minimum........	23	30	8	1	23	1	10
Number of roads found with above traveled width commonly used.....	8	13	2	0	4	0	2

Width of road in feet...............	21	22	23	24	25	26	33
Number of roads found with above traveled width as maximum........	10	1	0	2	4	1	1
Number of roads found with above traveled width commonly used.....	0	1	0	0	1	0	00

Harger and Bonney [1] measured New York State improved roads and found heavy traffic checked well with the Massa-

[1] Highway Engineers' Handbook, p. 19.

chusetts results but that the maximum widths were greater, averaging from 18 to 21 feet; this they explained as due to increase of automobile traffic since the Massachusetts measurements were made 1896–1900.

From the above it would seem that 7 feet is the minimum allowable width. If this could be increased a foot on each side the traffic would not be confined to such narrow trackway and rutting would be greatly diminished. Where two lines of vehicular traffic is required, 16 feet should be the minimum, but for safety and ease of passing while traveling at some speed, 20 feet will be better. If the number of lines (lanes) of traffic

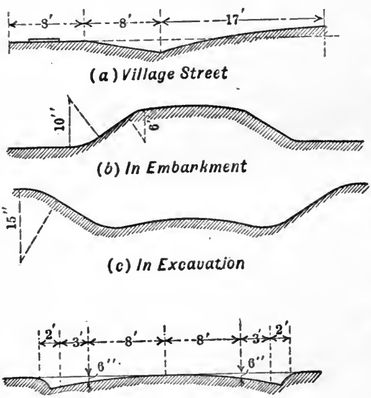


Fig. 70.

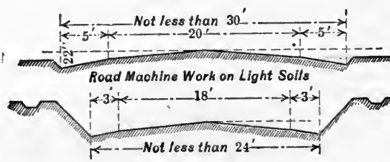


Fig. 71.

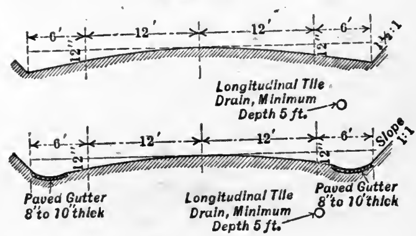


Fig. 72.

Typical Cross-sections.

it is desired safely to pass abreast be represented by n, the width in feet may be taken as

$$w = 10n.$$

Figs. 70, 71, and 72 show some standard cross-sections of earth roads as adopted by engineers and state highway commissions.

The following values for an earth road cross-section, Fig. 73, are suggestive:

A = width of traveled road = $10n$ feet;
n = integer, 1, 2, 3, 4, 5, 6; depending on traffic (lanes);
$B = 3\frac{1}{3}\sqrt{n}$ feet (in cuts or on high fills may be reduced $\frac{1}{2}$);
$C = 4n$ inches;
$D = 2B$ inches;
d = approximately $\frac{1}{16}A$; for level cross-sections.

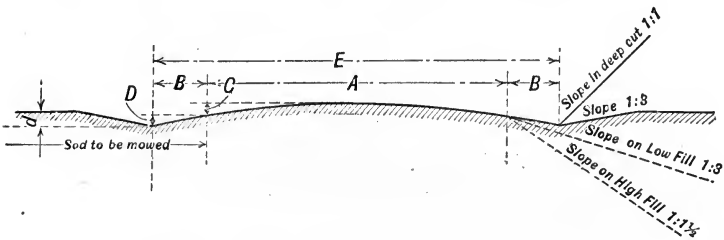


FIG. 73.—Typical Cross-section for Earth Road.

E = Width from bottom of ditch to bottom of ditch.
A = Width of Traveled Road = $10n$.
n = Interger 1, 2, 3, 4, etc., depending on traffic.
B = Width of Gutter = $3\frac{1}{3}\sqrt{n}$ ft. In cuts or on high fill may be reduced one-half.
C = Crown height = $4n$ inches.
D = Gutter depth = 2B inches.
d = Approximately $\frac{1}{16}$A for level cross-sections.

DIMENSIONS

n	A Feet	B Feet	C Inch	D Inch	E Feet
1	10	3.5	4	5	17
2	20	5	8	10	30
3	30	6	12	12	42
4	40	7	16	14	54
5	50	7.75	20	16	66
6	60	8.5	24	17	77

On a fill less than 4 feet high the slope of the bank may be 1 : 3, for greater fills 1 : 1½ with guard rails placed along the shoulder. In cuts slopes will depend on the character of the soil; for ordinary earth and clay 1 : 1 has proven sufficient. In a cut the depth of the gutter may be reduced to one-half the dimensions given in the table in order to lessen cost of excavation. On grades greater than 3 per cent, the slope of the crown may be increased slightly, and the bottom of the gutter paved with concrete, cobbles, broken stone, or brick. The width of a road should always be as narrow as the traffic will allow in order that the cost of construction and maintenance may be kept down. Few country roads, except near market centers, need to have a traveled way of more than 20 feet, or 30 feet from bottom of ditch to bottom of ditch.

Grading

The reduction of a roadway to conform to the grade (gradient) and cross-section suitable for use is called *grading.* In

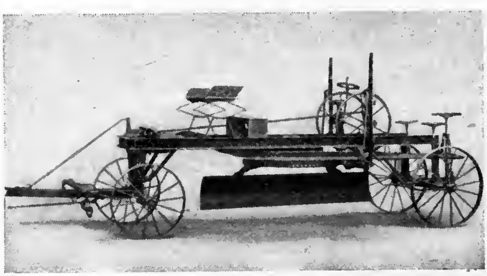


Fig. 74.—A Reversible Road Grader.

grading, the surplus earth in those places above grade is cut away and filled into those places below grade. Frequently the grade is established upon an embankment for purposes of drainage; the earth for the embankment may be brought in from the sides of the road, that is, *borrowed;* the places from which it is taken are *borrow pits.* Sometimes it is better to *waste* the earth from a cut along the roadway rather than haul it a long distance to a fill.

Grading Machines and Tools and Methods of Using Them.—*Blade Grader.*—The blade or scraping grader, Fig. 74, has proven itself to be a most efficient road making machine. By pulling a moderately heavy grader with a traction engine ordinary roads are being made in the Middle Western States at a cost of $50 to $100 per mile. There are many forms of this machine

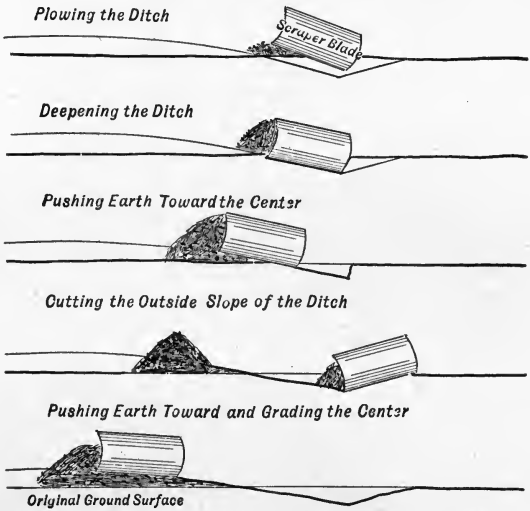


Fig. 75.—Diagrams Showing the Use of the Road Machine.

but all consist essentially of a slightly curved blade attached to a stout frame on wheels. The blade is usually made up of

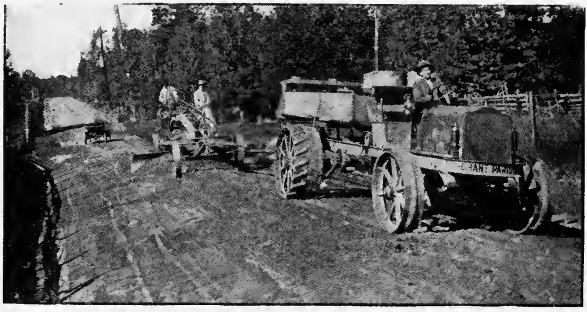


Fig. 76.—A Good Example of Grading Operations in Grant Parish, Louisiana.

two parts, a mold-board and a lay or cutting edge. It is adjustable to almost any position with either end forward and will throw the dirt as desired to right or left; it can be raised or lowered and set at various angles. It will also plow a furrow, push earth sideways, and level and smooth the surface. By shifting the wheels laterally or by tilting them on their axles, side thrust is taken care of.

The diagrams, Fig. 75, and Figs. 76 and 77, show the method of using the grader. The first round plows a furrow, succeeding rounds deepen and widen it, at the same time the loosened earth

FIG. 77.—Trimming Off the Side with a Road Grader on a State-aid Project in Nebraska.

is pushed toward the center of the road. In making the fill the earth is allowed to sift out beneath the blade as it is being pushed toward the center. It is better not to attempt to push too much earth at once, for if the center is not quite high enough a little more earth can be pared from the side ditch and moved over. If too full, on the other hand, the blade must be straightened across the roadway and the extra earth distributed over the graded way.

Harrow.—A tooth harrow such as is used on farms or the A-shaped harrow described in the chapter on gravel roads is useful for smoothing. It also assists the settling. Disk harrows, Fig. 78, may be used similarly.

Plow.—The common plow, Fig. 79, is indispensable. In fact, even when blade grader work is being done the plow is

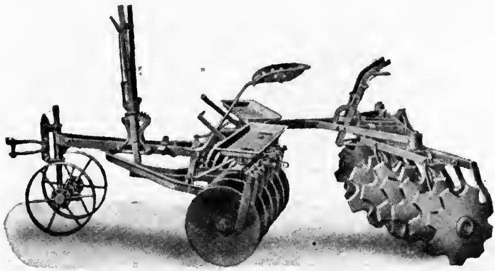


FIG. 78.—Double Disc Harrow, Useful in Working Earth Roads Preparatory to Smoothing.

useful to open the outlining furrow or for loosening earth that is too compact for the grader. While an ordinary field plow may be used heavier types are especially constructed for road work. Some turn the soil to the right others to the left; to the beam is attached a gauge wheel or shoe to control the

FIG. 79.—Road Plow.

depth; large plows are supplied with a cutter (coulter), rolling or stationary, to assist in separating the sod. Four or more horses may be used to advantage. With a driver and laborer to hold the plow about 400 cubic yards of loam may be loosened in a day of eight hours; in gravelly loam about 300 cubic yards; and in stiff clay or heavy sod, 200 cubic yards.

Drag or Slip Scraper.—This is a scoop or bowl, Fig. 80, to which is attached a bail by which it is drawn along. The front edge of the scoop is a sharpened plate while at the rear is attached a pair of handles. The ends of the bail are pivoted to

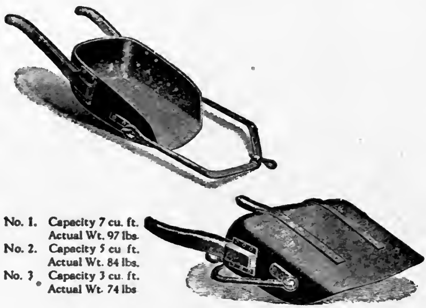


FIG. 80.—Drag Scraper.

the scoop in such a manner that when the handles are slightly lifted the cutting edge is brought into the loosened soil and the scoop filled; when the handles are lowered the edge just clears the ground and the scoop slides along on its bottom; by raising the handles a little higher than necessary to fill the scoop the

FIG. 81.—Tongue Scraper.

cutting edge catches in the ground and the scraper is dumped by the pull of the horses. In using the scraper ordinarily a stretch 6 or 8 feet wide and 100 or 200 feet long is plowed parallel to the roadway, preferably in a direction which will throw the earth toward the road's center. The teams drawing the scrapers are driven in a more or less elliptical course, the loosened earth being taken from the plowed land in such a manner that the horses will step on as little of it as possible, and dumped with the piles closely adjoining each other, making a comparatively smooth surface. The operator may help to smooth the surface by holding the scraper handles and not allow it to dump its

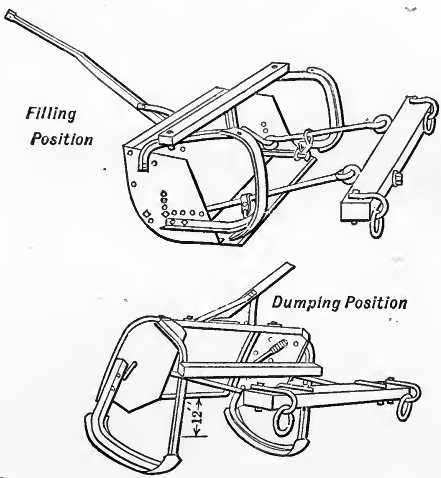


FIG. 82.—Fresno or Buck Scraper.

Made in Three Sizes.

No. 1.	5 feet wide.	Weight 360 pounds.	For three or four horses.
No. 2.	4 feet wide.	Weight 300 pounds.	For two or three horses
No. 3.	3½ feet wide.	Weight 260 pounds.	For two horses.

The Nos. 1 and 2 are most popular for road work.

entire load in one spot. The capacity of scrapers vary from 3 to 13 cubic feet, 5 to 7 being common.

Tongue or Pole Scraper.—This consists of a wooden box, Fig. 81, to which handles are attached and has a tongue as its name indicates. The cutting edge is a steel blade which can be taken off to sharpen or replace. The under side of the box is equipped with steel shoes upon which it slides. This scraper is useful for leveling up as the blade is straight and can be held at any angle by means of a chain, thus depositing the earth in layers from 1 to 10 inches thick. It is also suitable for filling tile ditches.

Fresno or Buck Scraper.—This scraper, Fig. 82, is about twice the width of the ordinary drag scraper, considerably deeper, and has a capacity of 12 to 18 cubic feet. It has one handle only and that at the center. The shoes are bent around the front of the scoop and answer for skids both when it is right side up and full and when tipped up and empty. The Fresno is especially useful for "bucking" light loamy earth from the side ditches into the fill. In such cases often a cubic yard, or even a yard and one-half, can be brought in, that is, pushed in at one time; much more than the volume of the scoop alone. Extra large fresnos are now made to be drawn by tractors.

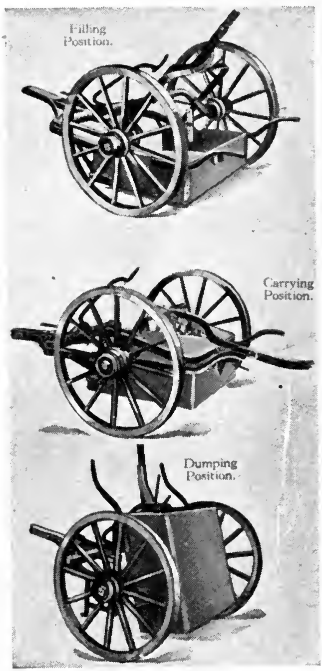


Fig. 83.—Wheel Scraper.

Wheel Scrapers.—The scoop of the scraper, Fig. 83, is mounted on two wheels with a bent shaft for the axle; it is equipped with levers for lowering, filling, raising, and dumping. It has a tongue and is drawn by two horses. Wheel scrapers are especially useful where earth is to be carried a considerable distance before dumping. Some makes have front end-gates which, by preventing the earth from sliding out in front, increase the carrying capacity.

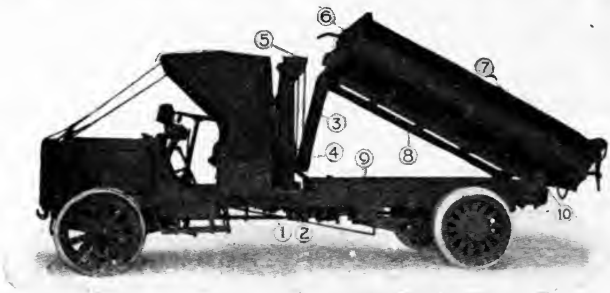
The ground should be thoroughly plowed. The operator drops the scoop by means of a lever and holds the lever upright or a little forward which brings the cutting edge of the scraper into the soil. When the scoop is filled, without stopping the horses, the operator draws the lever back and latches it thus lifting the scoop from the ground where it swings easily while riding to the dump. By again raising the lever and pushing it forward the cutting edge of the scraper catches into the ground and the forward motion of the team completes the dumping. The smaller wheel scrapers, except in very hard material, require but one man to operate them. The larger sizes require an extra man to assist with the loading. A "snatch" team can be used advantageously in loading. Four-wheel scrapers are also in use.

Dump Wagons.—A number of different kinds of dump wagons are on the market, most of them having hinged bottoms which can be locked into place by chains and levers and released when the load is to be dumped, Fig. 84. In a few wagons and

Fig. 84.—Dump Wagon.

many trucks the whole bed is tipped up by means of a hoist and the load slipped out the rear end. It is claimed the latter will spread the earth in uniform layers of any required thickness up to 1 foot. The wagons are filled either by men with hand shovels, by a steam shovel, or with an elevating grader. When cuts and fills are heavy and distances of haul great they are very efficient. Two horses are used on each wagon; the driver does the dumping. The tires are made at least 4 inches broad in order that they may not sink much into the soft earth.

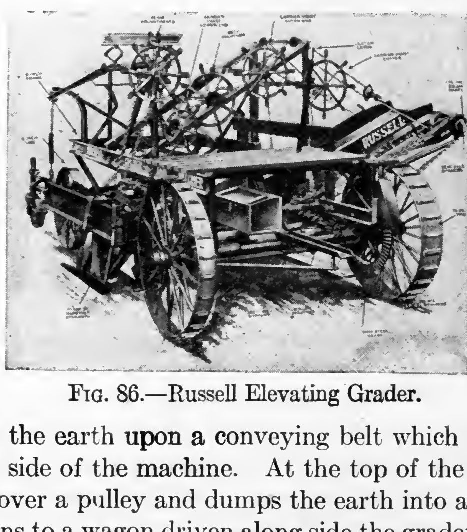
Dump Boards.—Dump boards are made of planks 2 inches thick and from 4 to 6 inches wide and about 10 feet long. They are used with an ordinary wagon. The bed is removed, a pair of side-boards about 12 inches wide placed against the standards and the several dump boards fitted between, these lying loosely upon the bolsters form the bottom of the box into which the earth is thrown. By turning the bottom boards up edgewise, first removing one side-board, the load is dumped through the running gears of the wagon. Dump boards are not as efficient



ɪɢ. 85.—Dump Truck Fitted with Kilbourne & Jacobs Hoist.

as the dump wagon, but farm wagons can easily be transformed into dump-board wagons at small cost for temporary use.

Elevating Grader.—The elevating grader, Fig. 86, consists of a heavy plow and an elevator mounted upon four wheels. The



Fɪɢ. 86.—Russell Elevating Grader.

plow turns the earth upon a conveying belt which carries it up and to one side of the machine. At the top of the elevator the belt turns over a pulley and dumps the earth into a chute down which it runs to a wagon driven along side the grader, or directly upon the ground near the middle of the roadway. The grader is generally drawn by a tractor but sometimes ten or twelve horses are used.

Spades and Shovels.—Spades are used for ditching and digging. The shovel is used for moving earth as it has a larger bowl than the spade. Some road men prefer the pointed shovel; it cuts better and can be used for digging. The square-edged shovel is better for mixing concretes, for cleaning a smooth surface or for leveling off earthwork. D-handles and long straight handles are both used. Scoop shovels having deep bowls especially designed for shoveling grain are valuable where a light material such as snow is to be removed.

Picks are usually two-pointed and are used for loosening the soil before the shovels. In stony soil they soon wear off and have to be repointed by a blacksmith. A *matlock* is a form of pick with one point replaced by a chopping ax-like edge and the other by an adz-like edge. They are serviceable for grubbing.

Axes and Brush Hooks are necessary where clearing is required.

A Corn Knife is valuable for cutting high weeds as well as corn stalks.

A Scythe and a Horse-drawn Mower are often useful to remove grass. Rakes and hoes also have their place in road work.

Steam Shovels, Drag Line Scrapers and Industrial Railways are all in use for heavy work. Steam shovels mounted on broad-tired trucks will excavate earth rapidly and deposit it either on the fill being made, to one side of the cut, or in wagons to be hauled to place of disposal. Drag-line scrapers and derricks with excavating buckets are used in a similar manner. Industrial railways are made of light rails joined together in sections for easy handling, spaced about 2½ to 3 feet apart, with portable switches, turnouts, and turntables. Trains of small dump cars operated by steam, gasoline or electric locomotives are pushed along the track which is laid along or parallel to the roadway being built. They are filled with a steam shovel or clam-shell bucket, or possibly by hand, and hauled to the point of emptying.

As the cut or the embankment is widened the track is shifted sideways. These can be used only where the magnitude of the operation is such as to warrant the high first cost. Embankments constructed by industrial railway, since they are not walked upon by the horses and men, shrink more than those built by scraper. Also additional help may be required to distribute the earth in the fill.

Borrowed Earth and Borrow Pits.—Usually sufficient material for the embankments may be obtained from the side ditches and the excavations as staked out by the engineer. Sometimes, however, earth must be "borrowed." Borrow pits should be made of regular shape in order that they may be easily measured. Also, they should drain completely; water collecting in borrow pits often soaks under the road and softens the subsoil, destroying the stability of the road. A berm of at least 3 feet should be left between the toe of the slope and the borrow pit.

Embankment.—The embankment should, preferably, be carried up in horizontal layers, each carried out to its proper width. While it is usually stated that organic matter should not be allowed in an embankment it will probably do no harm to allow sod to be placed in such providing it is covered to a depth of 1 or more feet or is thoroughly harrowed or disked to break it up.

Haul and Overhaul.—The contractor is usually paid for either excavation or fill but not for both. Transporting the material a specified distance, say 500 feet, is generally included in the contract price. The average length of haul is determined by locating the center of gravity of the cut and the center of gravity of the fill. If the center of gravity of the cut is more than the specified distance (500 feet) from the center of gravity of the corresponding fill, overhaul is allowed for the entire amount of material in the cut for the distance between the centers of gravity in excess of the free haul distance.

Shrinkage.—It should be remembered that earth fills will shrink from 10 to 15 per cent and due allowance should be made, say for depth of fill up to, 8 feet, 10 per cent; 8 to 12 feet, 12 per cent; 12 to 18 feet, 15 per cent.

Tractors vs. Horses.—There is no doubt that it is cheaper to construct earth roads by using a tractor to pull the grader than to use horses. A larger grader may be used; more earth is moved at one time, and because of the larger machine there is less jumping, and the operation is smoother and easier. Many counties buy the machines and keep the same outfit of men working on them all summer; the men become adept and the cost of building is correspondingly decreased. In the Prairie States, roads 18 feet wide are being graded at $50 to $100 per mile, including interest on the cost of machinery.

MAINTENANCE

Two systems for the maintenance of earth roads might be denominated periodic and continuous. The old scheme, handed

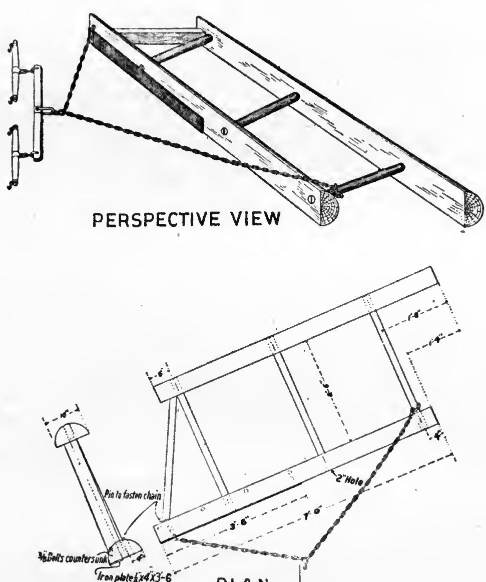


FIG. 87.—The King Split Log Drag.[1]

[1] From "The Use of the Split Log Drag on Earth Roads," by D. Ward King, Farmers' Bulletin 321, U. S. Department of Agriculture.

down from early history, of summoning free-holders to work the roads at certain seasons of the year represents the extreme periodic, and the patrol system, whereby a man spends his entire time in daily looking after a definite portion of road, the extreme continuous. No one now will uphold the extreme periodic system; on the other hand most earth roads are used too little to warrant the use of the patrol system.

Dragging.—The simplest and best method of maintaining an earth road is by dragging. For years race tracks have been dragged or floated for the purpose of keeping the surface smooth and reducing the tractive resistance. During recent years this method has been applied to the ordinary earth road and the

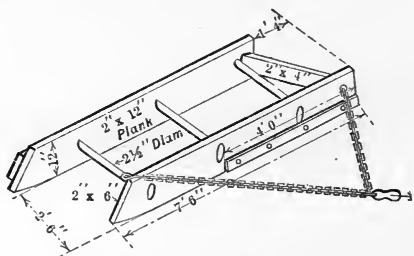


Fig. 88.—Plank Drag.

drag most generally used is some form of the original designed by D. Ward King of Maitland, Mo.

Drags.—Mr. King made his drag of a split log, Fig. 87, but now drags are constructed also of planks and of steel, Figs. 88 and 89.

In Farmers' Bulletin 321, U. S. Department of Agriculture, by D. Ward King, detailed description, method of construction and use are given. Fig. 87 shows a plan of the drag taken from that bulletin. The slabs are fastened together with stakes wedged into 2-inch holes and a brace of 2×4 inch material is placed diagonally at the ditch end of the drag. "The brace should be dropped on the front slab so that its lower edge shall lie within an inch of the ground while the other end should rest in the angle between the slab and the end of the stake. A strip of iron 3½ feet long, 3 or 4 inches wide and ¼ inch thick may be used for the blade. This should be attached to the front slab, so that it will be ½ inch below the lower edge of the slab at the ditch end, while the end of the iron toward the middle of the road should be flush with the edge of the slab. The bolts holding the blade in place should have flat heads and the holes to receive them should be countersunk. If the face of the log stands plumb it is well to wedge out the lower edge of the blade with a three-cornered strip of wood to give it a set like the bit of a plane."

A cover of inch boards spaced an inch apart and held by

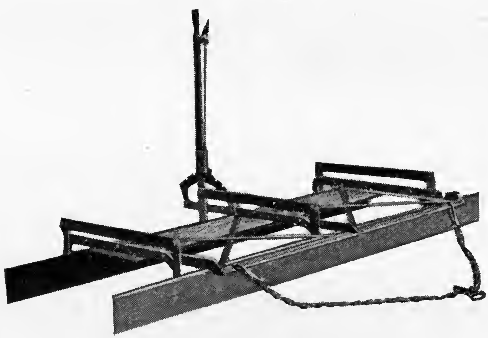


Fig. 89.—Steel Road Drag.

cleats on the under side is laid over the stakes to furnish a platform for the driver to stand upon.

The Theory and Use of the Drag.[1]—Dragging if properly done not only shapes and crowns the road by carrying a small amount of earth toward the center at each dragging, smoothing and honing the same, but it also is a *puddling* and *smearing* process, and if the highest success is to be obtained these last two elements must enter.

If soil taken from the field be placed in a sieve and water turned upon it, on account of the granular condition of the soil the water soon soaks in and much passes clear through and

[1] Abstracted from an article on "The Use of the King Road Drag," by G. R. Chatburn in Huebinger's Guide Book of the Omaha-Lincoln-Denver Highway.

out the meshes of the sieve. But if the water and soil be stirred and mixed to form sticky mud and then pressed into a cup shape in the sieve it will be found to *hold water*, that is, if additional water be put into the mud cup and covered by a glass plate to prevent evaporation, the sieve thus smeared inside with "puddle" will retain the water for a considerable number of days. Thus in the process of puddling, the air is worked out, the particles become pressed closely together and the voids between them filled with water; a sticky or gummy colloidal mass is formed which is impervious to the passage of more water, and, such water as is needed to form this colloidal state is tenaciously held and will be given up reluctantly only upon the application of pressure or through evaporation.

The water hole or storage reservoir of the stockman, the buffalo-wallow of the plains region, the ordinary mud puddle of the hog yard or the roadway, all hold water because lined with puddle—colloidal soil made dense and impervious by kneading. On the other hand if the contained water is of the right amount, such soil will pack under pressure or by tamping until if spread upon a firm foundation it is capable of sustaining a considerable load without either squashing or grinding into dust. A well-crowned road covered with puddle in its ideal condition of dampness has a water-tight roof and all it needs in addition is a thorough side and under drainage to give it a dry cellar; a road, like a house, should have a tight roof and a dry cellar.

Dragging a road immediately after a rain, while the ground is still wet, but not too sticky, puddles the soil and smears it over the top; presses out the surplus water and leaves the surface smooth and hard for service; and when the next rain comes, the water rapidly runs off before it has had time to soak deeply in. Another dragging puddles and smears some more; the drag having been set to bring fresh earth from the side toward the center, the thickness of the roof gradually increases with each dragging until in time there are from 2 to 6 inches of compact hard crust. The wheel tracks being obliterated, the entire surface of the dragged highway receives the uniform beating and packing of hoofs and wheels; the formation of ruts, the worst possible thing that can happen to any road surface is avoided.

Method of Using the Drag.—The successful use of the drag requires first a light drag; one so light that one man can easily load it into a wagon, but still stiff and rigid enough not to hinder materially its use on the road. The driver should ride the drag, not seated with an umbrella over him, but standing so that by changing his position he can make it dig deeper or not so deep as he wishes. To make it dig deeper, throw the entire weight on one foot near the cutting or forward corner of the drag at *A*, Fig. 90; if less deep throw the weight back upon the foot *B* or step to *C*. If the front rail or slab becomes clogged with weeds, or it is desired to drop a quantity of earth to fill a hole, the driver should step quickly to the point *D*, then back again to *A*. The earth dug up by the cutting blade should gradually work along and sift under the forward rail. The front rail may be set inclined backward so that it forms a plane-bit cutting edge while the rear crushes and plasters down the earth which has sifted under the forward rail, leaving it smooth as butter is left on a piece of bread by the knife, or mortar by the trowel of the workman. Lengthening the hitch will also cause the drag to move more earth.

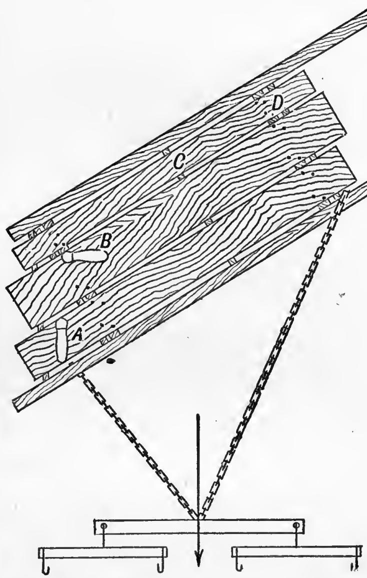


Fig. 90.—Method of Using the Drag.

It is impossible to state the exact length of hitch, the best angle to draw the drag, or the position of the driver, for these will all vary with the character and condition of the soil, the length of time the road has been dragged, and the condition of the roadbed at the time of dragging. The driver, if a man of intelligence, can by trial soon ascertain these things for himself. But it may be said the total amount of fresh earth brought toward the center should usually all be spread and crushed by the drag. A ridge or windrow of earth should never be left in the middle of the road. Care in digging up just as much earth as will uniformly sift out under the rail of the drag by the time the top of the road is reached, will avoid this. But if for any

FIG. 91.—A Well-dragged Earth Road.

cause more earth than sufficient has been conveyed to the center it can be smoothed by using the drag straight instead of diagonally the last trip over. If the center gets too high, or higher than the standard cross-section of the road, Fig. 73, the drag should be inclined in the opposite direction occasionally.

Rules for Dragging.—The Illinois Highway Commission distributed to its road overseers the following rules for dragging, which are both concise and explicit:

Make a light drag, which is hauled over the road at an angle so that a small amount of earth is pushed to the center of the road.

Drive the team at a walk.

Ride on the drag; do not walk.

Begin on one side of the road, returning on the opposite.

Drag the road as soon after a rain as possible, but not when the mud is in such condition as to stick to the drag. (It might also be added, as to ball up.)

Do not drag a dry road.

Drag whenever possible at all seasons of the year. If the road is dragged immediately before a cold spell it will freeze in a smooth condition.

The width of traveled way to be maintained by the drag should be from 18 to 20 feet. First drag a little more than a single wheel track, then gradually increase until the desired width is obtained.

Always drag a little earth toward the center of the road until it is raised from 10 to 12 inches above the edges of the traveled way.

If the drag cuts too deep, shorten the hitch.

The amount of earth that the drag will carry along can be very considerably controlled by the driver according as he stands near the cutting end or away from it.

When the roads are first dragged after a muddy spell, the wagons should drive to one side, if possible, until the roadway has a chance to freeze or partially dry cut.

The best results from dragging are obtained only by repeated applications.

Remember that constant attention is necessary to maintain an earth road in its best condition.

Patrol System of Maintenance.—This means that the roads are separated into sections and some one person detailed to look after a section. The patrol or overseer is supposed to go over his section at least once a day and repair any tendency to form ruts. He looks after the drainage, cleans the ditches, and sees that the culverts are not obstructed. A friendly rivalry is soon engendered between neighboring patrolmen to see which can have the best-kept road. Dragging earth roads after each rain and daily attention will keep them in usable condition and the money used in this manner will be well spent.

August 1, 1915, the state of Pennsylvania placed all roads under the patrol system. The following list of general duties of the patrolmen has been prepared by the State Highway Department.

Keep drains and ditches open at all times.

Special attention must be given to defects in planking and the condition of bridge floors.

Repair all defects in the surface of the road, maintaining the same in a true and even condition.

Repair and whitewash all guard rails.

Provide protection and red lights in cases of flood, washouts, or any other emergency condition.

Remove brush from along the sides of the road, giving special attention to this condition at curves, approaches to railway crossings, bridges, cross-roads, etc.

Keep the berms, or shoulders of the road, trimmed up, so that the surface water may be discharged freely from the road surface to the side ditches.

Remove all advertising signs from within the legal limits of the highway.

Paint and keep in first-class condition all department direction and warning signs.

Inspect culverts, head walls, cribbing, retaining walls, etc., and report defects immediately to the superintendent.

Whitewash large rocks and the bases of poles on narrow sections of highways and at sharp curves (spring and fall).

The poles are to be whitewashed to a height of 6 feet above ground.

All equipment, tools, and material placed in charge of each caretaker must be accounted for by him at all times, and all tools and equipment kept in thorough repair.

Economic and workmanlike results will be the most important factors recognized by the department.

Attention must be given to the entire section allotted to the caretaker, and work not confined to special and convenient portions.

When working on the road the caretaker must have a red flag, which will be supplied by the department, displayed at all times near the point where work is being performed.

When unusual conditions require additional help, team hire or material of any character, permission to secure same must first be obtained from the county superintendent.

A daily report postal-card must be mailed every evening to the county superintendent.

All additional help and team hire must be carried on foreman's daily report form, etc.

All bills for material, etc., in amounts less than $10 must be covered by a superintendent's purchase order, and larger amounts by a requisition of the superintendent and department purchase order.

Caretakers are to be paid an hourly rate (Note.—At present 15 to 20 cents per hour), and full value in service will be exacted for every dollar expended.

Caretakers must be courteous and considerate of the interests of the public at all times, and conduct themselves in a manner becoming representatives of this Commonwealth.

Sobriety, honesty, industry, good character and ability are the essentials required, and a failing in any of these will be met by dismissal.

The patrol system has been adopted by Maryland, Wisconsin, Michigan and in modified form by other States.

CHAPTER VII

SAND-CLAY AND TOP-SOIL ROADS

Theory of Sand-Clay Roads.—Sand being composed of small particles of rock that are only slightly subject to further decomposition under weather conditions has in itself very little power of cementation. When dampened the thin film of water which extends from one grain to another exerts a small binding force and this together with the mechanical bond of the rough particles themselves is sufficient to hold up a horse or wagon with but little disarrangement of the surface. When the sand is dry and the binding force of the water is absent, the mechanical bond being inconsiderable, the horse the wagon will sink in a varying distance of 1 to 4 inches, depending on the character of the sand.

If the sand contains clay, feldspar, or rock particles capable of further chemical reduction under the action of water or weather, it may cement into a more or less monolithic composition. Clay, being composed of extremely small particles of stone dust, so small that the particles swim more or less freely in the film of moisture surrounding them, has practically no mechanical bond, but it does possess a small cementing property. This property is manifest only, however, when the clay is in a rather dry condition. Therefore, sand is in its best state for road purposes when wet; clay, when dry. A mixture of the two in proper proportions furnishes an acceptable road surface for both wet and dry weather. The mechanical action of the sand and the cementing action of the clay assist each other just as in a gravel or a macadam road, or as cement and aggregate in concrete. Again clay, being extremely small particles, each surrounded by its film of water, shrinks on drying out much more than sand, the particles of which are comparatively large. This may be illustrated by imagining two walls, one laid up of Roman brick 1 inch thick, the other of stone blocks

1 foot thick having mortar joints the same thickness in each. Now, if the mortar be scraped out the wall of bricks will decrease in height twelve times as much as the one made up of the thicker stone blocks. As sand grains may vary from a fraction to 1000 or more times the size of the clay particles one can see how the shrinkage will differ. Adding coarse sand to clay will diminish its tendency to shrink and crack.

When surrounded by much water the particles of clay separate and float in the water quite freely. With a little less

Fig. 92.—A Sand-Clay Road.

water there is "slush"; with still less water, "stickiness"; then with kneading and further reduction of water the stickiness disappears and the clay is plastic; with still further reduction of water it hardens and becomes brittle and flours or rubs off like chalk. On the other hand sand, when sufficiently coarse, has opposite properties; it never becomes slushy or sticky or plastic or cements into a hard brittle body. These opposite tendencies are neutralized by mixing the sand and clay. Slushiness is lessened, stickiness minimized, and the mechanical bond of the sand and the cementing action of the clay diminish disintegration and disruption.

Selection of Materials

While for road purposes clay may be defined as earth particles of extremely small size (that which will pass a 200-mesh sieve) the properties of clays differ. Whether this is due to the original differences of the rocks from which the clays were decomposed or whether it is caused by the intermixture of organic and inorganic foreign substances is immaterial. The road man is concerned only with the question whether or not they can be used for road purposes, and if there are several varieties available, which is best. Is it better to get the gumbo soil from the bottom land, which is a very fine-grained (non-gritty) sticky clay strongly impregnated with organic matter, or the bank-clay from the hills, which may be almost pure kaolin? Upon this method of classification, practically all clays contain sand and all sands clay. In making up a mixture, therefore, both sand and clay must be investigated. Laboratory and field tests have not yet been standardized. The following tests may be made:[1] (1) Separation of sand and clay, (2) Mechanical analysis of sand content, (3) Slaking test on cylinder of sand-clay, (4) Examination for mica and feldspar, (5) Slaking test or clay cylinder.

Sampling.—Samples should be taken from several parts of the location and from different depths in the bed.

Separation of Sand and Clay.—1*st Method.*—The sample is first thoroughly dried in the air and pulverized with a wooden mallet. Then it is screened through a 10-mesh sand sieve, and then through a 200-mesh sieve. Coarse materials except grass, roots, etc., caught on the 10-mesh sieve are classified as gravel,[2] that caught on the 200-mesh sieve as sand, and that passing the 200-mesh sieve as clay.

2*d Method.*—Or the separation of sand and clay may be made by decantation thus: By successive quartering a portion of about 150 grams is taken and dried in an air bath at 100° C. to constant weight; 100 grams of this material are weighed and

[1] "An Investigation of Sand-clay Mixtures for Road Surfaces," by John C. Koch, Trans. Am. Soc. Civ. Eng., Vol. 77, p. 1454.

[2] Some engineers would classify all passing the ¼-inch sieve as sand.

placed in a porcelain evaporating dish; water is added and the sample rubbed well until the clay particles are in suspension. The clay in suspension is carefully poured off and more water added; the process is repeated until there is faint or no coloration of the water. When the residue is stirred up. By washing the materials properly, practically all the organic matter, silt and clay are removed, and only the sand particles are left, with possibly some mica and feldspar. The residue is dried and weighed.

Mechanical Analysis of Sand.—The dried residue in the evaporating dish or that which passes the 10-mesh sieve, if the first method is used, is screened through the 200-, 100-, 60-, 40- and 20-mesh sieves. If preferred, they may be taken in reverse order. The percentages passing the several sieves can be calculated and plotted.

Professor Koch's[1] studies of nearly a thousand analyses has led him to the following conclusions:

> The total relative sand content, disregarding the size of the sand grains, is no criterion of the value of the material.
>
> The sand smaller than No. 60 (passing 60-mesh sieve) is of little value in the mixture, that smaller than No. 100, except in very small quantities is detrimental.
>
> The greater the proportion of coarse to fine sand, the harder and more durable will the road surface be.
>
> For the best possible results with sand-clay mixtures, the sand smaller than No. 10 and larger than No. 60 should not be less than 60 per cent by dry weight, of the entire sample. In addition, the smaller than No. 10 and larger than No. 60 should be composed of about equal parts of Nos. 20, 40, and 60. The total sand content should in no case exceed 70 per cent by weight of the total sample.

Standard Sand-Clay Mixtures.—From experiments and investigations such as those of Professor Koch a standard mixture should be decided upon. The following might answer for a

I. STANDARD SAND-CLAY MIXTURE

Passing 200-mesh sieve 39 per cent				39 clay
Passing 100-mesh sieve 47 per cent	8	16	61 sand	
Passing 60-mesh sieve 55 per cent	8			
Passing 40-mesh sieve 70 per cent	15	45		
Passing 20-mesh sieve 85 per cent	15			
Passing 10-mesh sieve 100 per cent	15			

[1] Ib. Cit.

This does not quite satisfy Professor Koch's idea that the 10, 20 40 separations should together be 60 per cent. There is no doubt but that very coarse and very fine materials will give best results, but it is hard to find such a combination. If a 6 per cent allowance on either side of the above standard be made there results the following:

II. GOOD SAND-CLAY MIXTURES

Passing 200-mesh sieve	33 to 45 per cent
Passing 100-mesh sieve	41 to 53 per cent
Passing 60-mesh sieve	49 to 61 per cent
Passing 40-mesh sieve	64 to 76 per cent
Passing 20-mesh sieve	79 to 91 per cent
Passing 10-mesh sieve	100 per cent

If there is material that will not pass a ten-mesh sieve its use will be an advantage to the road and should be allowed to go in with the rest.

A. S. T. M. Specification.—At the 1920 meeting of the American Society for Testing Materials the following tentative specification for sand-clay roads was submitted by the Committee on Road Materials:

The sand-clay shall be composed of either a naturally occurring or artificially prepared mixture of hard, durable, preferably angular, fragments of sand, together with silt and clay with or without gravel, and shall be free from an excess of feldspar or mica.

(*a*) When tested by means of laboratory sieves and screens the sand-clay or gravel shall meet the following requirements for grading:

(*b*) The material, if any, retained on a ¼-inch screen shall be uniformly graded from the maximum size present to ¼ inch.

(*c*) The material passing a ¼-inch screen shall meet the following requirements:

	Per cent
Total sand	50 to 80
Sand over 50-mesh [1]	25 to 50
Silt	5 to 20
Clay	15 to 30

[1] For specifications for this sieve, see Standard Method for Making a Mechanical Analysis of Sand, or Other Fine Highway Material, except for Fine Aggregates Used in Cement Concrete (D7), 1918 Book of A. S. T. M. Standards, p. 663.

A Straight Line Method of Plotting Sieve Analyses

Table II may readily be plotted thus: On a sheet of ruled writing paper number spaces *OA*, Fig. 93, to represent the percentage passing the sieves. Draw a diagonal line *ON*, then *NB* perpendicular to *OB*. Draw perpendiculars *CD*, *EF*, etc., so they will cut the diagonal *ON* at heights indicated by standard sieve separations. Thus, that for the 200-mesh sieve, *CD*,

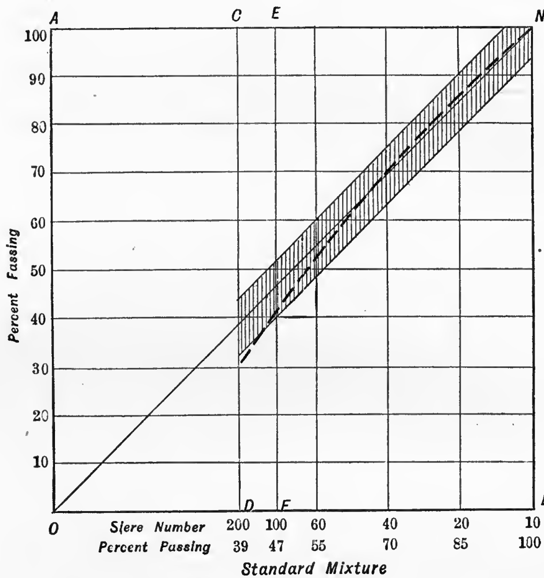


Fig. 93.—Straight-line Plot of Sieve Analysis.

will cut it at a point 39 per cent up, Table I; the 100-mesh sieve *EF*, at 47 per cent, etc. Draw lines 6 per cent above and below *ON*. The shaded area covers the grading given in Table II. Any loam or other natural mixture may be readily compared with the standard by making a sieve analysis and plotting on this diagram. Thus a natural mixture of top-soil (Professor Koch's No. 150) which has given excellent results shows the following percentages of amount smaller than No. 10 separation retained upon the several sieves:

Sieve No.	10	20	40	60	80	100	Sand dust	Clay
Per cent retained	6.3	13.7	16.6	17.7	7.5	2.3	11.5	30.7

The percentages passing the sieves arranged for plotting are:

Sieve No	10	20	40	60	80	100	200
Per cent passing	100	86.3	69.7	52.0	44.5	42.2	30.7

This is plotted on Fig. 93, broken line. It will be noticed that it everywhere falls within the shaded area (except No. 200) as might be seen by noting that the separation percentage nowhere varies more than 6 per cent from the standard assumed.

Method of Proportioning.—Having adopted a standard and drawn the vertical lines to represent the several sieve separations the diagram may be used to ascertain the proper proportions of a mixture of two or more sands, clays or soils.

To illustrate, in a certain locality is a road with a sand spot in it. Clay is obtainable at a distance of several miles and sand and loam near by, having the following analyses respectively:

	Percentage passing and retained on next finer sieve					
	200	100	60	40	20	10
Clay	88.2	10.8	0.9	0.0	0.1	0.0
Silt Loam	40.8	33.7	19.9	2.0	1.9	1.7
Sand	1.0	2.0	12.5	21.0	34.5	29.0

Calculating the total percentages passing the several sieves and plotting on the diagram gives Fig. 94.

Note that a mixture of 1 clay to 1 sand approximately agrees with the standard adopted. The mixture may be computed thus:

It might be the part of wisdom, however, to use the silt loam in connection with the sand and clay. A proportion of 1 clay: 3 loam : 3 sand gives the mixture shown in the last column and *E* of the plot. This is almost as good a mixture and it ought to be much cheaper than the material which has to be hauled a long

	A Clay	*B* Silt loam	*C* Sand	Sum $A+C$	Ave. = Sum ÷ 2	Mix *ABC* Ave. = $\frac{A+3B+3C}{7}$
200-mesh...	88.2	40.8	1.0	89.2	44.6	30.5
100-mesh...	99.0	74.5	3.0	102.0	51.0	47.8
60-mesh...	99.9	94.4	15.5	115.4	57.7	61.4
40-mesh...	99.9	96.4	36.5	136.4	68.2	71.1
20-mesh...	100.0	98.3	71.0	171.0	85.5	86.8
10-mesh...	100.0	100.0	100.0	200.0	100.0	100.0

distance; clay is reduced from one-half to one-seventh of the volume of the road surface.

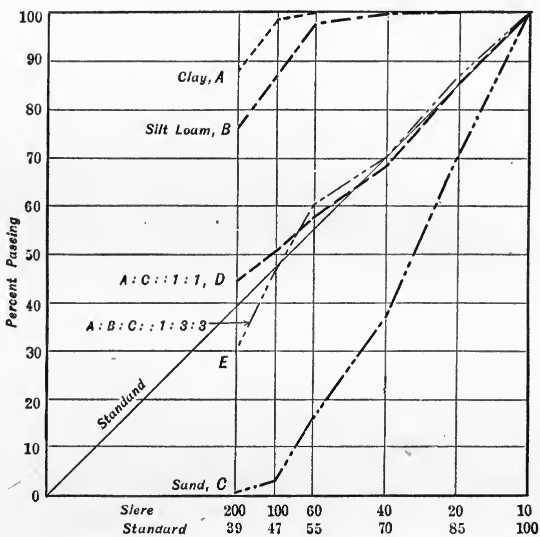


FIG. 94.—Plot of Sand-Clay Mixtures.

So far it has seemed easy to get mixtures plotting sufficiently near to the adopted standard. It may not always be practicable to get materials that will thus agree. Take, for example, an analysis of dune sand from the sand-hill region of western Nebraska, Table III, Fig. 95. This sand covers a region of many square miles in western Nebraska, extending into western Kansas, western Dakota, eastern Wyoming and eastern Colorado. And while it is naturally covered with bunch grass sod, this is soon destroyed by travel, leaving the roadway a pure sand bed through which it is very difficult to draw a vehicle. This sand, yellowish, or brownish-gray, is remarkably smooth and round and uniformly fine or medium in size. There is very little coarse material or material sufficiently fine to be called

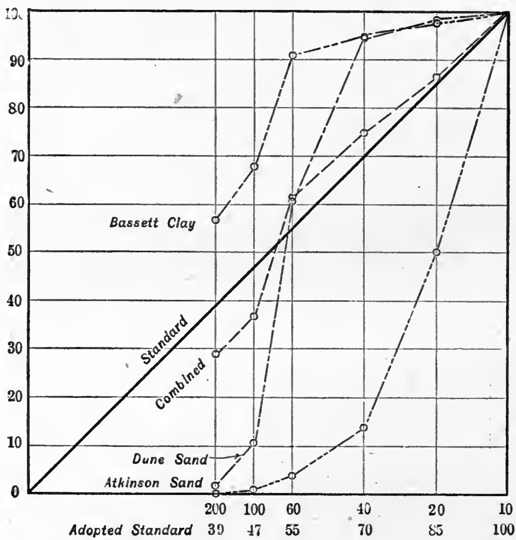


FIG. 95.—A Mixture of Nebraska Dune Sand, Bassett Clay, Atkinson Sand in Proportions of 1 : 1 : 2.

clay. Mechanical stability and binding qualities are both lacking. To make good roads of this sand will require a strong binder such as bitumen with some method of procuring a sound foundation. To make a good sand-clay road of this material will require additional coarse sand and fine clay in order to balance the mixture. Both these materials are exceedingly scarce in the sand-hill region. In the table a combination of Bassett clay and Atkinson coarse sand is worked out. While this is not the best of sand-clay roads it will give fair results. A

TABLE III

	Dune Sand [1]		Bassett-Clay [2]	Atkinson Sand	1 Dune Sand, 2 Bassett Clay, 1 Atkinson Sand	
200-mesh...	1.5	1.5	56.5	0.1	28.6	28.6
100-mesh...	9.2	10.7	10.9	0.5	7.9	36.5
60-mesh...	50.0	60.7	23.4	3.0	25.0	61.5
40-mesh...	34.7	95.4	4.0	10.0	13.2	74.7
20-mesh...	3.8	99.2	2.7	36.4	11.4	86.1
10-mesh...	.8	100.0	2.5	50.0	13.9	100.0
					100.0	

[1] Dune sands vary in texture as other sands:

Dune sands from:	200	100	60	40	20	10
Wood Lake	1	8	64	25	2	0
Halsey	1	8	46	38	6	1
Haigler	2	12	38	44	3	1
Cody	2	9	52	32	4	1
Total	6	37	200	139	15	3
Average	1.5	9.2	50	34.7	3.8	.8

[2] Found at Bassett, Stuart, Newport and other places along the Elkhorn River.

little richer clay having not quite so much sand would be better. These were selected because they occur near together. The Atkinson sand as found is about one-fifth gravel larger than a 10-mesh separation. This should be allowed to go in.

Other Tests.—In addition to the sieve tests other tests may be employed to confirm or modify the mixtures tentatively decided upon.

Slaking Test.—Two methods for making this test have been suggested but they do not differ in principle.

Koch's Method.—A test cylinder, 1 inch in diameter and 3 inches long is made of the material passing the No. 10 sieve by wetting it sufficiently to make a very stiff paste and after working it thoroughly together packing it in a metal mold with a tight filling plunger and a mallet. The cylinder is dried to constant weight in an air bath at 100° C. When entirely cooled it is immersed in a glass jar of water at a temperature of 21° C. and the time noted for its complete disintegration. Disintegration is supposed to be complete when the cylinder has broken down until the material is standing approximately at its natural slope of repose. Professor Koch says, "In sand-clay mixtures which have given satisfactory service the time to disintegrate completely varies from two minutes to nearly one hour. This test will give a fairly good idea of the resistance of any sand-clay mixture to the action of water. The most durable mixtures, in general, are those which take longest to disintegrate."

The same test is applied to clay alone and the slaking time of good clay cylinders varies from two minutes to twenty minutes. The sand may be mixed with clay in varying proportions and the times of slaking compared.

James' Field Test.[1]—Mixtures are made ranging from 1 part sand to 3 parts clay, up to 3 parts sand and 1 part clay, varying by one-half of one part:

Sand....................	1	1	1	1	1	1½	2	2½	3
Clay....................	3	2½	2	1½	1	1	1	1	1

Equal samples are taken from the several test-mixtures with a small measure. These are wetted and mixed to a stiff paste and rolled between the palms of the hands into reasonably true spheres and placed in the sun to dry. Designating marks may be placed on them. When dry they are placed in a circle in a flat pan or dish, and enough water poured in the pan to cover them, care being taken not to pour the water directly upon the samples. Slaking will begin at once and proceed at different rates. The sandy specimens will break down first, those with excessive clay will disintegrate second and those having about the proper proportions will act more slowly. Usually there will be one or two that determine the proper proportions.

[1] Transactions Am. Soc. Civ. Eng., Vol. 77, p. 1482.

Flouring Test.—Dry spheres, cubes, or pats made up of the mixtures and dried are lightly rubbed with the thumb and finger. Those having too much sand will break down rapidly; those having too much clay will soon begin to "flour" or "dust" away, while those having the most suitable mixtures will assume a slightly glazed effect under the light rubbing due to the moisture and oil of the skin. As a rule select the sample having next more sand than the one which glazes.

Test for Mica and Feldspar.—Examination of the sand with a small powered microscope will show mica or feldspar. Or they may be separated by water, the mica and feldspar being of lower specific gravity than quartz.

If mica exists in proportion, less than 5 per cent, no harm will ensue. Above that it acts as a lubricant and prevents consolidation of the road. Feldspar will do little damage, unless in greater proportion than 8 or 10 per cent, when the road will cut and wash easily.

Constructing Sand-clay Roads

Sand-clay roads as far as construction is concerned are of two kinds—clay roads upon which sand is to be put and sand roads upon which clay is to be put. The first might be called sanded roads.

Sanded Roads.—After the sand is selected it is a good plan according to W. L. Spoon, Office of Public Roads, Circular No. 61, to haul it, in advance alongside the road which is to be improved. When the road softens a quantity of sand should be spread broadcast over the traveled roadway for the desired width until the softened clay surface of the road is saturated with the sand. In this way the advantage of hauling the sand on a firm, dry clay road is obtained, and it is ready for use when the road is softened by rain and slightly cut by travel. For a first application the material should be mixed to a depth of from 5 to 8 inches according to the amount of traffic. Loose material will shrink 30 to 40 per cent in the process of packing. As the road dries somewhat it should be smoothed by dragging. The road will require constant attention for a year or more; mud holes, sand pockets, and ruts should be filled after each rain.

Clayed Roads.—The roadbed having been prepared by plowing and scraping the sand from the center of the road, Fig. 96, and piling it up along the side, the clay is placed in a uniform layer in the trench thus dug. This should be begun at the end of the road nearest the store of clay in order that the teams may walk over the harder clay. After depositing the clay the sand

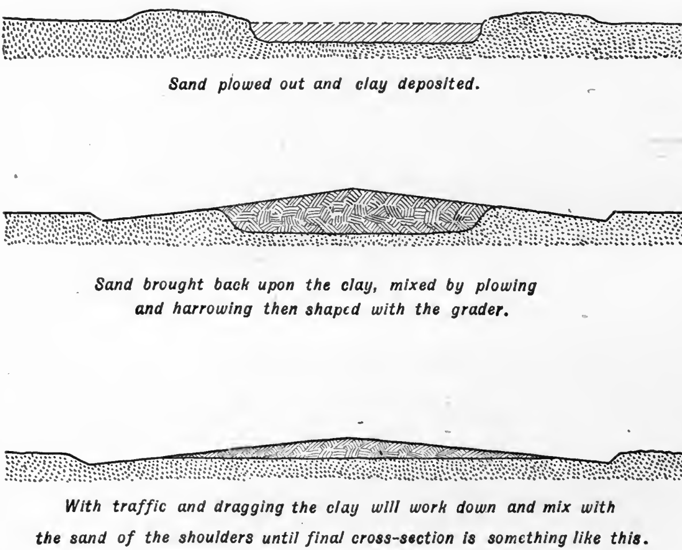


Fig. 96.—Claying a Sand Road.

on the sides is spread over the top to a depth of about 2 to 4 inches and the whole plowed and harrowed or disked so as to mix thoroughly the sand and clay. Finally the road is shaped and smoothed with the grader and drag. Traffic will work the clay at the center toward the edge. The drag will pull some sand from the edge back with this toward the center. With care, adding a little clay where needed the road may be made to take a form having a thick mass of sand clay mixture in the center to a feather edge at the sides. Side ditches should not be very deep. If the roadway is crowned about 1 inch to the foot rainwater falling upon the road will be carried to the sandy edge where it soon soaks into the soil. If the sand beneath the clay does remain a little damp it will add firmness to the foundation and prevent flouring of the clay mixture.

Top-soil Roads.—Fig. 97 shows a form of cross-section used for top-soil roads in Georgia. A top-soil road is one whose wearing coat is composed of top-soil which has been found by experience or examination to have about the requisite combination of sand and clay to form a good road.

The road surface is shaped and plowed then a layer of top-

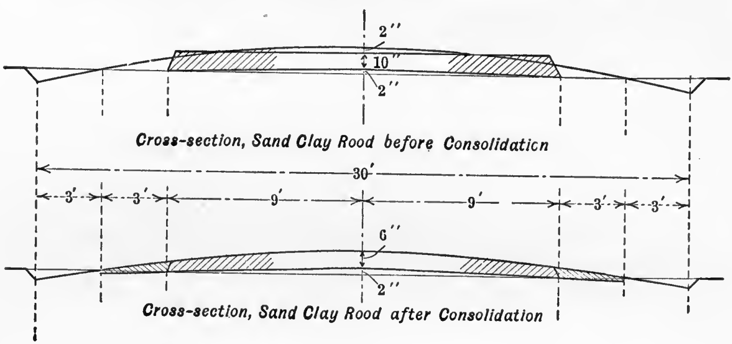


Fig. 97.—Top-soil Roads.

soil 10 to 12 inches thick is deposited uniformly. Earth from the shoulders and ditch brought against this and the whole shaped with the grader. Rolling is frequently dispensed with as the teaming, while hauling the material and subsequent traffic soon accomplish consolidation. In Alabama the specifications call for dumping the top-soil " on the road with three or more loads opposite each other; the distance between the loads depending on the width and thickness of the top-soil. The loads should be dumped in this way in three or more parallel lines until a hundred or so feet have been dumped. The shaping of the top-soil should be commenced before the individual load begins to pack." Other engineers believe it better to spread the soil as the loads are dumped because the settlement is more uniform.

Also, in Alabama " If the surfacing used is not a good natural mixture of sand and clay the mixture will have to be made on the road in the following manner: On a clay foundation the subgrade must be plowed up to a depth of 4 inches, all clods being thoroughly pulverized by harrowing or otherwise, and sand spread on to a depth of 6 inches, the mass shall then be mixed and puddled by turning with a plow and using a disk-harrow and dressed up with the road machine. On a sandy foundation the sand must be plowed to a depth of 6 inches and a suitable clay spread to a depth of 4 inches and mixed as above described. The mixing and puddling process must be kept up from time to time until a good mixture is obtained and the road packs firm and hard and is true to grade and cross-section and free from holes and bumps."

Maintenance

The maintenance of a sand-clay road is similar to that of an earth road and consists in dragging after rains. It will be found, however, that with a good mixture, the surface will become so hard that a light drag will not remove the bumps. A steel or heavy drag will be required. The road-grader followed by a drag will be found effective. The blade of the grader should be set so as merely to cut off the projecting hard bumps; the drag does the filling in and smoothing. Fresh material similar to the wearing surface will have to be brought occasionally to fill in ruts or holes where the surface has broken through or worn out. With constant care a sand-clay road should give satisfactory results for a great many years. Of course, when it has worn through a new road may have to be constructed, as with any other material.

Cost.—Sand-clay roads cost more than earth roads and usually less than macadam or even gravel. W. L. Spoon of the U. S. Office of Public Roads, Farmers' Bulletin 311, gives the following as approximate costs of constructing 1 mile of a

12-foot sand-clay road on the assumption that clay can be procured within a mile of the road which is to be improved, and that the cost of labor is about $1 per day and teams $3 per day:

Crowning and shaping with road machine, using two teams at $3 per day and 1 operator at $1.50 per day for 1 day	$7.50
Loosening 1,173⅓ cubic yards of clay with pick and shoveling into wagons at 15 cents per cubic yard	176.00
Hauling 1173⅓ cubic yards of clay, at 23 cents per cubic yard	269.86
Spreading clay with road machine, using 2 teams at $3 and expert operator at $1.50 per day for three days	22.50
Shoveling sand on clay, estimated at ½ cent per square yard	35.20
Plowing, using 1 team at $3 per day for four days	12.00
Harrowing, using 1 team at $3 per day for two days	6.00
Shaping and dressing with road machine, using two teams at $3 and expert operator at $1.50 per day for two days	15.00
Rolling estimated at ½ cent per square yard	35.20
Total	$579.26

Estimated cost $579.26 per mile or 8 cents per square yard

The Office of Public Roads gives as its experience the cost of sand-clay roads to range from $200 to $1200 per mile, in most cases running from $300 to $800. At Gainesville, Fla., a 14-foot roadway, 9 inches thick cost $881.25 per mile or 10 cents per square yard; at Tallahassee, Fla., a 16-foot roadway 7 inches thick cost $470 or 5 cents per square yard; at Marion, Ala., 11 to 22 cents. At Columbus, Neb., detailed costs for 3002 feet of sand-gumbo road graded 24 feet in cuts and 32 feet on fills, with sand-gumbo surface 16 feet wide are given in the table on p. 166. (Bulletin 53, U. S. Department of Agriculture, Office of Public Roads.)

Here both sand and gumbo were brought upon the road; the gumbo was hauled approximately 2 miles, the sand 4000 feet. The gumbo was spread to a depth of 7½ inches, and the sand to a depth of 6 inches, both measured loose. The two materials were then mixed by means of plows and harrows and shaped with a steel drag and road machine.

Earthwork	Amount	Unit Cost Per Cubic Yard	Unit Cost Per Square Yard Wearing Surface
760 cubic yards excavation	$120.00	0.158	0.0225
Shoulders and ditches	46.40	....	0.0088
5.337 square yards shaping subgrade	28.20	....	0.0052
Miscellaneous	1.40	....	0.0002
Superintendence	4.20	....	0.0008
Total	$200.20	....	0.0375
Sand-gumbo wearing surface:			
Purchase of gumbo pit	41.35	0.035	0.008
Loading gumbo	180.40	0.155	0.034
Hauling gumbo	698.80	0.600	0.131
Spreading gumbo	34.00	0.029	0.006
Loading sand	93.60	0.105	0.018
Hauling sand	299.00	0.336	0.056
Mixing sand and gumbo	37.20	0.018	0.007
Shaping	4.00	....	0.0025
Rolling	13.60	....	0.001
Miscellaneous	12.60	....	0.002
Superintendence	37.80	....	0.007
Total	$1462.95	....	0.2745
Grand total	$1663.15	....	0.3120

CHAPTER VIII

GRAVEL ROADS

GRAVEL is defined as an aggregate of small naturally formed stones or pebbles usually found in deposits more or less intermixed with sand and clay but in which mixture those particles that will not pass a 10-mesh sieve predominate. The differentiation between gravel, sand, silt, and clay should be made on the following basis:

Retained on a 10-mesh sieve..................	Gravel[1]
Passing a 10-mesh and held on a 200-mesh sieve..	Sand
Passing a 200-mesh sieve.....................	Clay and silt

Gravel is nearly always made up of pebbles which have been more or less rounded by the action of water and weather and the mechanical grinding of one particle of stone against another. Some so-called gravels are small angular fragments of broken rock which have not yet become rounded. Such is the gravel, or rather, " disintegrated granite " of Sherman Hill, Wyo., and other places in the West. This material lies in thick beds and when taken out with a steam shovel the walls stand perpendicular for 20 or 30 feet. It is extensively used for ballast and depot platforms by the Union Pacific railroad, and has also been used for road purposes with success.

The kind of gravel commonly utilized for roads is made up of the rounded water worn pebbles and this is what will be meant hereafter when the word " gravel " is used without modification. Such gravel is generally hard and durable and when

[1] Recommended by committees of the Am. Soc. for Testing Materials and the Am. Soc. of Civ. Eng. Many engineers believe this separation should be made on the ¼-inch screen.

properly graded in size forms excellent road-making material. In addition to a graded mixture of gravel there must be present a *binder* of fine dust or some other material that will grind or decompose into a cementing factor. For, while with the larger and more angular particles stability is obtained by mechanical bond, still, as in sand-clay roads, the cementing power of the dust, though weak, is the final requisite of success.

Mechanical Analyses Curves Defined

The gravel having been separated by screens, sieves, or otherwise into several parts determined by the size of the particles a curve is plotted with the sizes of the sieve openings, or particles, as abscissas and the percentage passing the several sieves as ordinates. This is a mechanical analysis, or granulometric analysis of the material. Woven brass wire sieves are used for separating the sand and screens the gravel.

TABLE I

Meshes Per Linear Inch	Diameter of Wire, Inches	Approximate Size of Opening, Inches
10	0.027	0.073
20	0.0165	0.0335
30 [1]	0.01375 (0.011)	0.01958 (0.022)
40	0.01025	0.01475
50	0.009	0.011
80	0.00575	0.00675
100	0.0045	0.0065
200 [1]	0.00235 (0.0021)	0.00265 (0.0029)

[1] The standard 200-mesh cement sieve of the U. S. Bureau of Standards, which is now also the standard for the A. S. T. M., has a diameter of wire of 0.0021 and a nominal opening of 0.0029. Also the A. S. C. E., the U. S. War Department and the A. S. T. M. standard No. 30 sieve for grading sand for cement testing has a wire diameter of 0.011 with a nominal opening of 0.022.

Sieves.—A standard sieve is 8 inches in diameter and $2\frac{1}{4}$ inches high. The number of meshes per lineal inch varies from 10 to 200. Since the wires occupy space it is necessary to determine the actual size of the openings in order to obtain the sizes of the separations made by the several sieves. These have been standardized by the American Society for Testing Materials[1] and are manufactured with such accuracy that they will not vary greatly from these standards. The table gives the A. S. T. M. standard as to number of meshes and size of wires, to this has been added the third column giving the calculated nominal or approximate opening.

Calibrating Sieves.—Sieves should be examined occasionally to see if they correspond with these sizes, and that the wires have not become displaced. The meshes or openings should be perfect squares. There are two ways of calibrating sieves—first, the actual size of the opening is observed by means of a microscope and micrometer; second, a number, 100 or 200, grains of the last sand that passes through in sifting a sample are counted and weighed. Knowing the specific gravity of the sand, the diameter of the grains can be calculated by the formula

$$d=\sqrt[3]{\frac{6W}{Sn\pi}}.$$

where d represents the diameter of the grain in cm.;
W, the weight of the counted grains in gm.;
S, the specific gravity of the sand, approximately 2.65;
n, the number of grains in W;
π, the abstract number 3.1416

The difference between d and the size of the opening where a round well-worn sand has been used is inconsiderable. The former of the two methods given is better adapted to calibrating the fine sieves and the latter the coarse sieves.

The commercial number of a sand sieve is the number of meshes or openings between wires per lineal inch. In gravel screens the openings are drilled round holes of the given diameter.

Density.—The more dense the mixture of gravel, sand and

[1] A. S. T. M. Standards, 1916, p. 535.

TABLE II.—SUGGESTED GRADING FOR GRAVEL

	Percentage Passing														
	Sieve Numbers									Screen Openings					
	200	100	80	60	50	40	30	20	10	1/8″	1/4″	1/2″	1″	2″	3″
Largest stone, 1 inch:															
Upper limit	24	30	33	34	38	43	49	56	70	74	78	85	100		
Medium	20	24	26	27	29	33	37	42	53	56	63	75	100		
Lower limit	15	18	19	19	21	22	25	28	35	39	48	65	100		
Largest stone, 2 inches:															
Upper limit	20	24	26	27	30	33	37	44	58	68	74	78	85	100	
Medium	17	20	22	22	24	26	29	34	43	50	56	63	75	100	
Lower limit	14	15	16	16	18	19	21	23	29	33	39	48	65	100	
Largest stone, 3 inches:															
Upper limit	18	22	23	24	27	29	33	38	50	60	72	75	80	90	100
Medium	16	18	19	20	21	23	26	30	38	45	54	58	67	83	100
Lower limit	13	14	15	15	16	17	19	21	26	30	36	42	53	77	100

clay the better the result. W. B. Fuller and S. E. Thompson [1] proposed a maximum density theory for proportioning concrete aggregate which is, briefly, that "the best mixture of cement and aggregate has a mechanical analysis curve resembling a parabola, which is a combination of a curve approaching an ellipse for the sand portion and a tangent straight line for the stone portion. The ellipse runs to a diameter of one-tenth of the maximum size of stone, and the stone from this point is uniformly graded."

Table II is worked out on the Fuller-Thompson theory and may be used as a rough guide for getting a well-graded mixture of gravel for road purposes. For the method of making up mixtures see Chapter XII, Concrete Roads.

Great Refinement in Grading not Necessary

Good roads have been made of gravel, varying greatly from the above-mentioned maximum density curves. Especially is this true where a coarser gravel is used; the traffic grinds off the gravel itself or tracks on from the side sufficient "fines" to act as a binder. While gravel has been used longer than any other material for hardening roads it, notwithstanding, has been used in a more or less careless, manner the gravel most convenient being hauled and dumped upon the road surface, trusting to time and traffic for the hardening. Therefore, in trying to fix upon a standard grading for gravel roads, it does not seem wise, with our present lack of knowledge, to confine this grading to very narrow limits. The above suggestion may be used until future investigation finds a better. New Jersey, whose gravel roads are considered to be exceptionally good, and several other States, have begun a scientific grading of gravel. The 1915 New Jersey Specifications for the construction of gravel roads are as follows:

Road Gravel.—Road gravel shall be composed of quartz pebbles, sand, clay and oxide of iron in such quantities that the gravel will compact under pressure into a hard, dense pavement. It must not contain over 5 per cent

[1] Transactions of the American Society of Civil Engineers, Vol. 59, '07.

of material retained on $1\frac{1}{2}$-inch circular openings nor over 35 per cent material retained on $\frac{1}{2}$-inch circular openings.

Road gravels shall be divided into three grades, as follows: Grade A is a pebbly gravel, the binder in which is clay. Grade B is a sandy, ferruginous gravel depending upon the oxide of iron for its cementing properties. Grade C is a gravel which does not meet the requirements specified in Grades A or B, but may, on approval by the engineer and the State Commissioner of Public Roads be used for foundation of gravel roads. All gravel for road work must, in addition to the above requirements, fulfill the additional requirement given below.

Grade A must be within the following limits of composition: Materials retained on $\frac{1}{4}$-inch circular openings, not less than 25 per cent, or over 35 per cent; total material retained on a 10-mesh sieve, not less than 40 per cent or over 60 per cent; material passing a 200-mesh sieve, not less than 8 per cent or over 20 per cent; balance of the material to be sand fairly well graded and sharp.

Grade B must not contain less than 20 per cent or over 40 per cent of material retained on a 10-mesh sieve, nor less than 10 per cent of material or over 25 per cent of material passing a 200-mesh sieve. Of the material passing a 200-mesh sieve, at least 40 per cent must be soluble in dilute hydrochloric acid, 1 : 3.

The Colorado Specifications contain this stipulation relative to sizes:

The gravel may be pit, bank or river gravel, and may be taken from the pit or run through the crusher, but at least 60 per cent must be of such sizes as will pass a $2\frac{1}{2}$-inch screen and be retained on a $\frac{1}{4}$-inch screen. The test for this quality to be made by shoveling against a screen inclined 45° to the horizontal.

The Missouri specifications require the gravel of the first course to be not less than 2 inches and not more than 4 inches measured on the greatest diagonal. For the second course not less than $\frac{1}{2}$ inch nor larger than 2 inches and "shall contain not more than 30 per cent of material of less dimensions."

In the American Society of Municipal Improvements specifications (1916) is found this stipulation:

Sizes of Gravel Mixtures.—Two mixtures of gravel, sand and clay shall be used . . . designated . . . as No. 1 product and No. 2 product.

No. 1 product shall consist of a mixture of gravel, sand and clay, with proportions of the various sizes as follows: All to pass a $1\frac{1}{2}$-inch screen and to have at least 60 and not more than 75 per cent retained on a $\frac{1}{4}$-inch screen; at least 25 and not more than 75 per cent of the total coarse aggregate, material over $\frac{1}{4}$ inch in size, to be retained on a $\frac{3}{4}$-inch screen; at least 65 and not more than 85 per cent of the total fine aggregate, material under $\frac{1}{4}$-inch in size, to be retained on a 200-mesh sieve.

No. 2 product shall consist of a mixture of gravel, sand and clay with the proportions of the various sizes as follows: All to pass a $2\frac{1}{2}$-inch screen and to have at least 60 and not more than 75 per cent retained on a $\frac{1}{4}$-inch screen; at least 25 and not more than 75 per cent of the total coarse aggregate to be retained on a 1-inch screen; at least 65 and not more than 85 per cent of the total fine aggregate to be retained on a 200-mesh sieve.

Adopting and Plotting a Standard Grading

While it is not necessary, in order to secure good gravel roads, to grade the material mechanically so as to produce a maximum density, there is no doubt but that such grading will hasten consolidation and retard raveling. It would seem as though five test sieves could be used for laboratory examinations in nearly every case without much trouble:

The finest, either 200 or 100-mesh.
The 10-mesh.
The coarsest.
The one separating about 35 per cent of the adopted standard.
The one separating about 65 per cent of the adopted standard.

In analyzing gravel, the coarsest sieve would probably be first used, and what passes placed on the next coarsest, and so on. The 10-mesh separates what has arbitrarily been denominated the sand from the gravel, and the 200-mesh, the clay from the sand, the other two separations determine whether or not the gravel is a graded mixture.

Having adopted a standard mixture, the curve may be plotted by the author's straight-line method and combinations made up from different pits as in the sand-clay road surface.[1] The advantages of plotting the standard curve as a straight line are: First, Ease of plotting, as any sheet of paper ruled one

[1] For method of plotting straight-line curves, see Chapter VII, p. 154.

way may be used; second, the ordinates representing the finer sieves are spaced farther apart, thus magnifying and making more distinct that portion of the curve; third, it is easy to compare any other grading with the straight-line grading.

Selecting Gravel.—Besides the sieve analysis, the common method of determining suitability of a gravel for road purposes is to note its action in and about the pit. If it is packed firmly in the pit and stands in almost perpendicular walls, it probably will bind well on the road. Cementing tests such as for macadam stone, page 184, should be made on each variety of gravel. The American Society for Municipal Improvements requires a cementation coefficient of 50.

Chemical tests will determine the character of the binding impurities found in the gravel. A mineralogical analysis will answer as well and is much easier made. Iron oxide often found with gravel and clay, makes an excellent binder. A ball of the fine materials may be formed, dried, and roasted in the furnace. If iron oxide is present the roasted product will show the characteristic brick red color.

The binding action may be and probably is both mechanical and chemical. The mechanical action is greatest when the stone is so graded that the voids of the larger particles are filled with smaller particles and the voids of the smaller by still smaller. The grading should, therefore, be such that a minimum of the impalpable dust is required. The extremely fine dust when subjected to moisture and pressure produces a weak cement. The cementing property may be due to chemical action. Some stones show this property very much more than others. Pebbles of bluish color usually cement together better than those of a reddish or brown color, hence the well-known superiority of "blue gravel" for road purposes. Trap rock gravels possess the property of cementation to a high degree; limestone to a fair degree; quartz wears well and is tough but has a small degree of cementation. Mica produces a lubricating effect and is, therefore, detrimental to road gravel. Gravels lacking in binding qualities may be improved by mixing with clay, marl, iron oxide, limestone, or trap-rock dust.

Construction

Drainage.—The sub-grade for a gravel road should be prepared in the same manner as that described for earth roads. Drainage is just as important with a gravel wearing surface, as without it. A dry cellar is necessary, if the roof is to be kept tight and in form. Furthermore, the thickness of the layer of gravel necessary for success diminishes with the degree of drain-

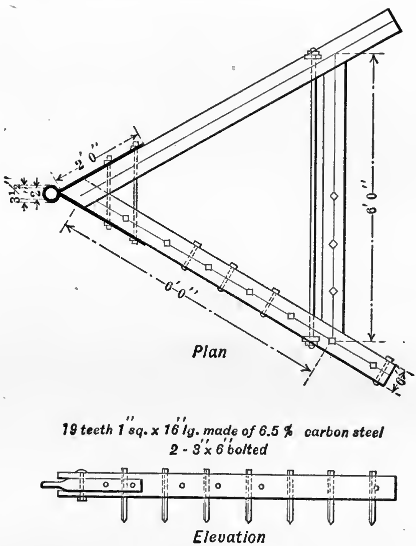


Fig. 98.—Harrow for Smoothing Gravel Roads

age. Where gravel is scarce it is, therefore, economy to look well to the drainage. With an extremely thick layer of gravel the under portion acts as a drainage system.

Design.—There are two methods of construction which are termed the surface method and the trench method. With either method the gravel may be deposited in one or several layers. Likewise the loose method, leaving the consolidation of the material to traffic, or the compressed method, where a roller is used for the compacting, may be employed, the former to be used only as a last expedient.

Surface Method.—The gravel is dumped upon a properly shaped sub-grade and spread with shovels and rakes. A heavy A-shaped [1] tooth-harrow will aid in distributing and mixing the gravel, also, a scraping grader will be found advantageous for spreading it.

This gravel by the *loose method*, which is not recommended, is spread only 3 or 4 inches deep and allowed to be consolidated by the traffic. Then another layer placed upon it and packed in the same manner, and this process continued until the required thickness is obtained. From time to time after rains while this is going on the road should be shaped and smoothed by the King road drag.

With the *compressed method* after harrowing and shaping a roller is placed upon the road and the rolling continued until a firm surface is produced. During the last of the rolling the surface should be sprinkled with water to assist with the compacting. Most road men prefer to have the gravel deposited in comparatively thin layers so that it is compacted from the

[1] Fig. 98 shows a spike-tooth harrow used by the Utah Highway Commission, who give the following method for its use:

"The method of harrowing ordinarily used is, briefly, as follows: After the gravel is dumped in the sub-grade, it is spread with shovels and stone rakes having the tines about $1\frac{1}{4}$ inch apart or with a road machine. Stones which the rake collects are pulled forward onto the earth sub-grade. After spreading the harrow is dragged over the loose gravel until a uniform mixture is obtained. As a rule, four or five trips are sufficient to accomplish this. If the road is narrow teams may be hitched so they can walk on the earth shoulders, which is an advantage. When gravel is laid in two courses the top course should receive the more thorough harrowing. Great care should be used to rake all over-sized stones out of this course. This is best accomplished while the harrow is in operation.

"In incorporating clay or loam binder in a sandy gravel, great care should be observed to see that the binder is in a dry and thoroughly pulverized condition. Damp clay cannot be harrowed in without leaving lumps to cause trouble in the future. Binder is best spread with shovels from a wagon or piles at the side of the road. It should never be dumped on the gravel. An even coat from $\frac{1}{4}$ to $\frac{1}{2}$ inch thick should be spread uniformly and the spike-tooth harrow used to mix it with gravel below. The quantity of binder is dependent upon the condition of the gravel and is best determined by trial on a short section of road."

bottom up and equally dense throughout. Figs. 99 and 100 show typical gravel road cross-sections.

Trench Method.—The subgrade is prepared in the usual manner and a trench is made along the roadway as wide and deep as the graveled wearing surface is desired. A shoulder of earth at least 3 feet wide is left outside the trench to assist in retaining the gravel in place. A layer of gravel 3 or 4 inches thick is placed in the trench and rolled. It is important that

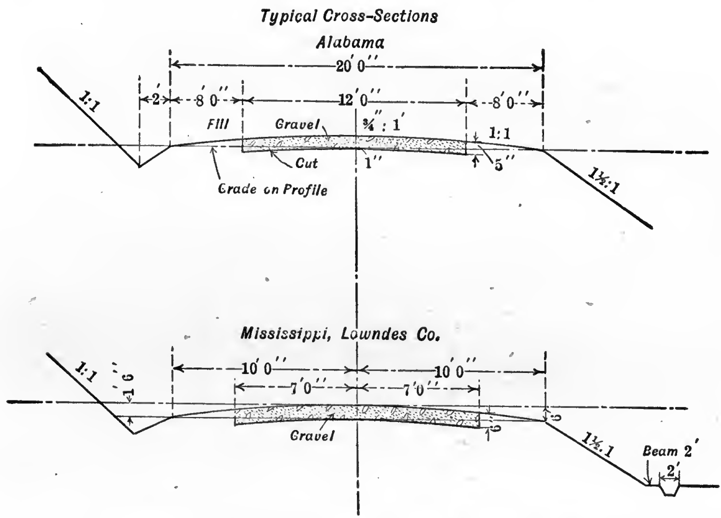


Fig. 99.—Typical Cross-sections for Gravel Roads.

the rolling should begin at the earth shoulders, which are first rolled and the roller gradually worked toward the center. A second layer is placed in the trench and the process repeated until the proper thickness has been obtained. During the latter part of the rolling a plentiful supply of water should be sprinkled on the roadway to assist with the consolidation. If this cannot be done rolling after a rain will answer.

Chert or Flint.—Chert, a non-crystalline variety of quartz which usually occurs in irregularly shaped concretions in limestone, is of a flinty structure, found in both dark and light colors and breaks with a conchoidal fracture. Where the original rockbed has been broken down, the chert nodules often remain as beds of gravel. It is usually much more angular than ordinary gravel. Bank chert may be quarried by blasting, then broken into smaller fragments by the hammer or crusher. Creek chert being washed and cleaned by the washing and grinding action of the water usually contains less binding matter than the bank cherts. Where insufficient binder is present the usual binders, sand and clay, should be added. The flint tailings or chats

FIG. 99a.—Spreading Gravel with a Blade Scraper. Courtesy of Iowa State Highway Commission.

from the zinc mills of southern Missouri are of this same character. Chert is found in the southern Appalachian region, southern Illinois, Missouri, Arkansas, Oklahoma, Kansas, and Nebraska. Excellent roads have been constructed of this material. The Office of Public Roads directed the construction of a road having creek chert as a foundation and bank chert for the wearing course that after four years' use was said to be in first-class condition although it had not been resurfaced.

Repairs and Maintenance

The repair and maintenance of a gravel road is somewhat like that of an earth road. If the gravel surface has rutted

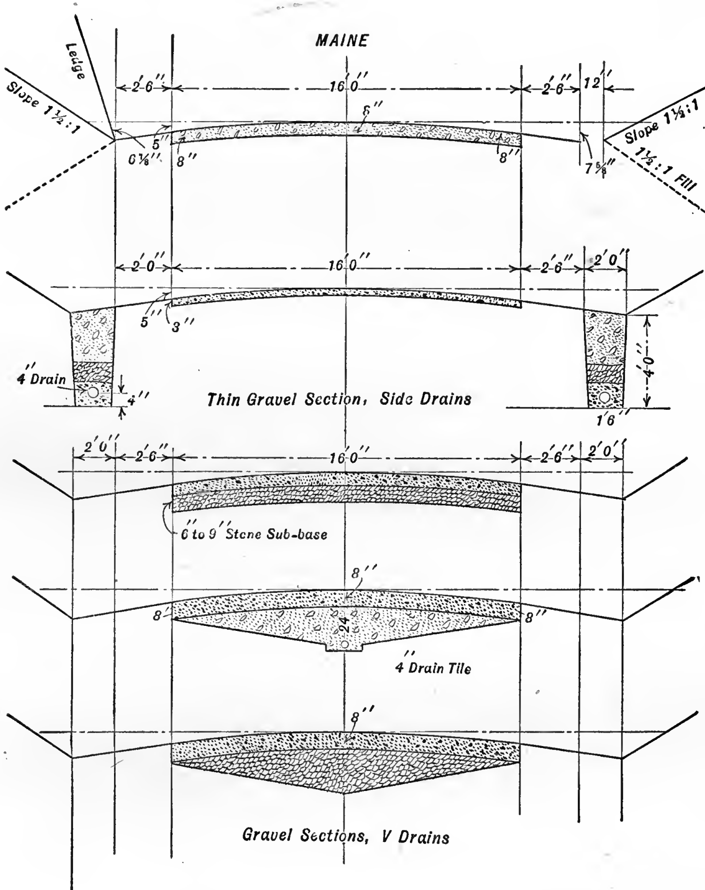


Fig. 100.—Typical Gravel Road Cross-sections

badly or has worn thin it should be picked up, plowed up, or loosened with a scarifier. The best method to use will depend upon the amount to be done and the tools at hand. After the surface has been loosened the stones should be raked or harrowed to allow the fine dirt to settle to the bottom. New gravel should then be placed upon the road spread and rolled to place. Before rolling, however, to save waste, the earth shoulders must be put in good condition.

The ordinary maintenance consists of filling pot holes and incipient ruts by sweeping, raking, or dragging. Sometimes a blade grader can be used to advantage. Steel drags, or drags shod with steel are best for use on gravel. Piles of gravel placed at short distances along the roadway are extremely convenient and allow the patrolman to make small repairs before raveling takes place. After a rain is an excellent time to mark the spots that should receive attention.

CHAPTER IX

BROKEN-STONE ROADS

UNTIL the advent of the automobile, broken-stone roads were thought to be the best type of so-called " permanent roads " for rural communities. The surface of such roads are of natural broken stone of varying sizes wedged firmly together by rolling and further " bound " or cemented by a weak cement, composed of the dust worn from the stones themselves in the process of rolling or by traffic, and water. Such a surface is generally spoken of as " water bound." Dust and moisture are essential elements in its life. For greatest durability, these must be in exactly right proportions. A road under heavy traffic should have an extremely hard, tough stone while one under light traffic will be best with a softer and more friable stone.

The quality of stone for road purposes may be tested by the methods and machines adopted by the U. S. Office of Public Roads, a brief synopsis of which is given here.

TESTING ROAD STONE [1]

The chief properties essential to good road materials are *hardness*, *toughness*, and *cementing* or *binding power*.

Hardness.—The test is known as the Dorry test and consists in grinding specimens with sand of a standard size and quality. Hardness thus found may be defined as the resistance which a material offers to the displacement of its particles by friction. The measure is inversely as the loss of weight arising from the scoring by an abrasive agent

[1] Bulletin No. 79. U. S. Office of Public Roads. See, also, Bulletins 28, 31, and 44.

Fig. 101 shows the Dorry machine. It consists of a revolving steel disk upon which is pressed by constant weights of 1250 grams, two small stone cylinders 25 millimeters (1 inch) in diameter and 25 millimeters long. Upon the cylinder as it revolves is spread standard quartz sand which will pass a 30- and be retained on a 40-mesh sieve. The test piece is made true

FIG. 101.—Dorry Hardness Testing Machine.

to shape then weighed and ground on one face for 1000 revolutions; it is then turned over and ground on the other face for 1000 revolutions. The loss in weight is found after each 1000 revolutions and the average is used in stating the hardness which is expressed by the formula

$$\text{Hardness} = 20 - \tfrac{1}{3}W,$$

where W = loss in grams per 1000 revolutions. Stone having a coefficient in hardness below 14 is called soft, 14 to 17 medium and above 17 hard.

Toughness may be defined as the resistance a rock offers to fracture under impact, such as the blow of a hammer; it is the opposite of brittleness and friability. It is tested by the machine shown in Fig. 102, which is essentially a small pile driver. A 2-kilogram weight falling a distance of 1 centimeter for the first blow, 2 centimeters for the second blow and increasing 1 centimeter for each blow until fracture occurs. The test piece is like that used in the Dorry machine, a cylinder

FIG. 102.

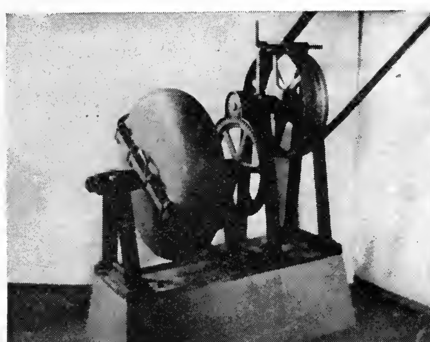


FIG. 103.

Photographs of a Page Impact Machine and of a Ball Mill in the Road Laboratory of the University of Nebraska.

(25 cm. in diameter) drilled with a core drill from the solid rock and faced off 25 cm. long. The number of blows which is the height of fall of the last blow in centimeters, is the measure of toughness. Rocks testing below 13 are low; from 13 to 19, medium; above 19, high.

Cementing Value.—This is defined as the binding power of the road material and the test for it is made as follows: Five hundred grams of the rock to be tested are ground in the ball mill, Fig. 103, with sufficient water to form a dense fine-grained paste. The ball mill is a hollow casting in which roll two chilled steel balls which weigh 25 pounds each and is revolved about 2000 revolutions per hour. The thoroughly kneaded paste or dough is removed and placed in a metal die, 25 mm. in diameter and subjected to a pressure of 132 kilos per square centimeter. The pressure is gradually applied until a weight

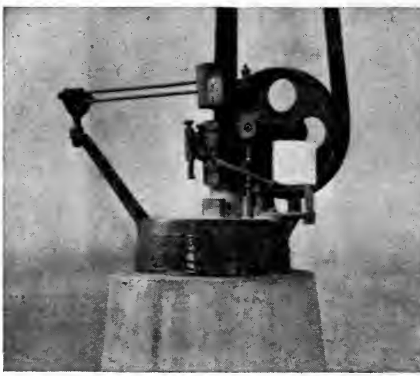


FIG. 104.—Photograph of a Page Impact Machine, for Testing Cementing Value, in the Road Laboratory of the University of Nebraska.

at the end of a lever is raised and it is then immediately released. The amount of paste used is just sufficient to form a cylinder 25 mm. long. Five briquettes are made and allowed to dry in air one day and in a hot oven at 200° F. for four hours, then cooled in a desiccator for twenty minutes. The briquettes after drying are tested in the machine shown in Fig. 104. A 1-kilogram hammer is raised by a cam and allowed to drop on plunger which transmits the impact to the test-piece. The instrument has a cylinder about which is wound a strip of silicated paper and on which is automatically recorded the number of blows struck to produce fracture, and the resilience of the test piece. The average number of blows on the five briquettes is taken as the result of the test. A result of 10 is low, 10 to 25 fair, 26 to 75 good, 76 to 100 very good, over 100 excellent. In making this test care must be taken that the dough in the ball mill has become thoroughly pulverized and kneaded.

Resistance to wear, although depending largely upon hardness and toughness, is a special property which cannot be exactly determined as a function of these. The method of

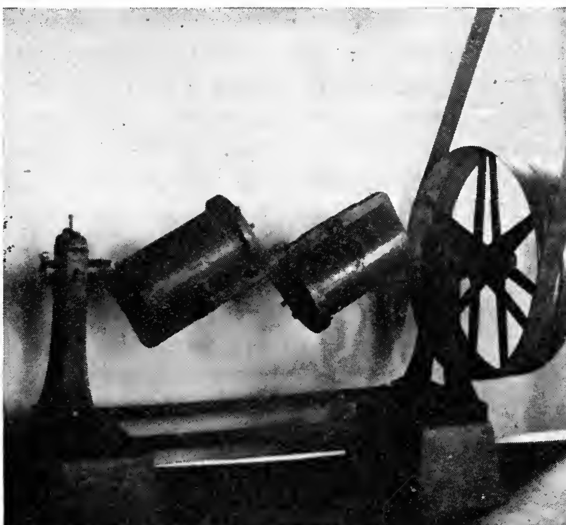


Fig. 105.—Deval Abrasion Machine.

testing for it was devised by the French and is done by means of the Deval abrasion machine, Fig. 105. The machine consists of one or more hollow iron cylinders mounted on a shaft so that the axes of the cylinders make an angle of 30° with the shaft. As the shaft is revolved the rock in the cylinders is thrown from one end to the other. The impact and abrasive action together tend to break the pieces of rock into finer and finer particles. The rock to be tested is broken into pieces from $1\frac{1}{4}$ to $2\frac{1}{2}$ inches in size. Five kilograms (within 10 grams) fifty pieces if possible, are placed in the diagonally mounted cast-iron cylinder and slowly revolved 10,000 times at a rate between 30 and 33 revolutions per minute. The material worn off which will pass a $\frac{1}{16}$-inch mesh sieve is considered the amount of wear. This is expressed either as a percentage of the charge (5 kilograms) or by the French coefficient of wear—

$$20\times\frac{20}{W}=\frac{400}{W},$$

W being the weight in grams of the detritus under $\frac{1}{16}$ inch in size—per kilogram of rock used. The French engineers who were the first to undertake the testing of road materials divided 40 by the percentage of wear in order that a higher coefficient might show a better rock than a lower coefficient. They found that their best-wearing rocks gave a coefficient of about 20. The number 20 was, therefore, adopted as a standard of excellence. A coefficient of 8 is low; 8 to 13, medium; 14 to 20, high; above 20, very high.

These are the principal tests used. Other tests may be made, thus:

Specific gravity is determined by weighing a rock in air and in water and dividing the weight in air by the loss of weight in water. If W = weight in air, and w = weight in water

$$\text{Sp. gr.}=\frac{W}{W-w}.$$

The specific gravity multiplied by $62\frac{1}{2}$ gives the weight of the rock substance per cubic foot.

Apparent Specific Gravity, A. S. T. M. Standard.[1]

$$\text{Apparent Specific Gravity}=\frac{A}{B-C},$$

where A = weight of sample, dried to constant weight at a temperature between 100 and 110° C., should be within .5 gram of 1000 grams, composed of pieces aproximately cubical or spherical which will be retained on a $\frac{1}{2}$-inch screen;

[1] 1918 Standards, p. 628.

B = weight of sample after having been soaked in water for twenty-four hours, the surface water absorbed by a blotting paper or a towel;

C = weight of sample suspended in water from the center of a scale pan in a wire basket less the weight of the basket suspended in water, that is, the weight of the saturated sample immersed in water.

Absorption.—The amount of water which a rock will absorb is sometimes taken to measure durability. The idea being, the more water absorbed, the more effect freezing will have on the rock. This does not always follow.

Compression.—High compressive tests usually mean good quality of stone for building purposes but not necessarily for road purposes; however, this property taken in combination with the other tests is of value.

Simpler Methods of Judging the Character of the Rock.—The durability of a rock under the action of the weather may be judged by the character of the outcropping of the ledge at the ground surface or by stones which have lain out for a number of years. If these show a decided tendency to disintegrate, they will probably do the same in the road. The toughness and hardness may be judged by breaking with a hammer. Easily broken brittle stones lack toughness. The effect of the hammer upon the appearance of a freshly fractured surface will furnish a general estimate of resistance to wear and specific gravity. But after all the best test is the behavior of the stone in the road itself or in roads of a similar character.

Classification of Rocks

The U. S. Office of Public Roads has divided rocks for road-making purposes into three classes and these are again divided into Types and Families as shown by the following table, taken from Bulletin 31, by Edwin C. E. Lord:

With the exception of rocks of the second class, where chemical distinctions prevail, structural features indicating

TABLE I.—GENERAL CLASSIFICATION OF ROCKS

Class	Type	Family
I. Igneous	1. Intrusive (plutonic)	*a.* Granite *b.* Syenite *c.* Diorite *d.* Gabbro *e.* Peridotite
	2. Extrusive (Volcanic)	*a.* Rhyolite *b.* Trachyte *c.* Andesite *d.* Basalt and diabase
II. Sedimentary	1. Calcareous	*a.* Limestone *b.* Dolomite
	2. Siliceous	*a.* Shale *b.* Sandstone *c.* Chert (flint)
III. Metamorphic	1. Foliated	*a.* Gneiss *b.* Schist *c.* Amphibolite
	2. Non-foliated	*a.* Slate *b.* Quartzite *c.* Eclogite *d.* Marble

mode of origin define a type, and mineral composition the family.

Igneous Rocks are those which are formed by solidification from a molten state either beneath the surface of the earth (intrusive) or upon reaching the surface (extrusive). Mineralogically some of the intrusive rocks may be the same as the extrusive, they will, however, differ in structure.

Sedimentary or Aqueous Rocks are the consolidated product of former rock disintegration or they have been formed from the accumulation of organic remains. These materials have been transported by water and deposited in layers giving the characteristic stratified structure.

Metamorphic Rocks are those which have undergone change due to prolonged action of physical and chemical forces such as heat, pressure, moisture and various attending chemical agencies.

Mineral Composition

Rocks, as ordinarily known, are combinations of minerals. Quartz, which is almost pure silica, is the most common. Orthoclase (silicate of alumina and potash) and plagioclase (silicate of alumina, lime, and soda) are prominent minerals in the feldspars or field stones and hence in road-making rocks. Other minerals of common occurrence are augite, hornblende, calcite, dolomite, and bistite. A number of others formed largely by decomposition of primary minerals furnish valuable cementing properties to road rock; for, example, chlorite, kaolin, epidote, calcite, and limonite.

Principal Road Rocks

Trap rocks have long been known to form the best road stone. These are finely crystalline igneous formations, and usually of a dark color. Many of them in cooling run over each other in broad steps or trappa (Swedish for stair) hence the name trap. The principal mineral constituent is plagioclase. Included among them and largely used for road purposes are:

Basalt, a glassy-porphyritic homogeneous rock of dark gray or black color.

Diabase, a holocrystalline or granular rock of green or dark gray color.

Peridotite, variable in structure, either crystalline, granular or porphyritic (a compact structure with large crystals) and greenish or black in color.

Andesite, glassy to holocrystalline in structure and varying from a greenish to reddish color.

Other rocks frequently used though less durable are:

Diorites, whose mineral elements are largely feldspar, plagioclase and hornblende. They are green, dark gray or black in color.

Granites are largely composed of quartz, orthoclase and plagioclase, combined with mica and hornblende. Are holocrystalline granular in structure.

Syenites are similar to granites except they do not contain quartz.

Gneisses have a holocrystalline granular structure arranged in parallel bands.

Construction of Stone Roads

The subgrade of a stone road should be prepared similar to that of an earth road. The drainage should be carefully looked after, side drains placed where necessary to lower the ground water below the frost line. Wet soil in freezing, " heaves " the roadway loosening the stones by breaking the bond allowing the larger stones to come to the top where they will pick out under traffic. A wet, soft material in the subgrade will be forced up into the interstices and the surface will become uneven. Surface water must be cared for by side ditches and suitable runways, culverts and bridges. The subgrade, if not already compact under traffic, should be thoroughly rolled to prevent settlement.

Stone roads are usually classified as telford and macadam, so named after Telford and Macadam, two eminent road builders of England.[1]

[1] Thomas Telford was born in Dumfriesshire, Scotland, August 9, 1757, and died September 2, 1834. He was one of the greatest civil engineers of his time. He constructed bridges over the Severn, across the Tay and at numerous other places, planned and superintended the Ellismere Canal, was commissioned by the government to report on the public works required for Scotland, constructed the Caledonian Canal, executed more than 1000 miles of roads in Scotland and England, and designed and constructed harbor improvements at Pullneytown, Aberdeen, Dover, London, and many other ports. He was one of the founders of the Institute of Civil Engineers and for many years was president. He received recognition and honor from his home and foreign countries. For the Austrian government,

Tresaguet in France had built roads previously and these men were, no doubt, familiar with his work, but the English-speaking nations have perpetuated these two names in lasting monuments by calling the two principal classes of stone roads "macadam" and "telford."

A macadam road is one surfaced with small angular broken stones compacted and wedged together and further bound by stone dust, all upon the earth subgrade. The broken stone is frequently spoken of as macadam. **The telford** road is essentially the same with this difference, the foundation is made by paving the earth subgrade with stones of a larger size and then upon this foundation placing the macadam surface. Nowadays, roads over very wet country adopt the telford, and those on comparatively solid well-drained ground, the macadam type, Fig. 106, also see Fig. 118, Chapter X.

he built the road from Warsaw to Brest. Because of his work on the Gotha Canal the King of Sweden conferred on him an order of knighthood; while at his death, his own country buried him in Westminster Abbey.

John Loudon Macadam was born at Ayr, Scotland, September 21, 1756, and upon the death of his father in 1770 went to live with an uncle in New York. He entered his uncle's counting house, became a successful merchant and on returning to Scotland in 1783 bought an estate in Ayrshire. He was later appointed deputy-lieutenant for the county and while performing the duties of that office became interested in roads. In 1810 he began experimenting by putting broken stone in the swampy roads. In 1816 he became inspector of the Bristol Turnpike Trust and superintended the reconstruction of 178 miles of road. In 1817 he built the first macadam roads in London, where he was appointed street commissioner the same year. Slowly the system of road making which he advocated, although he may not have been its actual inventor, spread throughout the empire. In 1827 Parliament appointed him Surveyor General of Metropolitan Roads and voted him $48,000. Three works on the subject of roads were written by him. He died November 26, 1836.

Pierre-Marie Tresaguet was a noted French engineer born at Nevers, in 1716, and died at Paris in 1796. He is sometimes called the father of modern road building, having built stone roads before either Macadam or Telford. He built roads on a plan similar to that afterwards used by Telford in Scotland. He laid the foundation for the splendid system of roads in France by recognizing the necessity for organized continouus maintenance after substantial construction.

Subgrade.—The subgrade is prepared for the stone by excavating a trench sufficiently deep and wide for the compacted stone surface. The bottom of the trench may be either level, V-shaped or parallel to the finished surface. The level surface is a little easier to make, the V-shaped furnishes additional drainage providing suitable outlets are made frequently along the road, but the crowned ditch is the one most usually used. This makes the thickness of the metal uniform over the roadway, thus saving in the quantity of material. The earth

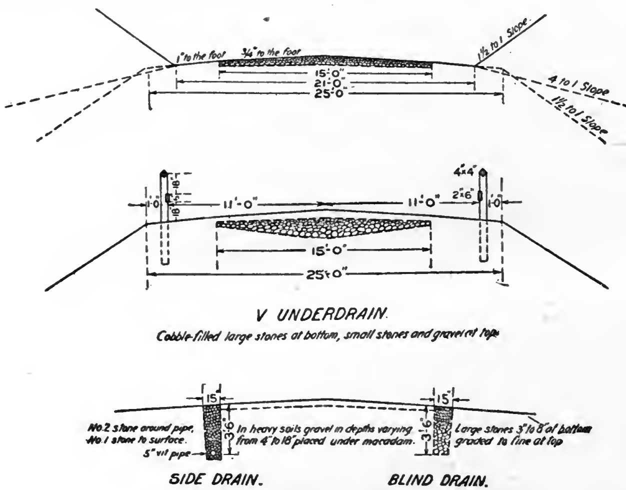


Fig. 106.—Typical Cross-sections.

from the trench is piled along the roadway and used for the shoulders later, and prevents the spreading of the macadam when it is rolled. The bottom of the trench should be rolled to a firm true surface so that under the roller or traffic the stone will not unduly cut into it or the earth squeeze up into the stone.

The cross-sections, Figs. 106, 107, all show a certain amount of crowning. Three-quarters of an inch to the foot is usually considered sufficient thus, for a roadway 16 feet wide the center would be raised 6 inches. On roads of considerable width, as, naturally, they will be roads having heavy traffic and constant attention, the crown may be reduced to $\frac{1}{2}$ inch per foot. There is little difference whether the crown be made of two sloping planes with the intersection rounded or of a parabolic form.

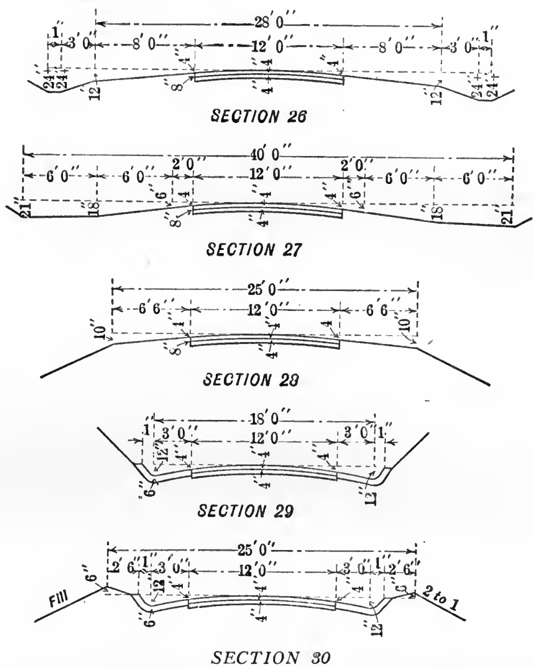


FIG. 107.—Standard Macadam Sections for Illinois Roads.

Section 26—Twelve-foot water-bound macadam roadway with earth shoulders. To be used in a level country. Section 27—Twelve-foot water bound macadam roadway with earth shoulders and broad side ditches available for traffic where width between fences permits. Especially adaptable for a low-lying level country. Section 28—Twelve-foot water-bound macadam roadway with earth shoulders. To be used on deep fills. For shallow fills use Section 1. Section 29—Twelve-foot water-bound macadam roadway for single track roads in deep cuts on grades that require grouted gutters. Section 30—Twelve-foot water-bound macadam roadway for single-track roads on deep fills where grouted gutters are necessary.

Courses.—Since it is difficult to compact a layer of stone more than 6 inches thick stone roads are best made in courses having the larger stones in the lower course. This insures better under-drainage and a smoother wearing surface, although many stone roads have been made with crusher-run stone. The voids between loosely spread broken stone amounts to about 40 or 50 per cent of the volume of the layer or course. In the process of rolling this is frequently reduced to 30 or 35 per cent. Therefore, the loose layer should be made about 40 per cent thicker than the compacted layer is desired. This is a rough estimate for calculating quantity of stone required. Trial upon the road is necessary for any particular location. At some places stones will sink more into the subgrade than at others; some rocks will pack better than others. Table II shows roughly thicknesses of macadam required:

TABLE I

Lower Course		Middle Course		Upper Course		Total Thickness	
Before Rolling	After Rolling	Before Rolling	After Rolling	Before Rolling	After Rolling	Before Rolling	After Rolling
3½	2½	......	......	2	1½	5½	4
4	3	......	......	3	2	7	5
5½	4	......	......	3	3	8½	6
5½	4	......	......	4	3	9½	7
5½	4	3½	2½	2	1½	11	8
5½	4	4	3	3	2	12½	9
5½	4	5½	4	3	2	14	10

In addition to the stone shown in the table there will have to be provided the "binder," which consists of stone dust and small fragments which will pass a ½-inch screen.

Placing the Broken Stone.—The lower course, consisting of the larger stones—1¼ to 2½ inches [1] in diameter—are spread first, Figs. 108, 109, 110.[2] Unless self-spreading wagons are used

[1] In three-course work still larger stones should be used in the bottom course.

[2] From Bulletin 29, Office of Public Roads, U. S. Dept. of Agriculture.

the stone should be shoveled from the wagons or dumped directly on the road and leveled the fragments appear to segregate and compact unevenly; no amount of rolling can remove the hummocks thus left.

After the stone has been spread by shovels to the required depth, due allowance being made for shrinkage, for a hundred or so feet the rolling of the first course is begun. Begin

Fig. 108.—Placing the Stone. Courtesy U. S. Dept. of Agri.

by rolling first a part of the earth shoulder, working inward toward the center a few inches with each round of the roller. This will prevent pushing the stone outward. The rolling should be continued until the first course is thoroughly compacted and does not wave before the roller. Sometimes the stone will not pack. This may be due to a wet soft subgrade, dry weather must be waited for; it may be the stone is too hard, in which case some screenings or sand should be used; the roller may be too heavy, a lighter one should be provided for early

FIG. 109.—Rolling. Courtesy U. S. Dept. of Agri.

FIG. 110.—Finished Road. Courtesy U. S. Dept. of Agri.

rolling. Unless the stone is "packing" continued rolling is detrimental. Absolute rigidity is not necessary here, but a firmness so the stones will not heave before the roller or quake under the foot should be obtained.

If depressions occur they should be filled with stone of the same size as the course being rolled. When the first course is smooth and true to cross-section the next course may be spread.

Upper Course.—This course, consisting of stones varying from $1\frac{1}{4}$ to 1 inch in diameter, is spread and rolled in the same manner as the lower course. When the stones have been compacted and tightly wedged together a small layer of binder is spread and the rolling continued to force it into the interstices. The watering cart is now used and the "fines" flushed in. Rolling is continued until a wave of slush is pushed along ahead of the roller. Only a very little more than enough "fines" to fill the interstices should be used. The durability of the road will depend largely on the rigidity obtained by the wedging action of the stones. Unless they are held firmly in close union the weak cementing action of the stone-dust will be of little value. Rolling is an important operation, for not only the rigidity, but the surface alignment and smoothness, depend upon the manner in which it is executed.

Since the greater cementing action of stone-dust comes only after the primary minerals have been disintegrated and the secondary set up[1] the true metallic ring of the road will come some little time after finishing. Use of the road as the setting of the cement takes place is beneficial.

If the subgrade will not harden sufficiently resort should be had to tile or other drainage, or a telford foundation may be used. In Jackson County, Mo., a bottom course of native limestone made up of large stones—"one-man-size"—is used as a foundation course, Fig. 118, Chapter X. A man with a sledge goes over this and breaks off projecting points and the whole is rolled to a comparatively smooth surface before the macadam is laid.

[1] See Bulletins 28, 31, 85 and 92, U. S. Office of Public Roads.

Shoulders.—The earth thrown out of the trench may be smoothed down and will furnish either an earth road along the macadam or room for turning out. Keeping the shoulders high and smooth will also help to preserve the macadam. If the earth sides are used more or less for traffic they will remain firm and the macadam will be held in place. In dry locations trees and shrubbery may be induced to grow along the roadway, which, serving as a wind break, will prevent the blowing away of the binder. The taller trees, because of their shade, prevent excessive drying out of the road, besides, they are of ornamental value.

Width and Thickness of Macadam.—The width of the macadamized way will depend upon local conditions. A one-way road with good earth on the side for turning out may be as narrow as 8 feet. The general practice is to build them from 16 to 18 feet in width. Thickness also depends somewhat on traffic conditions, 4 to 6 inches after compaction is common. A great number of French roads were measured and averaged a little less than 5 inches. Loose stone is estimated to consolidate from $\frac{1}{4}$ to $\frac{1}{3}$ under rolling and traffic. The table previously given is figured on approximately a 30 per cent basis. Frequently the macadam is made thinner on the outer edges than in the center for the reason that the outer portions receive a less share of traffic.

Maintenance

Continuous Method.—For all classes of roads the continuous method of maintenance is growing in favor. By this method a patrolman is kept on a given section of the road. He watches for depressions, which show up more clearly after a rain. If the depression is small, he may be able to fill it by sweeping into it loose materials from the surrounding surface or by bringing new material from a pile near at hand. If the depression is larger and takes on the nature of a rut or chuck hole, it may be necessary to pick up that portion of the roadway and apply new stone. The traffic will soon consolidate it. Dragging a macadam road with a split log or other drag will have a tendency to fill depressions with detritus and leave the surface in a smoother more acceptable condition.

Periodic Method.—When the roadway has worn so thin or it has become so rutted that these methods are not sufficient, the entire road is picked, plowed or rooted up, the larger stones raked or harrowed free from dirt and dust and the road rebuilt. The picking may be done by spikes placed in the wheels of the roller or tractor, or it may be done by "scarifiers" or "rooters," Fig. 111, especially made for that purpose. Sometimes a mere resurfacing of about 3 inches of stone is all that is necessary.

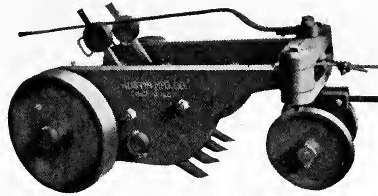


FIG. 111.—Scarifier or Rooter.

Effect of Automobile on Macadam.—One of the worst foes

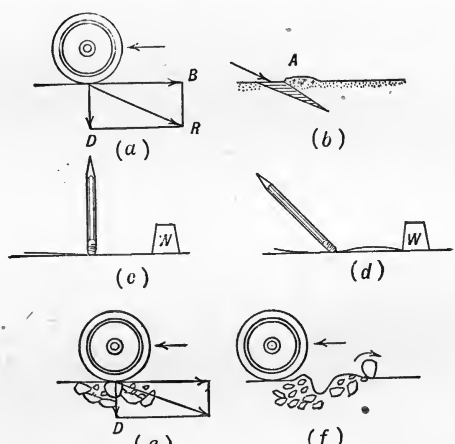


FIG. 112.—(*a*) The Resultant Pressure Exerted by an Automobile Wheel upon the Road Surface. (*b*) A Wedge of Earth Forced in by the Resultant Pressure Loosening the Road Metal Back of It. (*c*) and (*d*) Show How a Pencil, a Piece of Paper and a Weight on a Smooth Table Will Illustrate This Action. (*e*) and (*f*) Show How a Stone May be Rolled from the Surface by the Backward Force of Friction.

of the waterbound macadam road is the automobile. The power being applied through the wheel, the resultant force, *R*, Fig. 112, upon the road has for components the backward push of the wheel, *B*, and the downward weight of the wheel, *D*. The resultant force, *R*, acting on a small wedge of road surface tends to split out the material just above it as shown at *A* in Fig. 112 (*b*).

The friction of the wheel against the pusned-out portion lifts it and throws it into the air as dust or loosened fragments. The pneumatic tire of the automobile does not grind off new dust to replace that sucked up and blown away; soon the roadway deprived of its cementing property loosens and ravels. Again, if the automobile is in the act of starting, or stopping, or rounding a curve, or otherwise quickly changing its state of motion, the component backward force may become very large. The horizontal pull on a stone directly under the wheel, due to friction, may be sufficient to cause it to rotate, as one gear wheel acting upon another, which rotation will carry it out of and backward along the pavement. This backward force may actually shear off of the surface thin flakes of road material, as well as throwing backward loose particles and dust.

Crushers and Screens

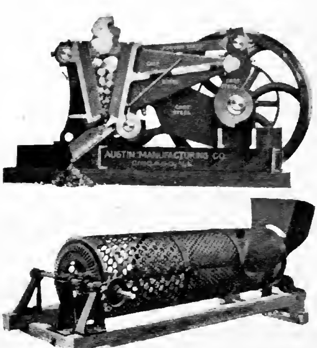


Fig. 113.

Where road stone is plentiful near the highway to be improved, a portable crusher may advantageously be installed. Such crushers are usually of the jaw type, Fig. 113, and so arranged that the crushed stone is elevated to the revolving screen which separates it into sizes and drops it into bins from which it is drawn into wagons for transportation to the road. With the jaw set for crushing two-inch stone the following capacities are given for jaw crushers:

Size of jaw opening at the top in inches	8 × 16	9 × 18	10 × 22
Capacity in tons per hour	9 to 14	12 to 20	16 to 25
Horse power required	12	15	25

The gyratory crusher, Fig. 114, is quite extensively used in permanent plants. The gyratory crusher is said to be more

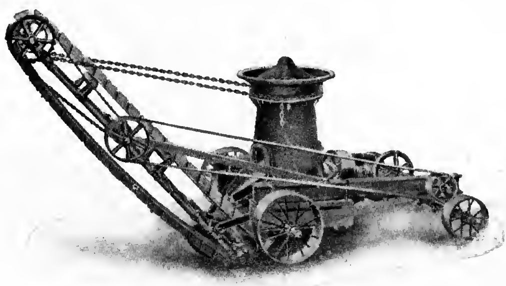


FIG. 114.—Portable Gyratory Stone Crusher and Elevator.

durable than the jaw crusher, is very rapid and turns out a uniform product. The following specifications are given:

Adaptable to portable plants:			
Receiving opening in inches	7 × 32	8 × 35	10 × 40
Capacity in tons per hour	10 to 20	20 to 40	30 to 60
Horse power required	15 to 20	18 to 25	30 to 60
Adaptable to permanent plants:			
Receiving opening in inches	10 × 38	12 × 44	14 × 52
Capacity in tons per hour	30 to 70	50 to 90	80 to 120
Horse power required	22 to 30	28 to 45	50 to 75

CHAPTER X

PAVEMENT FOUNDATIONS

THE growing tendency to pave[1] rural roads with brick, Portland cement concrete, wood blocks, bituminous macadam, bituminous concrete and sheet asphalt, makes it necessary to touch briefly upon pavements. Since the durability of a pavement depends largely upon the stability of its foundation, this chapter will be devoted to foundations entirely.

Definition.—A pavement foundation for the purposes of this chapter may be defined as that layer of the roadway differing

FIG. 115.—Typical Pavement Sections.

from the original subgrade which is placed upon the subgrade to reinforce the supporting power of it, Fig. 115. The soil of the subgrade, as a rule, is not sufficiently rigid to support without movement or settlement the weight of the traffic and the pavement. A slight unevenness of the pavement surface soon develops into a "pot hole" or a rut. So in best practice the

[1] The special Committee on Road Materials of the Am. Soc. of Civ. Eng. suggests this definition for "pavement." "The wearing course of the roadway or footway when constructed with a cement or bituminous binder, or composed of blocks or slabs, together with any cushion or 'binder' course."

roadway is made up of two or more layers, the lower one, resting upon the natural subgrade, being for the purpose of strengthening or supporting the upper courses. The lower supporting artificial course or courses comprise the foundation, and, specifically, all above this, the pavement. Generally, however, the word pavement includes the entire structure.

Subgrade.—The original earthy matter—soil, sand, gravel, rock—upon which the road rests is the subgrade or base. It evidently must bear the weight of the traffic and the pavement. The principal object of the entire pavement is to distribute the loads coming upon it in such a manner that an undue amount shall not fall on any portion of the subgrade. If a wheel load P, say, Fig. 116, rests upon an area A, it will be distributed through the pavement somewhat in the form of a pyramid and if the pavement be thick enough, while the intensity of pressure is not the same over the entire base B,[1] nowhere in the base will it exceed the safe bearing pressure of the subgrade material.

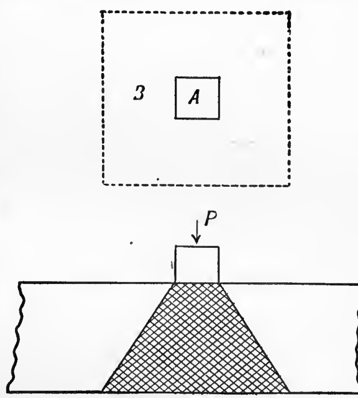


Fig. 116.—Diagram to Show Distribution of Pressure.

Safe Bearing Loads.—Builders give the bearing loads per square foot that may be safely used as follows:

	Tons.
Solid rock	12 to 15
Brick	8 to 12
Coarse sand or gravel in undisturbed and well-bonded strata	6 to 9

[1] Experiments carried on at the University of Illinois found the pressure through sand as shown in Fig. 117 taken from an article by M. L. Enger, in Engineering Record, January 22, 1916. Showing the greater the depth the more uniform the pressure on any horizontal plane but that a great depth must be attained for even near uniformity.

	Tons.
Well-drained clay	4 to 6
Moderately dry clay	2 to 8
Loam, dry	2 to 4
Sand, compacted and well held in place	2 to 4

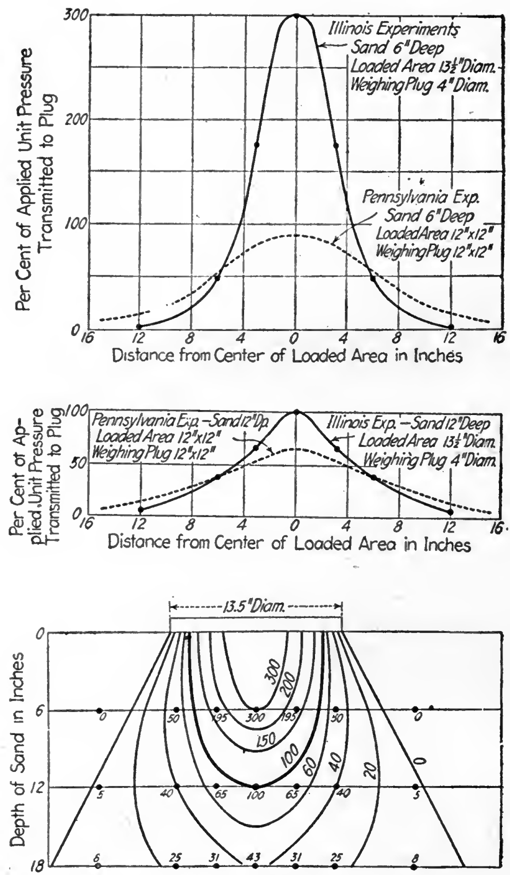


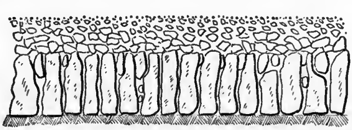
Fig. 117.—Distribution of Pressure through Sand.

When clays, sand or soils become wet the supporting power is very greatly decreased.

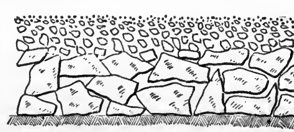
Strengthening the Subgrade.—Rolling the subgrade with a moderately heavy roller will generally improve it and will show soft places such as trenches that may have crossed the road, animal burrows, or "springy" spots. Where sufficient rigidity cannot be obtained by rolling, the soil may have to be removed and replaced by broken stone, gravel, sand, clay, cinders, shells, brickbats, burnt gumbo, clinkers, slag, sod, hay, brush, logs, plank, or whatever else may be most available. In Massachusetts a soft subsoil under a macadam road was improved by spreading over it a single sheet of cheesecloth. This prevented the individual stones from sinking into the mud and made it possible to consolidate the macadam. Grass, hay, and brush have frequently been used for a similar purpose. Such materials, when placed in very wet places, even if they do decay after the road is built, seldom do any harm. Plank has been used in swampy land and more recently at Gary, Ind., and in California, over very sandy places.

Foundations Proper

Stone Foundations.—**Telford,** Fig. 118, is a pavement of roughly broken stones placed upon a subgrade, usually parallel



Telford



Missouri

Fig. 118.—Stone Foundations.

with the finished surface of the road. The stones are set up on edge across the road and wedged together by spalls. Projecting portions above the surface are knocked off and the whole rolled with a heavy roller. This foundation for a broken-stone road is desirable where the subgrade is quite wet and better drainage than the ordinary macadam furnishes is necessary.

Missouri.—Large stones about as heavy as one man can easily handle are put in the bottom, hit or miss, as a foundation and rolled until comparatively of a uniform grade, Fig. 118.

Macadam.—Broken stone put in as ordinary macadam is not an uncommon foundation for brick and bituminous paved roadways. In fact, old macadam roadways swept clean and leveled up with new stone are frequently resurfaced with paving materials.

V-Drain.—The subgrade is excavated lower in the middle so as to form a V-shaped figure and filled with boulders or broken stone, Fig. 106. This furnishes an opportunity for good drainage under the wearing surface. Larger stone should be placed in the bottom and smaller at the top. In order to allow the water egress from the center of the roadway, about every 25 to 50 feet, trenches are cut to the side ditch and filled with the same kind of stones.

Hydraulic Cement Concrete Foundations.—This is by far the most important and best type of road foundations. Either "natural" or "Portland" cement may be used, though the latter is preferable.

Definition and Method of Proportioning.[1]—Concrete is an intimate mixture of rock, broken stone or gravel, and sand bound together by hydraulic cement. Theoretically the voids in the stone should be filled with sand and the voids in the sand filled with cement. The grading of the stone and sand should, therefore, be such as to secure the least possible amount of resultant voids. Experience has shown that stone grading approximately uniformly from fine to coarse, or more exactly, according to an elliptical and straight-line curve, as shown in Chapter VII, will give the densest and strongest mixture. A simple method of proportioning is to determine the voids in the stone and sand and proceed as follows:

Suppose voids in the stone......... =40 per cent
Suppose voids in the sand.......... =35 per cent

It is customary to increase these values so that the sand will overfill the voids in the stone 10 per cent and the cement, the

[1] See also Chapter XII.

voids in the sand 10 per cent, to allow for the "spreading" of the stone by the mortar and the spreading of sand particles by the cement. For a unit volume of concrete then take

Stone..............................	=1.00
Sand, 40% of stone and 10% of 40%......	= .44
Cement, 35% of sand and 10% of 35%..	= .17

The ratio then is

$$\text{Stone} : \text{sand} : \text{cement} = 1 : .44 : .17$$
$$= 6 : 2.6 : 1$$

That is, a 1 : 2.6 : 6 mixture is required. Generally the proportions are made easy aliquot parts as 1 : 2.5 : 5, 1 : 2 : 4, 1 : 3 : 6, etc., using a sack of cement in mixing, as the unit and measuring the other ingredients in terms of that unit.

Measuring Aggregates.—The measurement is frequently accomplished by noting how full three or four sacks of cement will fill a wheelbarrow and then filling the sand and stone accordingly. A more accurate plan, however, is to have at hand a measuring box by which the wheelbarrow loads may be frequently and easily tested. Such a box may be made as shown in the sketch, Fig. 119. Being bottomless, by lifting on the handles the material falls on the platform and can be mixed directly with the aggregate or shoveled into the mixer with very little waste of time.

Fig. 119.—Measuring Box, 4 cu. ft.

Hand Mixing.—Two methods of mixing are in use—by hand and by machine. For the former, a watertight platform is desirable on which first is spread the sand, and then the required amount of cement. The sand and cement are then systematically mixed together. It will be found advantageous to have two laborers work opposite each other, right and left-handed. They should cut into the pile which has been ricked up into a long, narrow windrow, toward each other, being sure the shovels go each time along the bottom, until they meet at the center, then lift the material and turn it away from the pile. Cut in again until the entire pile has been worked over and moved in the operation about 2 feet backward. A reverse direction of operation brings it back to its original position. The shovelers do more than just turn the material over. Each shovelful should leave the shovel with a spreading action as well as a turning. By cutting vertically into the pile the sufficiency of mixing can be determined. No streaks should show; all should be of a uniform color. The fine aggregate now mixed is spread out over the board, the coarse material is added and turned in and mixed in the same manner. Two turnings are usually enough. The water is now added; best in the form of a spray and the mixing continued until the entire mixture has become wet and plastic. Some add the water before mixing in the stone.

Machine Mixing.—When mixed with a machine, the sand, cement and stone are dumped into the mixer followed almost immediately by the water. The mixer, running at the rate of about thirteen to fifteen revolutions per minute, is continually mixing the material; it being carried up, turned over and dropped several times during each revolution. The turning should continue long enough to secure thorough mixing—each particle of aggregate being coated with cement. A wet mixture is now considered more likely to be homogeneous than, although perhaps not quite so strong, as a drier mixture well tamped. By wet mixture is not meant one that is "soupy," but just wet enough so that when gently tamped and smoothed with the back of the shovel, it will just show water on top; that is a "mushy" mixture.

Placing.—After mixing, the concrete should be placed as quickly as possible and smoothed by lightly tamping. Any perceptible drying of the concrete before or after placing and before setting, at which time there is a more or less rapid taking up of moisture, is detrimental to the concrete.

Protection during Hardening.—After the concrete has set, if the weather is warm and dry, it should be protected from the glaring of the sun or be frequently sprinkled. A week or ten days is usually allowed for hardening before the next course is laid. Flooding or ponding with water is also practiced.

The Aggregate.—The sand and stone or gravel together are called the aggregate and the cement the matrix. The aggregate is subdivided into coarse and fine.

Coarse Aggregate.—Broken stone and gravel are both used. The stone being angular furnishes a greater mechanical bond, while the gravel being more or less rounded packs closer and makes a denser concrete. Either should be clean, free from dust which will prevent the adhesion of cement.

Organic matter is detrimental, therefore loam should be excluded; a very small percentage of clay is not detrimental. The size of the largest stone will depend on the type of the work; for road foundations 1½ inches down to ¼ inch is considered about right—a graded mixture being better than uniformity in size.

Fine Aggregate.—Sand ranging in size from ¼-inch down is most used. Stone screenings of the same size, if free from dust, are considered just as good. Sand containing much mica, shale, clay, loam or silt, may require careful washing before using. The best sand is almost pure quartz. A small amount of feldspar is not detrimental. Since the surface area of a given weight of sand rapidly increases as the size of the grains become smaller, the amount of sand a unit quantity of cement will coat varies with the fineness. It is estimated that 1 gram of sand just passing a 10-mesh sieve, 1.5 millimeters in diameter, has a surface area of 15 square centimeters; 1 gram just passing a 200-mesh sieve, diameter .08 millimeter, has a surface area of 283 square centimeters.[1] It will be seen, therefore, that 1 pound of cement will only paint, with the same thickness of coating, 15/283 (approximately, 1/19) as much 200-mesh sand as it will 10-mesh sand. Consequently, the finer the material the more cement must be used. On the other hand, with irregu-

[1] "The Modern Asphalt Pavement," by Clifford Richardson, 1912, page 358; Wiley & Sons.

larly broken stone thrown together at random, a uniformly screened size would show more voids than a graded mixture.[1] Therefore, it is more economical to use a graded mixture from the finest sand to the coarsest rock allowable. With average graded materials a 1 : 3 : 6 mixture makes a good pavement foundation.

Concrete Manufactured in Place.—A layer similar to the bottom course of a macadam road is placed and rolled. A 1 : 3 mixture of cement and sand is spread uniformly over the surface and swept in. The surface is then flushed with water and more cement and sand distributed until the interstices are completely closed. The surface is continually rolled during the process of filling.

Another plan is to mix the sand and cement to a grout of creamy consistency in boxes and then fill the interstices, rolling and grouting until the voids are closed. This is a patented method; the patentees use a 1 : 4 grout.

Concrete slabs may be molded in a factory, transported to and laid upon the prepared subgrade. A thin sand cushion on the subgrade can be readily struck off to a uniform surface and by furnishing a good bearing will prevent cracking.

Bituminous concrete foundations have been used, the manufacturers claim, very successfully, but are not as cheap or rigid as hydraulic concrete.

Brick.—Old brick pavements which have worn uneven have been used frequently and successfully for foundations for sheet asphalt and asphaltic macadam pavements. Stone blocks may be used in the same manner.

[1] The percentage of voids with spheres of uniform size is the same no matter what the diameter of the spheres.

CHAPTER XI

BRICK, STONE, WOOD, AND OTHER BLOCK ROADS

As here used " block roads " refers to those the wearing surface of which is composed of blocks that have been made or prepared prior to being placed in the road. Only the following, suitable for country roads, will be mentioned: Brick, stone block, concrete block, wood block, bituminous block, and bituminized brick.

Brick Roads

Vitrified Paving Brick.—Shales and impure fire clays have proven themselves best adapted for the manufacture of paving brick. In order to insure the requisite shape, hardness and toughness, the clay in the process of manufacture must be both plastic and fusible and at the same time capable of retaining its shape under intense heat. The shales, which are clays that have undergone physical and possibly chemical changes, becoming hardened and laminated, possess these properties in a much greater degree than do the later formed surface clays. Approximately the following composition is required for a good paving brick:[1]

	Per Cent
Silica	56
Alumina	22.5
Flux	13
Volatile matter	8.5

The flux may be various oxides of iron, lime, magnesia, or other minerals. The volatile matter is water of crystallization and organic.

Shales from different deposits are seldom alike; they require

[1] Blanchard and Drown's "Highway Engineering," Wiley & Sons, N.Y.

different treatment in the process of manfacture to obtain best results. Scientific and experimental study of each individual deposit is necessary, and ingredients may have to be brought from different localities and mixed. The shale deposits used, however, are generally open pits and the material is obtained therefrom by means of steam shovels. The shale, if not of an easy variety, is crushed in grinding mills or by large rolls running in a pan having gratings for its bottom. The screened material is mixed with water in a pug mill to the proper consistency. The pug mill is a trough in which revolves a shaft, or shafts, with attached fingers or blades that passing through the mud work it up to the point of greatest plasticity. The fingers of the pug mill are arranged in a spiral form about the shaft or flattened and turned a little so as slowly to move the mud toward the molding machine in which is an auger that in turn forces it through the die. The mud comes from the die in the form of a prism and as it passes along is cut by wires on a suitable framework into bricks. The machine operating the cutting wires either causes a plane surface cut along the side of the brick or a warped cut which forms a lug. The plane-cut brick are, by one process placed in a receptacle, where they are re-pressed; at the same time the corners are rounded off and the lugs, grooves and brand of brick are stamped on the side, Fig. 120. "Vertical fiber" brick have grooves and lugs formed by the die,[1] in which case the

Fig. 120.—Paving Brick.

[1] Brick are now being made without lugs of any kind, the lug being considered unnecessary when a thin filler, such as grout or pitch is used.

brick are laid in the street with a cut surface up. The wabbly or warped surface cut is characteristic of what are known commercially as "wire-cut-lug" brick, Fig. 120. There has been much contention among manufacturers as to the relative merits of "re-pressed," "vertical fiber," and "wire-cut-lug" brick. Good pavements have been made of all kinds. If they will stand the rattler test they will probably prove to be satisfactory.

The molded brick are placed on cars in such a manner that there may be a free circulation of air about them and taken to the drying chambers. These are usually heated by the escaping hot gases from the kilns or by air forced through the burned kiln to cool it. The heated air comes into the drying chamber at the "dry" end and as it passes along it takes up moisture and loses heat. When it reaches the "green" end it is moist and comparatively cool. The cars of brick are from time to time moved along through the drying chambers, a "dry" car being pushed out and a "green" car in. It takes from one to three days to dry the brick, as this must be done slowly enough to prevent checking. The brick are then burned, usually in down-draft kilns, from seven to ten days. The temperature necessary to burn brick is a cherry red, that is, 1500 to 2000° F. for shales, and 2000 to 2800° F. for impure fire clays and requires from seven to ten days. The temperature will depend on the clay used and the character and quantity of the fluxing ingredients. While vitrification or melting down should be incipient, it must not proceed far enough to destroy the shape of the brick. When the brick are sufficiently burned the kiln is tightly closed and allowed to stand for several days. The brick are thus annealed and acquire toughness. After annealing the final cooling may be more rapid, and the air drawn through the kiln to cool it may be used in the drying chambers. In the best kilns some of the brick will not be first class. Upon opening the kiln the brick must be sorted into No. 1 pavers, No. 2 pavers, and builders. With impure fire clay as high as 80 to 90 per cent of the kiln are No. 1 pavers; with shale the percentage is 60 to 80.

Testing Paving Brick

The quality and acceptability of paving brick are usually made to depend on the specifications of the American Society for Testing Materials and those of the National Paving Brick Manufacturers Association. These are, in brief, the **Rattler Test** and **Visual Inspection.** The rattler test is "for the purpose of determining whether the material as a whole possesses to a sufficient degree strength, toughness and hardness." Visual inspection is "for the purpose of determining whether the physical properties of the material as to dimensions, accuracy and uniformity of shape and color, are in general satisfactory, and for the purpose of culling out from the shipment individually imperfect or unsatisfactory brick."

The Rattler Test.—The samples are taken either at the brick factory or at the locality where used depending upon the size of the shipment. The samples selected should be as near as possible an average of the shipment. One sample of ten bricks for each 10,000 bricks contained in the lot under consideration is taken, and care should be used that samples are not damaged in transportation or otherwise before testing. The rattler,[1] Fig. 121, is a barrel-like chamber, 28 inches in diameter by 20 inches length inside measure, in which the sample is tumbled with cast-iron shot. The percentage, by weight, of the brick worn away in 1800 turns accomplished in one hour, is a measure of the quality of the brick. The charge of the rattler consists of the sample of brick, ten in number for ordinary

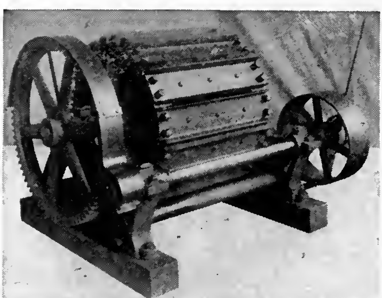
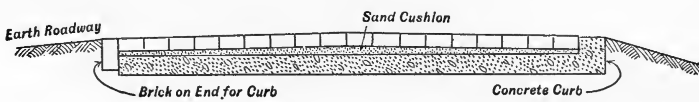


Fig. 121.—Standard Brick Rattler.

[1] For complete specifications see standards of the American Society for Testing Materials, 1918, p. 549.

sizes (length 8 to 9 inches, breadth 3 to $3\frac{3}{4}$ inches, thickness $3\frac{3}{4}$ to $4\frac{1}{4}$ inches), and of a quality passing the visual inspection test, together with the abrasive shot. The shot consists of cast-iron spheres of two sizes. The larger, when new are 3.75 inches in diameter weighing approximately 7.5 pounds (3.40 kilograms) each, and ten are used. The weight of no sphere shall be less than 7 pounds. When new, the smaller spheres are 1.875 inches in diameter and weigh approximately 0.95 pound (0.43 kilogram) each. No sphere shall be retained in use after it has worn down so that its diameter is less than 1.75



Cross-Section of Brick Rural Road

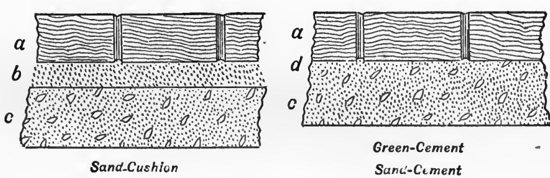


FIG. 122.—Brick Pavement.

inches or weighs less than 0.75 pound (0.34 kilogram). The collective weight of the large and small spheres shall be as near 300 pounds as possible.

The following scale of average losses is given; the percentage for rejection on any particular job should be specified by the engineer in charge or the buyer:

For bricks suitable for heavy traffic........	20 to 24
For bricks suitable for medium traffic......	22 to 26
For bricks suitable for light traffic..........	24 to 28

A great many shale bricks will give losses as low as 15 per cent.

Visual Inspection.—Bricks that are broken in two or chipped so that neither surface remains intact or so that the lower or bearing surface is reduced in area by more than one-fifth; or are cracked in such a degree as to produce such defects, either from shocks received in shipment or in drying, burning and cooling; or bricks which are off size, or so misshapen, bent,

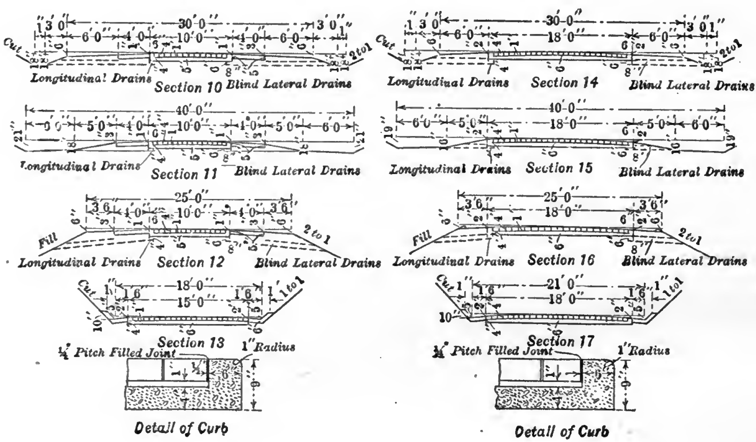


Fig. 123.—Illinois Standard Cross-sections for Single-track and Double-track Brick Roads.

Section 10—Ten-foot roadway with 4-ft. macadam shoulders. To be used in a level country. Section 11—Ten-foot brick roadway with 4-ft. macadam shoulders and broad side ditches available for traffic where width between fences permits. Especially adaptable for low-lying level country. Section 12—Ten-foot brick roadway with 4-ft. macadam shoulders. To be used on deep fills. For shallow fills use Section 1. Section 13—Fifteen-foot brick roadway for single-track road in deep cuts and on grades that require grouted gutters. Section 14—Eighteen-foot brick roadway. To be used in a level country. Section 15—Eighteen-foot brick roadway with broad side ditches, available for traffic where width between fences permits. Especially adaptable for low-lying level country. Section 16—Eighteen-foot brick roadway. To be used on deep fills. For shallow fills use Section 1. Section 17—Eighteen-foot brick roadway for double-track road in deep cuts and on grades that require grouted gutters.

twisted or kiln marked, that they will not form a proper surface; and all bricks which are obviously too soft or too poorly vitrified to endure street wear should be culled out and rejected. Color, in itself, is no criterion of a brick's quality. Bricks from different plants vary greatly. But color may be used to assist in comparing bricks from the same plant.

Design and Construction of Brick Roads

Figs. 122 and 123 show recommended cross-sections of modern brick construction.

Subgrade and Drainage.—The building of the subgrade and the drainage should be as carefully looked after as for any other kind of roadway.

Curbing.—In order to prevent the margins from loosening a curb is generally supplied. This may be of natural or artificial stone, oak plank, or merely bricks placed on end. Where the shoulders outside the brick roadway are macadam no marginal curb need be used. Also in monolithic (green-cement or sand-cement) construction curbs are not required.

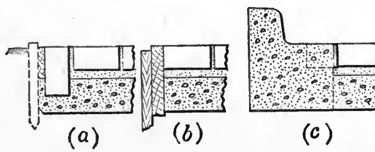


Fig. 124.—Curbs for Brick Roads.

Natural stone curb may be about 12 inches wide and 4 inches thick. These stones should be hauled and set in place before the grading is completed. They will then serve as a guide to finish the subgrade and place the concrete foundation. Artificial stone, cast in the factory may be used in the same way.

Forms of plank can easily be erected and concrete curbs cast in place either before, at the same time or after placing the foundation. Or wood blocks may be used to fill out the ends of the brick courses, later removed and a curb cast in place which will interlock with the brick. This is done after the brick is rolled and just before the grouting is poured. Plank or brick set on end will offer no difficulties. The brick will hold better if cement mortar is " spaded in " back of them, but the cost will be greater.

Foundation.—Brick pavements have been laid on earth foundations, on a course of cheaper brick laid flatwise, on macadam and on concrete.

Concrete foundations are to be recommended. They have the power to bridge or arch over a short soft spot and thereby prevent depressions and unevenness of surface due to unequal settlement. Maintaining an even smooth surface is an essential factor in the durability of a pavement.

Where a **cheaper grade of brick** is used for a foundation, they are laid flatwise on a 2-inch cushion of sand and rolled to surface. A grout is sometimes made of 1 part Portland cement and 2 parts clean sand with which the spaces between the bricks are thoroughly filled.

Sand Cushion.—A layer of sand $1\frac{1}{2}$ to 2 inches thick is placed upon the foundation and spread to an even surface by aid of a template. It should be clean and free from foreign or loamy matter. It need not be sharp. This cushion furnishes a smooth even surface to rest the brick upon, insures good bearing over the entire lower surface of the brick, and lessens noise which in places may be annoying, Fig. 122.

Laying the Brick.—The brick should be laid at right angles to the curb or length of the roadway. At turns or road intersections they may be placed at an angle of 45°. The brick should be laid with best edge uppermost as near in contact as possible. Soft brick or those badly checked and spalled should be removed and discarded.

Rolling.—After the brick in the pavement are inspected and the spalls swept off, they should be rolled with a roller of about 4 tons weight. Brick that cannot be reached by the roller should be thoroughly tamped with a wooden tamper. Rolling should begin at the outside shoulders and proceed gradually toward the center. If the roadway is wide enough to justify, it should also be rolled diagonally at an angle of 45° to the curb.

Expansion Joints.—If the roadway is more than 25 feet wide expansion joints are required. These are made by placing 1-inch boards longitudinally along the curb and about every 50 feet transversely across the roadway. After the rolling is completed, the boards are withdrawn and the spaces filled with asphalt or pitch. Patented fiber expansion-joint material can be purchased. This is put in like the boards and allowed to remain. The National Paving Brick Manufacturers Association recommends the omission of transverse expansion joints.

The Filler.—The spaces between the bricks should be filled with Portland cement grout or a bituminous filler. Formerly dry sand was used, but of late years this has been practically discontinued. Portland cement grout filler should be composed of one part cement to one part sand that is free from loam, clay or other foreign matter. Sharpness is not a requisite. Sand and cement in equal volumes are placed in a box, Fig. 125, and mixed until of a uniform color. Enough water is then added to form a grout of the consistency of thin cream. The sides and edges of the brick should be wet before the filler is applied. The creamy grout may be shoveled on the pavement from the box with a scoop-shovel. Care being taken

FIG. 125.—Recommended Grouting Box.

that the grout be constantly agitated during the entire process. The grout must be immediately broomed into the joints. After covering thus a distance of 15 or 20 yards the force should be turned back and cover again with a richer grout composed of 2 parts Portland cement to 1 part sand. After the joints have been entirely filled and time has elapsed for the cement to set a ½-inch coating of sand should be spread. An occasional sprinkling with water for two or three days is necessary to harden the cement properly.

The Illinois Highway Department[1] is very particular about the grouting and specifies a 1 cement to 1 sand grout mixed

[1] See statement by H. E. Bilger, Road Engineer, Illinois Highway Department, in Engineering and Contracting, Dec. 6, 1916.

dry, then with water to the consistency of cream. This is shoveled from the box to the pavement, which has been thoroughly wetted, and broomed into the openings between the brick. After about 200 feet is filled the gang is turned back to the place of beginning and the surface gone over again in the same manner except that the consistency is a little thicker and a squeegee replaces the rattan broom for pushing the grout into the cracks. This is repeated as many times as may be necessary. The statement is made that one barrel of cement will make sufficient grout to cover the area below:

4-inch brick on ordinary sand cushion.
32 square yards if repressed brick is used.
24 square yards if wire-cut lug brick is used.

4-inch brick on $\frac{3}{8}$-inch mortar bed.
30 square yards if repressed brick is used.
22 square yards if wire-cut lug brick is used.

The American Society for Testing Materials specifications[1] require the Portland cement to conform to their standards; the sand is to be of clean, hard, durable stone, preferably siliceous and free from clay or other foreign objectionable matter; the sand is to be well graded and must meet the following:

Total passing 10-mesh sieve..............	100 per cent
Total passing 20-mesh sieve not less than.	80 "
Total passing 200-mesh sieve not more than	5 "

The mortar made from 1 cement to 3 of this sand at the ages of 7 and 28 days shall have at least 75 per cent of the strength of similar mixtures and ages with standard Ottawa sand.

Bituminous Filler.—Coal-tar pitch and asphalt are both good fillers. Care must be taken that the filler will retain a suitable consistency under extreme temperatures. American Society for Municipal Improvements specifications require for coal tar:

[1] "A. S. T. M. Standards Adopted in 1920," p. 80.

Specific gravity, 15.5° C. (60° F.), 1.23 to 1.35.
Melting-point, cube method, 46° to 57° C. (115 to 135° F.)
Inorganic matter, not more than, 0.5 per cent.
Ductility at 25° C. (77° F.), not less than 60 centimeters.

Typical specifications for asphalt require:

Specific gravity, not less than, 0.98.
Penetration at 25° C. (77° F.), 60 to 100.
Distillation loss 163° C. (325° F.), not more than 3 per cent.
Penetration of residue, 25° C. (77° F.), not less than 50.
Melting-point, ring and ball method, not less than 80.

Pouring.—The filler is heated to a temperature between 149 and 177° C. (300 to 350° F.) and poured into the joints. A can in the form of an inverted cone with an opening at the smaller, lower end, is convenient. The workman moves this along the joint to be filled and regulates the flow by means of an iron rod passing down to a stopper at the opening at the small end of the can. Bituminous fillers have the advantage that no expansion joints are needed and the pavement is less noisy than the grout filled. The disadvantages are a tendency to "bleed" in hot weather and to crack in cold weather. The claim is made, also, that bituminous-filled bricks are inclined to chip off at the upper edges and become "turtle backed." With a filler of right consistency this, however, seldom occurs. After filling, a thin sprinkling of sand will take up the surplus bituminous cement.

Paint Coat.—Some engineers require a paint coat of hot asphalt or tar over the entire pavement. This is thinly sprinkled with sand or stone screenings. It serves to give a surface as smooth as asphalt and if renewed every year or two will preserve the pavement indefinitely. The paint coat is put on with a "squeegee," that is, an apparatus which allows a stream of hot pitch to flow onto the pavement in front of a wooden block on which is nailed a strip of rubber belting which spreads and rubs the pitch thinly on the pavement. Brick manufacturers, as a rule, do not recommend a paint coat.

Monolithic Brick Pavement

Bedding Method.—A coating or bed of cement mortar is spread on the concrete foundation and the brick laid in this mortar and as quickly as possible rolled or tamped to an even surface. The mortar furnishes a bond between the brick and foundation of about the same kind as between bricks in a wall.

Paris or Cement-sand Method.—(So called because used at Paris, Ill.) Cement and sand properly proportioned (1 cement to 4 sand is recommended) are thoroughly mixed dry in a a mixer or by hand. The mixture is spread uniformly over the prepared concrete foundation about 1 inch thick, compressed with a 300-pound roller and struck off with a template to the true contour of the pavement. If any depressions occur they should be filled and the "cement-sand" bed again rolled and struck off. The bricks are immediately laid, inspected and rolled. It is quite necessary specially to prepare the cement foundation. A substantial template or double template is drawn over the plastic foundation bringing it to exact contour. As soon as the foundation has sufficiently hardened to stand the pressure the cement-sand is distributed and brick laid. The setting of the cement-sand layer and its proper binding to the foundation and the brick is said to be best when it takes up sufficient water from the foundation to moisten it thoroughly. Tests show a remarkable adhesion of the bricks and foundation by this process. It is claimed that the cement-sand course eventually becomes part of the foundation, so that if a 5-inch foundation is needed, it should be designed 4 inches of concrete and 1 inch of cement-sand. Before filling with cement grouting the brick should be wet down with a spray, this insures the setting up of the binder course even had it not taken up enough moisture from the foundation.

Direct Method.—Another form of monolithic construction is obtained by laying the brick directly on the concrete foundation without the use of the cement-sand course. The foundation is finally finished to exact contour by means of a wooden tamping template. This is moved along the side forms with a simple tamping motion bringing the mortar of the concrete to the surface, leaving a smooth bed on which to drop the brick. For wide streets guiding strips set along the street to proper grade are used. Small bridges or stools must be provided for the men to stand upon. These with the strips are moved along and depressions filled. The laying of the brick closely follows. The brick should be laid, rolled and inspected before the concrete takes its initial set.

Green Cement Method.—A variation or combination of the above methods known as the green cement method is recommended by the National Paving Brick Manufacturers' Association.

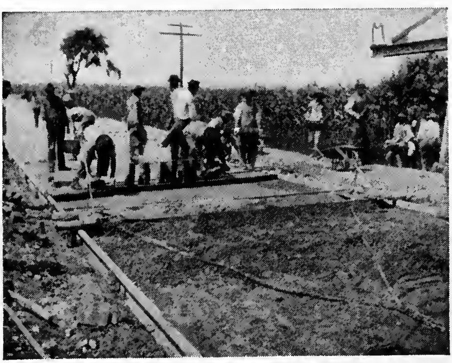


Fig. 126.—Laying Monolithic Brick Pavement.

The concrete foundation is brought approximately to grade by spading and settling and finished for the brick with a double template consisting of a 6-inch I-beam in front and a 6-inch I-beam or channel in the rear, Fig. 126. These are to be held rigidly upright by framing them together, parallel and 2 feet apart. The rear channel is to be $\frac{3}{16}$ inch higher than the front. Rollers attached to the frame and resting on the guide rails facilitate moving the template along. As the template is pulled forward the front parallel member strikes off the roughly deposited concrete. A dry mixture of the fine aggregate and cement in the proportion of one part cement to three parts sand is placed between the parallel members of the template; this is spread by the rear channel uniformly $\frac{3}{16}$ inch thick over the struck-off concrete. It immediately takes up moisture from the concrete and becomes an integral part of it, Fig. 127. The brick are carried from the piles and placed convenient to the dropper in such a manner that their projections are all in one direction and the better edge uppermost. The dropper then

FIG. 127.—Green Cement Pavements, Courtesy of Nat. Pav. Brick Mfg. Assn.

lays them upon the prepared surface. Alternate layers begin with a half-brick in order that joints may be broken; the broken end of the half-brick should be inward. Each course should be laid true and even and closed and straightened by tapping lightly with a sledge or a 4×4 timber 3 feet in length with an upright handle.

Inspecting and Rolling.—Immediately after laying, the brick should be swept clean, the brick inspected, those not having the better edge upward turned over, and broken and poor brick rejected. The pavement should then be rolled with a hand roller approximately 30 inches long and 24 inches in diameter, made in sections and filled with water, weighing not less than 20 pounds per inch of length. The rolling should be kept close to the laying and continued until the surface is smooth. Such portion of the surface as may be inaccessible to the roller should be brought to an even surface by tamping upon a 2-inch board. At the end of the day, no matter which method is used, the laying, inspection and rolling should be completed to the limit of the foundation. Grouting may be done the following day.

On country roads the edging or curb may be omitted, as the brick are so firmly bound to the foundation that it is not needed. A shoulder of earth or broken stone, however, should be provided for use in turning out and to prevent chipping the edges of the bricks.

Maintenance.—The maintenance of a brick road consists in replacing soft or broken bricks as they appear through action of frost, excessive loads or such as may be caused by the lug of a traction engine. A squeegee coat of bituminous material placed every one or two years will help maintain a smooth surface and increase the durability of the pavement. The average life of a brick pavement has been given as fifteen years, but if brick of a uniform quality are well laid upon a good foundation they ought to last on an ordinary country road for at least fifty years.

Stone Block Pavements

Stone block, while one of the oldest and most durable pavements, is not in general use for country roads; it is used in cities and villages about warehouses and depots where the traffic is heavy. The reader should look for a more extended and detailed discussion in works dealing directly with city pavements.

Size of Blocks.—In the very early period of road building the stone blocks used for surfacing, as in the noted Roman roads, were irregular in shape and dimensions and were fitted together in a sort of hit or miss mosaic. In our own country some communities are still using cobble-stone pavements laid before the Civil War of small bowlders or rounded field stones.[1] Modern methods demand that the stones after quarrying be split into nearly uniform sizes of approximately 8 to 12 inches long, $3\frac{1}{2}$ to $4\frac{1}{2}$ inches wide, and $4\frac{3}{4}$ to $5\frac{1}{4}$ inches deep. The number of blocks per square yard of surface runs from 28 to 32.

Physical Properties.—Good paving block stone should be of such a character that it will break easily into the required sizes and have a comparatively smooth surface; it should be moderately hard, tough and durable; and so homogeneous that it will wear uniformly. Under wear it should retain a grit and not become slippery. Uniformity of wear and non-slipperiness is of more importance in a paving material than hardness. Unless the blocks can be broken with smooth surfaces they cannot be laid with close joints and will chip, giving the pavement a cobble-stone effect.

Varieties of Materials Used.—*Granite* is the most important rock used for paving blocks in the United States. It has the required properties to a high degree. Granite is found pretty generally over the whole country, but has been most largely used for paving in the Eastern States. *Sandstone*—Medina sandstone found in central and western New York, while not as hard as granite has proven very satisfactory and durable; pavements of more than fifty years' service being known. Minnesota furnishes the Kettle River sandstone, which is extremely gritty and somewhat harder than Medina. It breaks well and can be laid with close joints. Colorado sandstone, varying in color from red to gray, is another popular stone for paving. It is hard and tough and wears well and uniformly; does not become slippery and is so strong that it will not easily break under traffic. Sioux Falls (South Dakota) granite, which is really a quartzite, has been used to a considerable extent. It is hard, tough and strong, but is difficult to prepare and wears slippery.

[1] A cobble-stone pavement still in daily use at Alexandria, Va., is said to have been laid in 1776.

Specifications.—The American Society for Municipal Improvements specifies that the "blocks shall be medium grained granite, showing an even distribution of constituent materials, of uniform quality, structure and texture, without seams, scales or disintegration, free from an excess of mica or feldspar." For heavy traffic the specifications require a toughness of not less than 9, and a French coefficient of wear of not less than 11; for medium traffic, 7 and 8 respectively. Tests to be made according to the methods described in Bulletin 44, Office of Public Roads, U. S. Dept. of Agriculture.

The same organization gives this stipulation for sandstone paving blocks: "shall be sound, hard sandstone, free from clay, seams or defects which would injure them for paving purposes, of uniform quality and texture."

These specifications give extreme dimensions as follows: Granite—length, 8 to 12 inches on top; width $3\frac{1}{2}$ to $4\frac{1}{2}$ inches on top; depth, $4\frac{3}{4}$ to $5\frac{1}{2}$ inches. A slightly shallower and narrower block may be specified when the French coefficient will warrant. Sandstone—length, 8 to 10 inches on top; width, $3\frac{1}{2}$ to 6 inches on top; depth, $4\frac{3}{4}$ to $5\frac{1}{4}$ inches.

Recut and redressed blocks may be used provided they "comply with the specifications for the quality of stone, as required for new blocks. The dimensions may be varied, depending upon the size of the old blocks which are to be redressed, and the character of the pavement which it is sought to obtain."

Construction.—Upon a stable foundation about 2 inches of sand is spread. Into this cushion the blocks are individually bedded by hand, using a stone mason's or bricklayer's hammer with an adz-shaped peen to crowd the sand under the block until its upper side is in line with the street surface. The blocks are usually laid at right angles to the street, but occasionally, especially in intersections, are placed diagonally. Joints should always be broken, the minimum lap being 3 inches. After laying, the blocks are rammed to bring them to a firm bed and true surface. The fillers used are either sand, grout or bituminous materials. If sand, it should be very dry in order that it may run easily into the joints and thoroughly fill them. The joints may be left about $\frac{1}{2}$ inch wide when sand is used for filling. Cement grout is applied in the same manner as already described for brick paving; when asphalt or tar pitch is used the joints should be as close as it is possible to make them. The pitch is heated and poured from conical or from sprinkler shaped cans. In some cases the joint has been left wide and first filled with gravel, the voids then being filled with hot pitch. Or a mastic may be made of pitch and sand and forced into the joint. Grouting makes a solid pavement, but one more noisy than a pitch filled. If grout is used, expansion joints as in brick pavements should be provided.

Small and Recut Blocks.—Old blocks which have become "turtle backed" may sometimes be taken up, recut, and used on those streets where the traffic is moderate. In Europe small blocks more or less cubical in form, varying from $2\frac{1}{2}$ to 4 inches in size, are laid in circular arcs of small radii, something like the stitching in an old-fashioned quilt. Thus very few of the joints are parallel to any lane of traffic. The blocks themselves are broken to size by a machine which is said to do the work very rapidly. In England this pavement is known as the Durax, while a similar pavement in Germany is called the Kleinpflaster.

Wood Block Pavement

Wood blocks impermeated with coal tar creosote make an excellent road material. They are durable, smooth, sanitary and noiseless. The wood fiber at the top of the block "brooms" down under the traffic, forming a nap or carpet which is elastic and resilient, thus decreasing further wear on the pavement as well as lessening jar and consequent injury to the vehicles (Fig. 128). Wood blocks are especially adaptable for bridge covering, and for places where noise is objectionable. The cost only has prevented this type of pavement being used more extensively.

Wood, Varieties Used.—A reasonably hard and tough wood is desirable. Long-leaf yellow pine is preferred. But shortleaf pine, Norway pine, black gum, tamarack, and Douglas fir are American woods used. Any wood of uniform texture having a crushing strength of 8000 pounds or more per square inch, and susceptible to impregnation by creosote, would make good paving blocks. However, a real hard wood might wear slippery; this is said to be the tendency with long-leaf yellow pine.

Preparation.—The timber is first sawed into planks and dressed so that the width of the plank equals the required length of the block, and the thickness of the plank, the width of the block. It is then cross-sawed into short lengths equal to the depth of the block. The ordinary sizes of the completed blocks are: Length, from 5 to 10 inches; width, 3 to 4 inches; depth, 3½ to 4 inches. The width should be greater or less

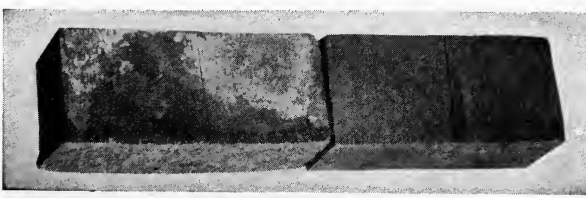


FIG. 128.—Showing Wear of Wood Blocks.

than the depth by at least ¼-inch to insure their being laid with fibers vertical. In the same job, or a definite portion of it such as a city block, the dimensions for depth and width should not vary more than 1/16 inch.

Treatment.—The properly prepared blocks are placed in a cylinder or a tank which can be hermetically closed. They may be run in on small cars and after treatment drawn out, or conveyed by machinery directly from the block saw to the tank and withdrawn, after treatment, by gravity. The tank being closed the blocks are sterilized by live steam under a pressure of at least 30 and not more than 50 pounds per square inch, for a period of at least three hours and not to exceed seven hours, and a temperature between 250 and 280° F., as the condition of the wood and the season of the year demands. The object of steaming is to drive off the surplus moisture if the wood is green, to add moisture, if the wood is too dry, and partially to coagulate the albumen of the sap thus decreasing the hygroscopicity of the wood.

After steaming air pumps create a partial vacuum (at least 24 inches) in the tank drawing the steam and air from the heated wood. Creosote—dead oil of coal tar or coal tar products—at a temperature of 180 to 200° F., is then allowed to flow into the tank and forced and maintained under sufficient pressure to impregnate the blocks with the required amount of creosote. Eighteen pounds per cubic foot is ordinarily specified, although 20 pounds is sometimes used, and in Europe as low as 10 pounds. The excess of creosote oil in the tank is then withdrawn, the blocks drained and prepared for shipment.

Tests.—The blocks ready for use should not absorb more than 4½ per cent of their dry weight after being heated at 100° F. during twelve hours and then placed under water twelve hours. They must stand also the indentation test made by a die 1 inch square pressed against the end of the fibers with a pressure of 8000 pounds for one minute. The indentation must be less than ⅛ inch.

Laying.—The foundation is preferably prepared by sprinkling the concrete with water and distributing over it a layer of mortar at least ½ inch thick, composed of one part Portland cement and three parts sand, and the same struck off to a smooth surface. The blocks are laid immediately upon the mortar bed with close joints, usually at right angles to the curbs, so that they break joints with a lap of at least 3 inches. Closure or end blocks should be at least 3 inches long. After a few rows of blocks have been laid they are gently rammed and rolled to a firm bearing and uniform surface.

Filling.—As in the case of brick and stone block pavements there is a difference of opinion as to what constitutes the best filler. Some prefer dry sand while others prefer pitch. Asphalt and refined tar are both used. Adherents of the sand filler claim it prevents or at least mitigates the nuisance of " bleeding " by absorbing the surplus oil exuded on a warm day. The bituminous filler is claimed to prevent the penetration of water into the pavement with consequent swelling and heaving of the blocks. The character of, and methods of applying the fillers are practically the same as explained for brick blocks.

Expansion Joints.—For wide streets expansion joints are provided between the wood blocks and the curb of such thickness as may be required, to $1\frac{1}{2}$ inches, filled with pitch. These are unnecessary when a bituminous filler is used.

Bituminous blocks, to a limited extent, have been used for rural roads. These are made in the factory by a suitable mixture of stone, sand and bituminous cement, hauled to the road and laid on the concrete foundation. They require no filling, as the joints under a roller or under traffic soon make up and the blocks become practically cemented together into one continuous surface. The exact mixture must be determined after an investigation of the materials to be used, but is somewhat similar to the "Topeka" specification for asphalt concrete (see also Chapter XIII, p. 308).

Bituminized brick are made by treating common brick with asphalt or tar under pressure. The brick are ordinary size and should absorb from 6 to 12 per cent of water in forty-eight hours' immersion. It is recommended that the crushing strength be 3500 pounds per square inch. The brick are loaded on cars which are then run into pre-heating chambers, the interior of which are kept at 400° F., until the bricks have been freed from moisture and have expanded. In from two to four hours' time they are ready for treatment in cylindrical steel tubes about 6 feet in diameter and 36 feet long capable of withstanding a pressure of 200 pounds per square inch. The door is closed, the interior temperature raised to 350°. A 25-inch vacuum is produced and retained about one hour by suitable apparatus. Hot asphalt, 350°, is then admitted to the chamber, care being taken to maintain the vacuum until all bricks have been covered. The valves are then reversed and a pressure of 160 pounds per square inch applied to the hot contents. Surplus asphalt is then forced out of the chamber and the brick cooled, a pressure of 160 pounds per square inch being maintained until this is accomplished.

Rattler tests show a very small percentage of wear. The bricks take up by this process about 5 to 10 per cent of bitumen. Their durability in the road has not yet been determined. The special claim for the material is that it can be produced wherever asphalt and a good, uniform common brick can be secured. If so, a cheap pavement may be provided for those sections of the country where other approved road materials are scarce.

CHAPTER XI

CONCRETE ROADS

THE deleterious effect of automobile traffic on waterbound macadam caused road men to seek for a stronger binder than stone-dust. They very naturally turned to Portland cement. Has Portland cement concrete sufficient resilience to withstand the impact of traffic; will it crack and disintegrate under the action of the weather? These are questions that no laboratory test can determine; experience is the only absolute criterion. But notwithstanding that these questions have not been fully answered, the building of concrete roads has gone on apace. Each year's output shows great increase over the preceding. While defects have developed, a study of these defects has shown that a closer inspection of materials and better methods of grading, mixing and laying will soon, if they have not already, overcome them.

A concrete road is one whose wearing surface is composed of hydraulic cement concrete. The foundation course, if there be one, is usually also of concrete, making truly a monolithic construction.

MATERIALS [1]

Cement.—For concrete roads only Portland cement such as will pass the specifications of the American Society for Testing Materials should be used.[2] These are as follows:

[1] See "Specifications and Recommended Practice" of the National Conference on Concrete Road Building, Chicago, 1914.

[2] For a completer statement of the specifications and methods of making the tests see "A. S. T. M. Standards, 1918," page 503.

SPECIFICATIONS

1. Portland cement is the product obtained by finely pulverizing clinker produced by calcining to incipient fusion, an intimate and properly proportioned mixture of argillaceous and calcareous materials, with no additions subsequent to calcination excepting water and calcined or uncalcined gypsum.

I. Chemical Properties

2. The following limits shall not be exceeded:

Loss on ignition, per cent	4.00
Insoluble residue, per cent	0.85
Sulphuric anhydride (SO_3), per cent	2.00
Magnesia (MgO), per cent	5.00

II. Physical Properties and Tests

3. The specific gravity of cement shall be not less than 3.10 (3.07 for white Portland cement). Should the test of cement as received fall below this requirement a second test may be made upon an ignited sample. The specific gravity test will not be made unless specifically ordered.

4. The residue on a standard No. 200 sieve shall not exceed 22 per cent by weight.

5. A pat of neat cement shall remain firm and hard, and show no signs of distortion, cracking, checking, or disintegration in the steam test for soundness.

6. The cement shall not develop initial set in less than forty-five minutes when the Vicat needle is used or sixty minutes when the Gillmore needle is used. Final set shall be attained within ten hours.

7. The average tensile strength in pounds per square inch of not less than three standard mortar briquettes (see Section 51) composed of one part cement and three parts standard sand, by weight, shall be equal to or higher than the following:

Age at Test, days	Storage of Briquettes	Tensile Strength, lb. per sq. in.
7	1 day in moist air, 6 days in water	200
28	1 day in moist air, 27 days in water	300

8. The average tensile strength of standard mortar at twenty-eight days shall be higher than the strength at seven days.

III. Packages, Marking and Storage

9. The cement shall be delivered in suitable bags or barrels with the brand and name of the manufacturer plainly marked thereon, unless shipped in bulk. A bag shall contain 94 pounds net. A barrel shall contain 376 pounds net.

10. The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment, and in a suitable weather-tight building which will protect the cement from dampness.

IV. Inspection

11. Every facility shall be provided the purchaser for careful sampling and inspection at either the mill or at the site of the work, as may be specified by the purchaser. At lease ten days from the time of sampling shall be allowed for the completion of the seven-day test, and at least thirty-one days shall be allowed for the completion of the twenty-eight day test. The cement shall be tested in accordance with the methods hereinafter prescribed. The twenty-eight day test shall be waived only when specifically ordered.

V. Rejection

12. The cement may be rejected if it fails to meet any of the requirements of these specifications.

13. Cement shall not be rejected on account of failure to meet the fineness requirement if upon retest after drying at 100° C. for one hour it meets this requirement.

14. Cement failing to meet the test for soundness in steam may be accepted if it passes a retest using a new sample at any time within twenty-eight days thereafter.

15. Packages varying more than 5 per cent from the specified weight may be rejected; and if the average weight of packages in any shipment, as shown by weighing fifty packages taken at random, is less than that specified, the entire shipment may be rejected.

Aggregates

Fine Aggregate.—This may be either sand, or stone screenings less than $\frac{1}{4}$-inch in diameter. It should be hard, approximately as hard as flint or quartz, tough, dense, and free from loam, clay, sticks, or organic matter. Siliceous quartz is preferable although sands from any durable rock may be used. Sharpness is no longer considered a requisite. While sharp sands give a little greater mechanical bond between the particles the voids in rounded sand is less. The less the voids the denser the mortar and denseness is considered of more importance than the small mechanical bond that may ensue from sharpness. Likewise since denseness is desirable a graded mixture of grains from the coarsest to the finest is best. If the particles could be carefully laid up together like bricks in a house, some particular uniform size would be most convenient, but in a random mixture the best results seem to come from a regular grading of the grain sizes. A granulometric or sieve analysis will, therefore, give an indication of the value of the sand for mortar. A first class sand for concrete is coarse,

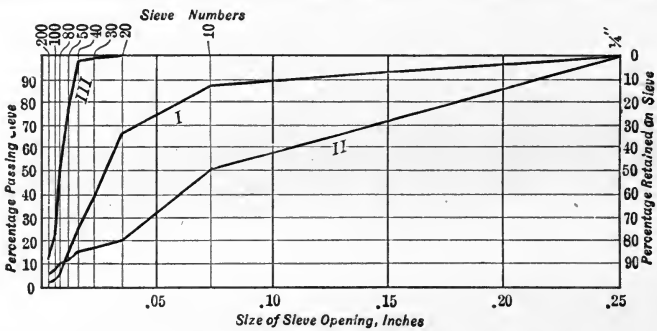


FIG. 129.—Mechanical Analysis of Sand Curves.

I. A Platte River sand (medium fine).
II. Joliet, Ill., limestone screenings (coarse sand).
III. An Illinois bank sand (fine).

that is, one in which not more than 15 to 20 per cent will pass a No. 50 sieve, and not more than 2 per cent will pass a No. 100 sieve. Cement will not adhere as well to some sands as to others. Sands should then show when mixed into a mortar in the proportions of 1 cement to 3 sand, by weight, a tensile strength equal to that given by standard Ottawa sand with a like mixture. Dust on the sand may prevent its adhering; washing will remove it. Careful washing may also remove mica, which occurs in small flakes, as well as loam, clay or sticks. As previously stated, coarse sand has less surface area per unit of weight than fine sand. If each grain were a sphere it would be easy to calculate the relative areas. The total area of a given weight of No. 300 sand would be about nineteen times as much as the area of the same weight of No. 10 sand. Consequently it would require considerably more cement to coat the No. 100 sand than it would to coat the No. 10 sand. There is also a mechanical stability due to the coarser material. Fig. 129 shows plots of the mechanical analyses of three sands.

Graded Sand.—Fuller's [1] experiments for concrete indicate that for cement, sand and stone the curve should closely approximate a parabola, or, perhaps, with most materials a straight line combined with an ellipse. The curves drawn in Fig. 130

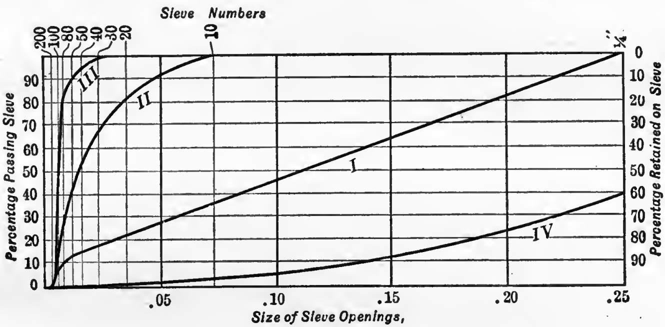


FIG. 130.—Well, graded Sands.

I. Well-graded coarse sand.
II. Well-graded medium sand.
III. Well-graded fine sand.
IV. Crusher-run broken stone.

show average values for medium sand and coarse sand, graded between the No. 100 sieve and ¼-inch screen. However, with medium and fine natural sands, there is usually not so much of the coarser grains and the curve will reach the 100 per cent line at the No. 10 or No. 8 sieve sizes. It is hardly worth while to attempt a very close grading to any standard until that standard has been better established than at the present time. Perhaps one or two sieves will furnish sufficient information for most jobs. A direct test for strength with the particular cement

[1] Taylor and Thompson's "Concrete, Plain and Reinforced," Wiley & Sons, New York. "Laws of Proportioning Concrete," by W. B. Fuller and S. E. Thompson, Transactions Am. Soc. Civ. Eng., vol. 59, 1907.

to be used is the best criterion. For average use it may, however, be stated that results within the following limits should be obtained:

CLASSES OF SAND

	No. 1	No. 2	No. 3
Specific gravity, not less than	2.6	2.6	2.6
Voids, not more than per cent	33	35	38
Suspended matter, not more than per cent	2	6	8
Through No. 100 sieve, not more than per cent.	10	15	25
Through No. 50 sieve, not more than per cent	40	45	95
Through No. 30 sieve, not more than per cent	50	60	98
Through No. 20 sieve, not more than per cent.	60	80	100
3 : 1 Tensile strength compared with 3 : 1 mortar made of Ottawa sand, per cent	100	90	80

No. 1 sand is a concrete sand. No. 2 sand when used for concrete requires some additional coarser material; this may come from the stone which, if this sand is used, should include all fine material from the crusher except that which will not pass a No. 8 sieve. No. 3 sand is too fine for concrete, but may be used for grouting brick paving, for plastering where smoothness is desired, or for sheet asphalt pavements.

Coarse Aggregate.—A tough, hard stone is best, but in many sections of the country the medium grades must be used. The stone may be tested by the Duval abrasion machine. A coefficient of wear of not less than 12 is desirable. This will allow the better grade of limestones. The stone should be clean and show durability as noted from outcroppings at the quarry. It should be free from flat or elongated pieces and from vegetable or other deleterious matter. It should be graded in size and all should be retained on a $\frac{1}{4}$-inch screen.

Water.—Water should be clean, free from oil, acid, alkali or vegetable matter.

Reinforcement.—All reinforcement should develop an ultimate tensile strength of not less than 70,000 pounds per square inch and bend 180° around one diameter and straighten without fracture.

Proportioning Concrete.—The National Conference on Concrete Road Building recommends that the proportions do not exceed 5 parts of fine and coarse aggregate to 1 part of cement and that the fine aggregate should not exceed 40 per cent of the mixture of fine and coarse aggregates.

Proportioning by Arbitrary Selection.—Arbitrary proportions such as 1 : 2 : 3, 1 : 2 : 4, 1 : 2 : 5, etc., are most common and least scientific. A recommended practice is to use at first twice as much coarse aggregate as fine aggregate and then vary the proportions as the work progresses. If there is a harsh working of the concrete the quantity of sand may be lessened. If stone pockets appear and it is difficult to fill the voids more sand should be used.

Proportioning by Voids.—This method of proportioning, as explained in the chapter on foundations, requires the fine aggregate to a little more than fill the voids of the coarse and the cement to a little more than fill the voids of the fine aggregate. It is necessary because of the swelling of the bulk to take from 5 to 10 per cent excess sand and from 5 to 10 per cent excess cement. With gravel having, say, 40 per cent voids, use 45 to 50 per cent sand. Then if the sand is to be twice the cement the proportions are

$$\begin{array}{ll} 1 & \text{part stone} \\ .45 & \text{part sand} \\ .22\tfrac{1}{2} & \text{part cement} \end{array}$$

$$\text{cement} : \text{sand} : \text{stone} = .22\tfrac{1}{2} : .45 : 1.00$$
$$= 1 : 2 : 4\tfrac{1}{2}$$

If the sand voids are 32 per cent, say, use 5 per cent more, 37. Then

$$\begin{array}{rl} 1 & \text{part stone} \\ .45 & \text{part sand} \\ .37 \times .45 = .16\tfrac{2}{3} & \text{part cement} \end{array}$$

$$\text{cement} : \text{sand} : \text{stone} = .16\tfrac{2}{3} : .45 : 1.00$$
$$= 1 : 2.7 : 6$$

When the stone is uniformly of a large size the sand may be taken equal to the voids or only slightly in excess and the cement somewhat in excess of the voids in the sand, 5 to 15 per cent is recommended. With stone having 40 per cent voids and sand of 32 per cent voids, the computation is

$$
\begin{aligned}
& 1 \text{ part stone} \\
& .40 \text{ part sand} \\
(40+10)32 = \; & .16 \text{ part cement}
\end{aligned}
$$

$$
\begin{aligned}
\text{cement} : \text{sand} : \text{stone} &= .16 : .40 : 1.00 \\
&= 1 : 2.5 : 6.25.
\end{aligned}
$$

The principal error of this method of proportioning is probable inaccuracies in determining voids. The usual method is to fill a vessel with the stone and pour water in to fill the vessel. By comparing this quantity of water with the volume of the vessel, the percentage of voids is obtained. In the concrete, however, the particles of sand get between and spread the pieces of stone apart so there is probably a greater void space. Second, many grains of sand are larger than the void spaces between particles of stone and consequently the stones cannot come into touch and there is again swelling in bulk. An analysis of this subject would probably lead to a conclusion that two sizes—a very coarse and a very fine—are requisite for densest mortar. Feret so concluded [1] from artificial mixtures of sands of different sizes. His experiments lead to these statements: " That a sand composed of 4 parts of very coarse sand (0.08—0.20 inch diameter) to 1 part of very fine sand (less than 0.02 inch diameter) makes the strongest possible mortar of 1C : 3S. That the strength of such mortar is more than twice as much as the same mortar 1C : 3S when the sand is composed of what is commonly regarded as " coarse sand " and more than three times as strong as the same mortar when the sand is very fine. That a mixture of two grades of sand of widely different sizes

[1] Johnson's "Materials of Construction," Wiley & Sons, New York. Taylor and Thompson's "Concrete Plain and Reinforced," Wiley & Sons, New York.

gives a great deal stronger mortar for given proportions of sand and cement than does any particular size used by itself." Feret would use as coarse aggregates as possible leaving in the small sizes but exclude the very small sizes. The present practice is toward a graded mixture as giving all around better results.

Proportioning Concrete by the Maximum Density Curve.—The theory on which this depends is (1) " With the same percentage of cement the strongest concrete is usually that in which the aggregate is proportioned to give the greatest density; (2) with the same aggregate the strongest concrete is that containing the largest percentage of cement in a given volume of concrete, the strength varying in proportion to this percentage." Fuller has determined that the maximum density curve closely follows a curve made up of an ellipse and a straight line.[1] The data for plotting the curve may be taken from the following table:[2]

Materials	Intersection of Tangent with Vertical at Zero Diameter	Height of Tangent Point	Axes of Ellipse	
			a	*b*–7
Crushed stone and sand......	28.5	35.7	0.150D	37.4
Gravel and sand.............	26.0	33.4	0.164D	35.6
Crushed stone and screenings..	29.0	36.1	0.147D	37.8

D is the diameter of the coarsest stone.

To construct the curve, lay off a scale along the *Y*-axis, Fig. 130*a*, to represent the percentages passing the sieves; and a scale along the *X*-axis to represent the sieve openings or size of grains. Draw a straight line, *AB*, from *A*, the "intercep-

[1] "Laws of Proportioning Concrete," by W. B. Fuller and S. E. Thompson, Trans. A. S. C. E., Vol. 59, 1907.

[2] Taylor and Thompson's "Concrete Plain and Reinforced," 2d Edition, Wiley & Sons, New York.

tion of tangent with vertical at zero," as given in the table, to B, which is the point $(D, 100)$. Draw the axes of the ellipse through the point C, where $x=1/10D$, and $y=7$. Draw in the ellipse by any of the standard methods; the trammel

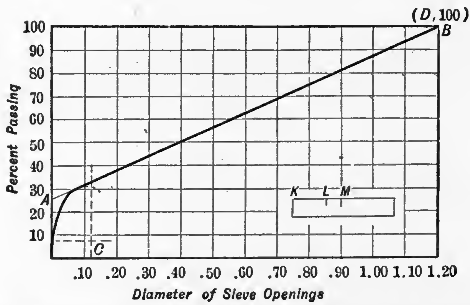


FIG.—130*a*.—Method of Constructing the Fuller-Johnson Maximum Density Curve.

method is recommended. Mark off on a small card KL equal to the horizontal semi-axis, and KM equal to the vertical semi-axis of the ellipse. Rotate the card about C so that the

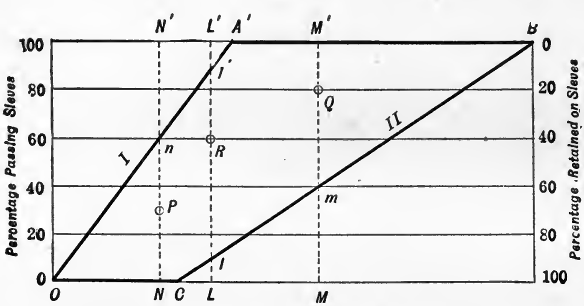


FIG. 130*b*.—Diagrammatic Sieve Analysis Curves.

point L will always follow the vertical axis and M the horizontal axis; the point K will describe the ellipse.

A Mathematical Analysis of Proportioning.—The following analysis, developed by the author, will not only apply to proportioning concrete, but to any other mixture in which there is a predetermined ideal sieve-analysis curve. It has been successfully used in proportioning sheet asphalt mixtures. It can, of course, be used with the author's straight-line method of plotting described in a previous chapter.

Having drawn the mechanical analysis curves of the several ingredients and decided on an "ideal" curve for the mixture, the process of proportioning is one of "alligation medial" or it is analogous to the reverse operation of finding the centroid in mechanics.

Fig. 130*b* shows diagrammatic sieve analysis curves for two ingredients, *OAB* for I, and *OCB* for II. Suppose it is desired to make a mixture of these two ingredients so that the sieve *N* (vertical *NN'*) will separate the mixture into two portions such that 24 per cent will pass and 76 per cent be retained on that sieve. It will be noted that 60 per cent of I is finer than (passes) this sieve while none of II passes the sieve.

Let x = percentage of mixture to be taken from I;
and y = percentage of mixture to be taken from II.

Then

$$x \text{ at } 60 = 60x$$

$$y \text{ at } 0 = 0$$

$$(x+y) \text{ at } 24 = 60x + 0$$

Algebraically

$$(x+y)24 = 60x$$

but

$$x+y = 100$$

Therefore

$$2400 = 60x$$

$$x = 40$$

$$y = 100 - 40 = 60.$$

Suppose the sieve *M* (vertical *MM'*) is to retain 20 per cent and allow 80 per cent to pass. As before

$$x \text{ at } 100 = 100x$$

$$y \text{ at } 40 = 40y$$

$$(x+y) \text{ at } 80 = 100x + 40y$$

Algebraically

$$(x+y)80 = 100x + 40y$$

and

$$x+y = 100$$

Solving for x and y

$$80x+80y=100x+40y$$

$$-20x+40y=0$$

$$x=2y$$

$$3y=100,\ y=33\tfrac{1}{3},\ x=66\tfrac{2}{3}.$$

Suppose along LL' the desired mixture is to have 60 per cent pass the sieve.

$$x \text{ parts at } 90=90x$$

$$y \text{ parts at } 10=10y$$

$$(x+y) \text{ at } 60=90x+10y$$
$$60x+60y=90x+10y$$

$$50y=30x$$

$$x/y=5/3$$

$$x/x+y=5/8$$

$$y/x+y=3/8$$

but,

$$x+y=100 \quad \therefore \quad x=62\tfrac{1}{2},\ y=37\tfrac{1}{2}.$$

It will be noticed that in each case the ratio of the parts taken are inversely proportional to the distances along the ordinate from the point representing the desired mixture, indicated on the diagram by the small circles, to the lines representing the sieve analyses. Algebraically,

For sieve N,

$$x/y=NP/nP$$

or

$$x/x+y=NP/(NP+nP)=NP/Nn$$

$$x=(x+y)(NP/Nn)=100NP/Nn$$

and

$$y/x+y=nP/(NP+nP)=nP/Nn$$

$$y=(x+y)(nP/Nn)=100NP/Nn$$

For sieve M,

$$x/y=Qm/QM'$$

$$x=100Qm/M'm$$

$$y=100QM/M'm$$

For sieve L,

$$x=100Rl/ll', \quad y=100Rl'/ll'.$$

This last is a general expression including the other two as special cases. The values of x and y in either case are easily calculated by slide rule.

Application to Proportioning Concrete.—The National Conference rule quoted is, that the fine aggregate shall not exceed 40 per cent of the mixture of fine and coarse aggregate.

Suppose, then, the sieve analysis of the sand and coarse aggregate to have been plotted, Fig. 131.

Put the point R at 40 on the sieve ordinate separating the fine from the coarse aggregate, then the part of I to be taken is $Rl = 38$ per cent, and of II, $Rl' = 58$ per cent. Check by substituting in the formula:

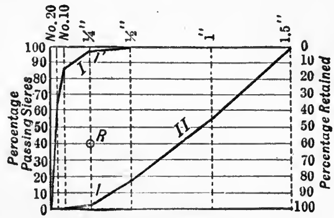


FIG. 131

$$x = 100Rl/ll'$$
$$= 100 \times 38/96 = 40 \text{ per cent}$$
$$y = 100Rl'/ll' = 60 \text{ per cent.}$$

That is by weight the quantities of sand : stone = 40 : 60. The conference also recommends that the proportions do not exceed five parts of fine and coarse aggregate to one part of Portland cement.

cement : aggregate = 1 : 5.

But the five parts of aggregate are divided as 40 to 60.

Sand = 40/100 of 5 = 2

Stone = 60/100 of 5 = 3.

The proportions then are

Cement : sand : stone = 1 : 2 : 3.

These proportions will in practice have to be reduced to volumes unless the cement sand and stone have approximately the same specific gravities.

Let the specific gravities and weights per cubic foot of the ingredients be

Cement	3.14	196 (one sack)
Sand	2.65	166
Stone	2.60	162

Since the volumes are inversely proportional to the specific gravities or the weights

cement : sand : stone = 1 : 2 : 3. by weight

$= 1/3.14 : 2/2.65 : 3/2.60$ by volume

$= 1 : 2 \times 3.14/2.65 : 3 \times 3.14/2.60$

(By slide rule)

$= 1 : 2.37 : 3.61$

To obtain a mixture that will coincide with the ideal curve at any number of points.

As has been stated, p. 241, the mechanical or sieve analysis curve for maximum density closely follows a curve composed of an ellipse and a straight line. Where several ingredients, then, are to be mixed the problem is to obtain a mixture which will approach as near as may be this "ideal" curve. The method given may be used to secure a mixture which will fit any predetermined curve.

Consider the sieve analysis curves, Fig. 132. Let q_1, q_2, q_3, q_4, . . . represent the percentage (number of parts) of the whole mixture to be taken of the ingredients I, II, III, IV, . . . respectively. Let p_1 represent the percentage of I which will pass a given sieve, p_2 the percentage of II which will pass the same sieve, p_3 of III, p_4 of IV and so on; and P represent the percentage of the whole mixture that will pass the same given

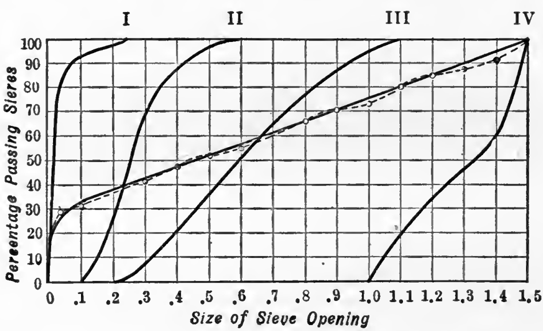


FIG. 132.—Combining Four Ingredients.

sieve. Then for any sieve ordinate an equation can be written by noting that q parts of I of which p will pass the sieve is equal to pq parts of the whole mixture passing that sieve. Taking the parts of each of the ingredients in order:

q_1 parts of I fineness $p_1 = p_1q_1$ parts of the whole.

q_2 parts of II fineness $p_2 = p_2q_2$ parts of the whole.

q_3 parts of III fineness $p_3 = p_3q_3$ parts of the whole.

q_4 parts of IV fineness $p_4 = p_4q_4$ parts of the whole.

The whole mixture to be "ideal" must have a "fineness" of P, that is, P per cent must pass the given sieve. Therefore the statements above may be expressed algebraically.

$$(q_1+q_2+q_3+q_4\ .\ .\ .\ )P = p_1q_1+p_2q_2+p_3q_3+p_4q_4\ .\ .\ .$$

$$P = \Sigma pq/\Sigma q. \qquad (1)$$

When all the ingredients will pass the largest screen

$$q_1+q_2+q_3+q_4+\ \ldots\ =\Sigma q=100,$$

and

$$P=\Sigma pq/100. \quad . \quad . \quad . \quad . \quad (2)$$

This is the general equation to be used in proportioning concrete so that the density curve will approach the ideal curve.

An equation of this kind may be written for every ordinate of the diagram. When there are n ingredients, n of these equations may be taken as independent equations and the values of q computed; the density curve resulting from this computation will agree with the ideal curve at n points.

For example, using Fig. 132, first writing the general equation in the form

$$p_1q_1+p_2q_2+p_3q_3+p_4q_4+\ \ldots\ =100P,$$

there results for the ordinates through

$$\begin{array}{ll} 0.1, & 93q_1 = 3200 \\ 0.5, & 100q_1+95q_2+35q_3 = 5200 \\ 0.8, & 100q_1+100q_2+75q_3 = 6600 \\ 1.5,^1 & 100q_1+100q_2+100q_3+100q_4=10{,}000 \end{array}$$

[1] It is necessary that one equation be taken for the ordinate where the ideal curve meets the 100 per cent line, otherwise, Σp would not equal 100 and Equation (2) would not hold.

And so on for as many ordinates as may be desired. Using these four equations, that is, assuming that the density curve is to coincide with the ideal curve on the ordinates considered, and solving, there results, omitting fractions,

$$q_1=34$$

$$q_2=\ 7$$

$$q_3=34$$

$$q_4=25$$

Theoretically a solution for any four ordinates is possible; practically the values thus found will not always answer, because negative quantities cannot be used. The small value of q_2 here indicates that the ingredient II might be omitted without great detriment to the mixture; a suggestion given, also, by a view of the plot, Fig. 132.

Plotting the Curve.—Substitute the calculated or selected values of

q_1, q_2, q_3, q_4, in the general equation for as many ordinates as desired and find P. For example (the subscript indicates the ordinate):

$$P = \frac{\Sigma pq}{100} \text{(general equation)}$$

$$P_{0 \cdot 05} = \frac{85 \times 34}{100} = 29$$

$$P_{0 \cdot 3} = \frac{100 \times 34 + 67 \times 7 + 8 \times 34}{100} = 41$$

$$P_{0 \cdot 6} = \frac{100 \times 34 + 100 \times 7 + 39 \times 34}{100} = 54$$

$$P_{1 \cdot 0} = \frac{100 \times 34 + 100 \times 7 + 94 \times 34}{100} = 73$$

$$P_{1 \cdot 2} = \frac{100 \times 34 + 100 \times 7 + 100 \times 34 + 35 \times 25}{100} = 84$$

$P_{1 \cdot 3} = 75 + \frac{1}{4}$ of 46.

$P_{1 \cdot 4} = 75 + \frac{1}{4}$ of 62.

A curve plotted through these points will approximately coincide with the "ideal" curve. It will also show wherein other ordinates should have been used to determine the proportions q; or how the values of q may be modified to fit the "ideal" curve better.

Proportions Used in Practice

The practice of the last few years is toward a denser and richer mixture. The Standard Specifications of the "American Concrete Institute," 1914, state:

"The concrete shall be mixed in the proportions of one bag of Portland cement to not more than 2 cubic feet of fine aggregate and not more than 3 cubic feet of coarse aggregate, and in no case shall the volume of fine aggregate be less than one-half the volume of coarse aggregate. A cubic yard of concrete in place shall contain not less than 1.7 barrels (6.8 bags of cement." Calling a bag of cement 1 cubic foot the limiting proportions above would be

$$\text{cement} : \text{sand} : \text{stone} = 1 : 2 : 3$$

These proportions apply to one-course pavements and the upper or wearing course of two-course pavements. The lower course of a two-course pavement may have concrete of the protions of "one bag Portland cement to not more than $2\frac{1}{2}$ cubic feet of fine aggregate, and not more than 4 cubic feet of coarse aggregate." That is,

$$\text{cement} : \text{sand} : \text{stone} = 1 : 2\tfrac{1}{2} : 4.$$

Abrams' Fineness Modulus Method.—Abrams has, as a result of a number of years' experimenting and approximately 50,000 tests, given out the statement that:

"Our experimental work has emphasized the importance

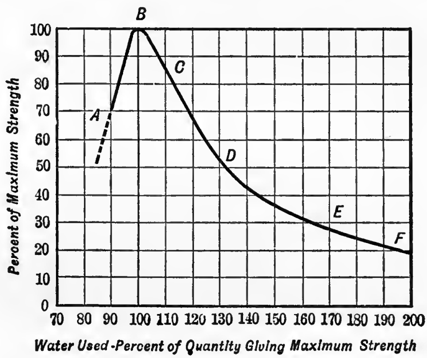


FIG. 133.—Effect of Water on the Strength of Concrete (Abrams).

C (105 to 115) is about the proper consistency for concrete road work. With the "sloppy" concrete, *E* sometimes used, two-thirds to three-fourths the possible strength of the concrete is lost.

of the water in concrete mixtures, and shown that the water is, in fact, the most important ingredient, since very small variations in the water content produces more important variations in the strength and other properties of concrete than similar changes in the other ingredients." [1]

Fig. 133 shows what Professor Abrams found to be the effect

[1] Bulletin No. 1, Structural Materials Research Laboratory, Lewis Institute, Chicago, "Design of Concrete Mixtures," by Duff A. Abrams, Professor in Charge. A series of bulletins have been published by the Laboratory on the results of researches in the properties of concrete and concrete materials carried on through the co-operation of Lewis Institute and the Portland Cement Association, Chicago.

of water on the strength of concrete. The vertical distances represent the relative strength of concrete, expressed as a per cent of the maximum which can be secured from the same mixture of cement and aggregates with varying quantities of water. The horizontal distances indicate the relative quantity of water used in the mix, considering the amount which gives the maximum strength as 100 per cent. A decrease or an increase of the quantity of water causes the strength to fall off rapidly. The absolute quantity of water corresponding to maximum strength of concrete will vary with the method of handling and placing an over-watered concrete. Puddling, rodding, tamping, rolling, vibration, troweling, or the application of pressure will have a tendency to strengthen the concrete. The quantity of water required is, according to Abrams, governed by (*a*) the condition of workability of concrete which must be used—the relative plasticity or consistency; (*b*) the normal consistency of the cement; and (*c*) the size and grading of the aggregate—measured by the fineness modulus.

Abrams' investigations lead him to the following equation for the comparative strength of concrete and water content:

$$S=\frac{A}{B^x}, \qquad (1)$$

where S is the strength of the concrete and x the ratio of the volume of water to the volume of cement in the batch. A and B are constants whose values depend on the quality of the cement used, the age of the concrete, curing conditions, etc. For the conditions under which Abrams' tests were made this becomes

$$S=\frac{14{,}000}{7^x}. \qquad (2)$$

Fig. 134 is a plot of this curve which is an average of the results of tests of the several mixes.

He then finds the following relation between the quantity of water for given proportions and conditions:

$$x=R\left[\frac{3}{2}p+\left(\frac{0.30}{1.26^m}+a-c\right)n\right], \qquad (3)$$

or approximately,

$$x = R\left[\frac{3}{2}p + \left(\frac{m}{42} + a - c\right)n\right], \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where x represents the water ratio $= \dfrac{\text{volume of water}}{\text{volume of cement}}$,

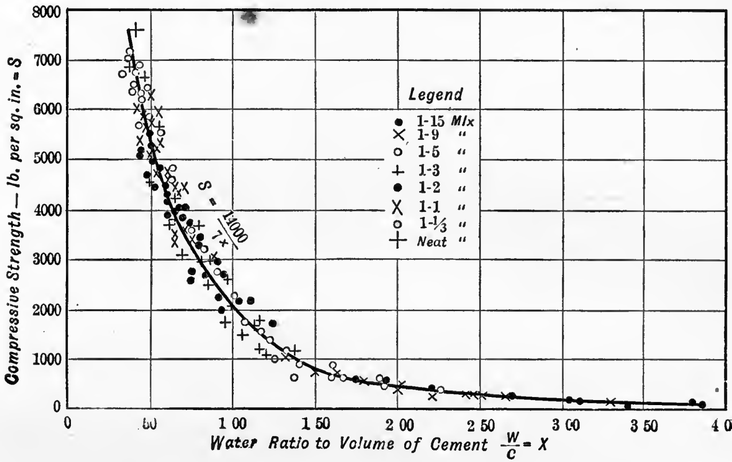


FIG. 134.—Relation between Strength of Concrete and Water Content (Abrams)

Twenty-eight-day compression tests of 6 by 12-inch cylinders. (Series 83.)

R, the relative consistency of concrete or "workability factor." Normal consistency requires the use of such a quantity of mixing water as will cause a slump of ½ to 1 inch in a freshly molded 6×12-inch cylinder of about 1 : 4 mix upon withdrawing the form by a steady upward pull. A relative consistency of 1.10 requires the use of 10 per cent more water and under above conditions will give a slump of about 5 to 6 inches.

p, the normal consistency of cement, ratio by weight;

m, the fineness modulus of aggregate;

a, the absorption of aggregate, three hours' immersion;

c, the moisture contained in aggregate—ratio volume contained to volume of aggregate.

The Fineness Modulus is determined by a sieve analysis. The sieves used are the Tyler standard in which the clear mesh-opening of each sieve is just double that of the preceding one. The sieve analysis is expressed in terms of either volume or weight as the percent coarser than each sieve. The fineness modulus of an aggregate is defined as the sum of the percentages given by the sieve analysis divided by 100. The following table taken from the bulletin cited gives the method of calculating the fineness modulus:

TABLE I

METHOD OF CALCULATING FINENESS MODULUS OF AGGREGATES

The *sieves* used are commonly known as the Tyler standard sieves. Each sieve has a *clear opening* just double that of the preceding one.

The *sieve analysis* may be expressed in terms of volume or weight.

The *fineness modulus* of an aggregate is the sum of the percentages given by the sieve analysis, divided by 100.

Sieve Size	Size of Square Opening		Sieve Analysis of Aggregates Per Cent of Sample Coarser than a Given Sieve						
			Sand			Pebbles			Concrete Aggregate
	in.	mm.	Fine (A)	Medium (B)	Coarse (C)	Fine (D)	Medium (E)	Coarse (F)	(G)[1]
100-mesh	.0058	.147	82	91	97	100	100	100	98
48-mesh	.0116	.295	52	70	81	100	100	100	92
28-mesh	.0232	.59	20	46	63	100	100	100	86
14-mesh	.046	1.17	0	24	44	100	100	100	81
8-mesh	.093	2.36	0	10	25	100	100	100	78
4-mesh	.185	4.70	0	0	0	86	95	100	71
⅜-inch	.37	9.4	0	0	0	51	66	86	49
¾-inch	.75	18.8	0	0	0	9	25	50	19
1½-inch	1.5	38.1	0	0	0	0	0	0	0
Fineness modulus			1.54	2.41	3.10	6.46	6.86	7.36	5.74

[1] Concrete aggregate "G" is made up of 25 per cent of sand "B" mixed with 75 per cent of pebbles "E." Equivalent gradings would be secured by mixing 33 per cent sand "B" with 67 per cent coarse pebbles "F"; 28 per cent "A" with 72 per cent "F," etc. The proportion coarser than a given sieve is made up by the addition of these percentages of the corresponding size of the constituent materials.

Maximum Permissible Values of Fineness Modulus.—Practical considerations make it necessary to establish upper limits for the fineness modulus of aggregates. Professor Abrams' table for these values follows:

TABLE II

MAXIMUM PERMISSIBLE VALUES OF FINENESS MODULUS OF AGGREGATES

Mix	Size of Aggregate													
Cem. Agg.	0–28	0–14	0–8	0–4	0–3 [1]	0–$\frac{3}{8}$	0–$\frac{1}{2}$ [1]	0–$\frac{3}{4}$	0–1 in. [1]	0–1$\frac{1}{2}$	0-2.1 [1]	0–3 in.	0–4$\frac{1}{2}$	0–6 in.
1–12	1.20	1.80	2.40	2.95	3.35	3.80	4.20	4.60	5.00	5.35	5.75	6.20	6.60	7.00
1–9	1.30	1.85	2.45	3.05	3.45	3.85	4.25	4.65	5.00	5.40	5.80	6.25	6.65	7.05
1–7	1.40	1.95	2.55	3.20	3.55	3.95	4.35	4.75	5.15	5.55	5.95	6.40	6.80	7.20
1–6	1.50	2.05	2.65	3.30	3.65	4.05	4.45	4.85	5.25	5.65	6.05	6.50	6.90	7.30
1–5	1.60	2.15	2.75	3.45	3.80	4.20	4.60	5.00	5.40	5.80	6.20	6.60	7.00	7.45
1–4	1.70	2.30	2.90	3.60	4.00	4.40	4.80	5.20	5.60	6.00	6.40	6.85	7.25	7.65
1–3	1.85	2.50	3.10	3.90	4.30	4.70	5.10	5.50	5.90	6.30	6.70	7.15	7.55	8.00
1–2	2.00	2.70	3.40	4.20	4.60	5.05	5.45	5.90	6.30	6.70	7.10	7.55	7.95	8.40
1–1	2.25	3.00	3.80	4.75	5.25	5.60	6.05	6.50	6.90	7.35	7.75	8.20	8.65	9.10

[1] Considered as "half-size" sieves; not used in computing fineness modulus.

For *mixes* other than those given in the table, use the values for the next leaner mix.

For *maximum sizes* of aggregate other than those given in the table, use the values for the next smaller size.

Fine aggregate includes all material finer than No. 4 sieve; *coarse aggregate* includes all material coarser than the No. 4 sieve. *Mortar* is a mixture of cement, water and fine aggregate.

This table is based on the requirements for *sand-and-pebble* or *gravel* aggregate composed of approximately spherical particles, in ordinary uses of concrete in reinforced concrete structures. For other materials and in other classes of work the maximum permissible values of fineness modulus for an aggregate of a given size is subject to the following corrections:

(1) If *crushed stone* or *slag* is used as coarse aggegate, *reduce* values in table by 0.25. For crushed material consisting of unusually flat or elongated particles, *reduce* values by 0.40.

(2) For *pebbles* consisting of *flat particles, reduce* values by 0.25.

(3) If *stone screenings* are used as fine aggregate, *reduce* values by 0.25.

(4) For the top course in *concrete roads, reduce* the values by 0.25. If finishing is done by *mechanical means*, this reduction need not be made.

(5) In work of *massive proportions*, such that the smallest dimension is

larger than ten times the maximum size of the coarse aggregate, *additions may be made* to the values in the table as follows: for $\frac{3}{4}$-in. aggregate 0.10; for $1\frac{1}{2}$-in. 0.20; for 3-in. 0.30; for 6-in. 0.40.

Sand with fineness modulus lower than 1.50 is undesirable as a fine aggregate in ordinary concrete mixes. Natural sands of such fineness are seldom found.

Sand or *screenings* used for fine aggregate in concrete must not have a higher fineness modulus than that permitted for mortars of the same mix. Mortar mixes are covered by the table and by (3) above.

Crushed stone mixed with both finer sand and coarser pebbles requires no reduction in fineness modulus provided the quantity of crushed stone is less than 30 per cent of the total volume of the aggregate.

Steps in the Design of Concrete Mixtures.—The following is an abstract of the outline of procedure given in the bulletin cited:

1. Knowing the compressive strength required of the concrete, determine by reference to Fig. 134 the maximum water-ratio which may be used. A given water-ratio can be secured with a minimum of cement if the aggregate is graded as coarse as permissible.

2. Make sieve analyses of fine and coarse aggregates, using Tyler Standard sieves of the following sizes: 100, 48, 28, 14, 8, 4, $\frac{3}{8}$, $\frac{3}{4}$, and $1\frac{1}{2}$ inches. Express sieve analyses in terms of percentages of material by weight (or separate volumes) coarser than each of the standard sieves.

3. Compute fineness modulus of each aggregate by adding the percentages found in (2) and dividing by 100.

4. Determine the "maximum size" of aggregate by applying the following rules: If more than 20 per cent of aggregate is coarser than any sieve the maximum size shall be taken as the next larger sieve in the standard set; if between 11 and 20 per cent is coarser than any sieve, maximum size shall be the next larger "half sieve"; if less than 10 per cent is coarser than certain sieves the smallest of these sieve sizes shall be considered, the maximum size.

5. From Table I determine the maximum value of fineness modulus which may be used in the mix, kind and size of aggregate, and the work under consideration.

6. Compute the percentages of fine and coarse aggregates required to produce the fineness modulus desired for the final aggregate mixture by applying the formula:

$$P = 100\frac{A-B}{A-C} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where P is the percentage of fine aggregate in the total mixture;

A, the fineness modulus of the coarse aggregate;

B, the fineness modulus of the final aggregate mixture;

C, the fineness modulus of the fine aggregate.

7. With the estimated mix, fineness modulus and consistency enter Fig. 135 and determine the strength of concrete produced by the combination. If the strength shown by the diagram is not that required, the necessary readjustment may be made by changing the mix, consistency or size and grading of the aggregates.

The quantity of water can be determined from Equation (3) or approximately from Table 3.

IMPORTANCE NOTE.—It must be understood that the values in Fig. 135 were determined from compression tests of 6 × 12-inch cylinders stored

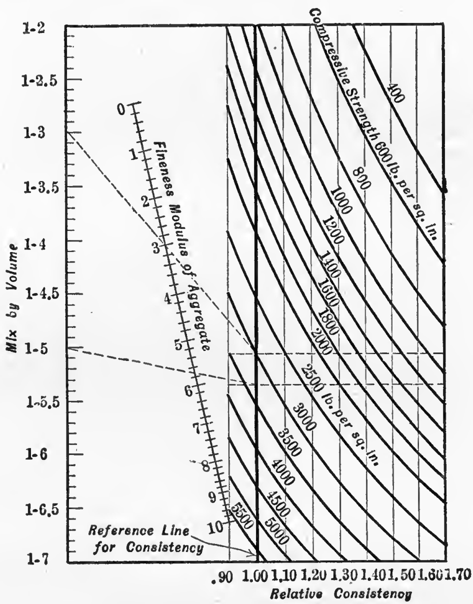


FIG. 135.—Abrams' Diagram for Designing Concrete Mixtures.

for twenty-eight days in a damp place. The values obtained on the work will depend on such factors as the consistency of the concrete, quality of the cement, method of mixing, handling, placing the concrete, etc., and on the age and curing conditions.

Strength values higher than given for relative consistency of 1.10 should seldom be considered in designing, since it is only in exceptional cases that a consistency drier than this can be satisfactorily placed. For wetter concrete much lower strengths must be considered.

The quantity of water to be used may be calculated by Formula (3) or taken from the table below, which is calculated

Abrams' Table of Proportions and Quantities for One Cubic Yard of Concrete

Based upon laboratory investigations, using approved materials, compressive strength, 28 days, with workable plasticity, 6 by 12-inch cylinders, 3,000 pounds per square inch.

SIZES		FINE AGGREGATES, SCREEN OPENINGS PER INCH														
COARSE AGGREGATES Inches	Cement in Barrels Aggregates in Cubic Yards	0-28			0-14			0-8			0-4			0-⅜ In.		
		Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse
No. 4 Screen to ¾	Proportions	1	1.3	2 4	1	1.6	2.4	1	1.8	2.3	1	2.0	2.3	1	2.7	1.5
	Quantities	1 96	.37	69	1.85	44	66	1 82	48	62	1.75	52	59	1.79	.72	40
No. 4 Screen to 1	Proportions	1	1.3	2.7	1	1.6	2 6	1	1.8	2.6	1	2.0	2.5	1	2.6	1.8
	Quantities	1 90	36	76	1 77	42	68	1.72	46	66	1 67	.50	.62	1.72	66	46
No. 4 Screen to 1½	Proportions	1	1.2	3.1	1	1.6	3.2	1	1.7	3.1	1	2	3	1	2.4	2.4
	Quantities	1 82	.32	84	1 68	40	79	1 63	41	75	1 61	47	.72	1 62	.57	57
No. 4 Screen to 2	Proportions	1	1.2	3.5	1	1.5	3.5	1	1.6	3.7	1	1.9	3.6	1	2.2	3.1
	Quantities	1 75	.31	90	1 63	36	85	1 55	.36	.85	1.52	.43	.81	1 53	.50	70
No. 4 Screen to 2½	Proportions	1	1.1	3.8	1	1.4	3.9	1	1.6	4.0	1	1.8	4.0	1	2.1	3.5
	Quantities	1 72	28	97	1 58	33	91	1 51	.35	.89	1 49	.40	.88	1 50	.46	.78
No. 4 Screen to 3	Proportions	1	1.1	3.9	1	1.4	4.1	1	1.5	4.1	1	1.7	4.1	1	2.0	3.7
	Quantities	1 69	28	97	1 58	33	97	1.49	33	90	1.49	37	90	1 49	.44	81
⅜ to ¾	Proportions	1	1.3	2.3	1	1.7	2.3	1	1.9	2.3	1	2.2	2.2	1	2.8	1.4
	Quantities	1 96	37	67	1 85	46	63	1.82	51	62	1.75	57	57	1 79	75	.37
⅜ to 1	Proportions	1	1.3	2.6	1	1.7	2.6	1	1.9	2.5	1	2.2	2.4	1	2.7	1.7
	Quantities	1.90	.36	74	1 77	44	68	1.72	48	64	1.67	54	59	1 72	68	43
⅜ to 1½	Proportions	1	1.3	3.0	1	1.7	3.0	1	1.9	3.0	1	2.1	2.9	1	2.6	2.2
	Quantities	1 82	35	80	1 68	43	75	1 63	46	73	1 61	.50	.68	1 62	.63	53
⅜ to 2	Proportions	1	1.3	3.3	1	1.7	3 4	1	1.8	3.5	1	2.0	3.4	1	2.4	2.9
	Quantities	1 75	34	86	1 63	41	83	1 55	42	80	1 52	.45	77	1 53	62	66
⅜ to 2½	Proportions	1	1.3	3.7	1	1.6	3.7	1	1.7	3.9	1	2.0	3.8	1	2.3	3.3
	Quantities	1 72	.33	95	1.58	37	87	1.51	.37	87	1.49	44	84	1 50	51	74
⅜ to 3	Proportions	1	1.2	3 8	1	1.6	3.9	1	1.7	4.0	1	1.9	4.0	1	2.2	3.5
	Quantities	1 68	.30	95	1 58	.37	91	1 49	.37	88	1.49	42	88	1 49	48	.77
½ to ¾	Proportions	1	1.5	2.3	1	1.9	2.2	1	2.1	2.2	1	2.3	2.1	1	2.8	1.3
	Quantities	1.96	44	67	1 85	.52	.61	1.82	56	.59	1 75	.59	.54	1.79	.75	.34
½ to 1	Proportions	1	1.5	2.5	1	1.9	2.5	1	2.1	2.4	1	2.3	2 4	1	2.8	1.6
	Quantities	1 90	42	.70	1.77	50	66	1.72	53	61	1.67	57	.59	1.72	.72	41

by that formula for average conditions. A relative consistency of 1.10 is about right for road work; of 1.25 for reinforced concrete bridges if a drier mixture cannot be used.

A Table of Proportions issued by the Portland Cement Association over the name of A. N. Johnson will simplify the application of Abrams' theory:

The accompanying table shows the various proportions by which to combine a variety of fine aggregates, five selected sizes, with various sizes of coarse aggregates. The fine aggregates, or sands, shown in the table include, first, one with all particles passing a sieve with 28 openings per linear inch and another with 14 openings, one with 8, one with 4 and a sand with ⅜-inch size particles down. The range of coarse aggregate is apparent from the table.

To determine whether a given aggregate is to be classed as 3-inch or

Abrams' Table of Proportions and Quantities for One Cubic Yard of Concrete

Based upon laboratory investigations, using approved materials; compressive strength, 28 days, with workable plasticity, 6 by 12-inch cylinders, 3,000 pounds per square inch.

SIZES		FINE AGGREGATES, SCREEN OPENINGS PER INCH														
		0-28			0-14			0-8			0-4			0-3/8 In.		
COARSE AGGREGATES Inches	Cement, in Barrels Aggregates in Cubic Yards	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse
½ to 1⅓	Proportions	1	1.4	2.8	1	1.9	2.9	1	2.1	2.9	1	2.2	2.8	1	2.7	2.1
	Quantities	1 82	.37	.75	1.68	.47	.73	1.63	.51	.69	1.61	.52	.66	1.62	.65	.51
⅓ to 2	Proportions	1	1.4	3.3	1	1.9	3.3	1	2.0	3.4	1	2.2	3.3	1	2.7	2.7
	Quantities	1.75	.36	.86	1.63	.46	.79	1.55	.46	.78	1.52	.50	.74	1.53	.62	.62
½ to 2½	Proportions	1	1.4	3.6	1	1.8	3.6	1	1.9	3.7	1	2.1	3.7	1	2.6	3.1
	Quantities	1.72	.35	.91	1.58	.43	.85	1.51	.42	.83	1.49	.46	.81	1.50	.57	.69
½ to 3	Proportions	1	1.3	3.7	1	1.8	3.8	1	1.8	3.9	1	2.1	4.0	1	2.4	3.3
	Quantities	1.68	.33	.92	1.58	.42	.89	1.49	.40	.86	1.49	.46	.88	1.49	.53	.63
¾ to 1	Proportions	1	1.7	2.4	1	2.1	2.4	1	2.4	2.1	1	2.6	2.2	1	3.1	1.6
	Quantities	1.90	.48	.68	1.77	.55	.63	1.72	.61	.53	1.67	.64	.55	1.72	.79	.39
¾ to 1½	Proportions	1	1.7	2.7	1	2.0	2.8	1	2.3	2.7	1	2.5	2.7	1	3.0	2.0
	Quantities	1.82	46	.73	1.79	.50	.70	1.63	.55	.65	1.61	.59	.64	1.62	.73	.48
¾ to 2	Proportions	1	1.7	3.1	1	2.0	3.1	1	2.3	3.1	1	2.5	3.0	1	3.0	2.4
	Quantities	1.75	.44	.80	1.63	.48	.75	1.55	.53	.72	1.52	.56	.67	1.53	.68	.55
¾ to 2½	Proportions	1	1.7	3.3	1	2.0	3.5	1	2.3	3.4	1	2.4	3.4	1	2.9	2.8
	Quantities	1.72	.43	.84	1.63	.47	.83	1.51	.52	.76	1.49	.53	.75	1.50	.64	.62
¾ to 3	Proportions	1	1.7	3.5	1	2.0	3.7	1	2.3	3.7	1	2.4	3.6	1	2.8	3.1
	Quantities	1.68	.43	.88	1.58	.47	.87	1.49	.51	.81	1.49	.53	.79	1.49	.62	.68
1 to 1½	Proportions	1	1.7	2.8	1	2.0	2.9	1	2.3	2.7	1	2.6	2.6	1	3.1	2.0
	Quantities	1.82	.46	.75	1.68	.50	.73	1.63	.55	.65	1.61	.62	.62	1.62	.75	.48
1 to 2	Proportions	1	1.6	3.2	1	1.9	3.6	1	2.2	3.3	1	2.4	3.3	1	3.0	2.6
	Quantities	1.75	.39	.83	1 63	.46	.85	1.58	51	.76	1.52	.54	.74	1.53	.68	.59
1 to 2½	Proportions	1	1.4	3.4	1	1.9	3.8	1	2.0	3.7	1	2.3	3.7	1	2.7	3.1
	Quantities	1 72	.35	.86	1.58	.45	.89	1.51	.44	.83	1.49	.51	.81	1.50	.59	.69
1 to 3	Proportions	1	1.3	3.6	1	1.8	4.0	1	2.0	3.9	1	2.2	3.9	1	2.7	3.3
	Quantities	1 67	.33	.90	1.58	.42	.94	1.49	.44	.86	1.49	.48	.86	1.49	.59	.73

2½-inch or 2-inch, or whatever the upper limit of size may be there should be not less than 10 per cent of the sample between the upper limit and the next lower size. Thus, if a material is to be classed as a 3-inch aggregate there should be not less than 10 per cent of the total volume of the sample between the 3-inch and 2½-inch sizes; otherwise it will be classed as 2½-inch size. Similarly, if there are 2-inch pieces it will be classed as 2-inch aggregate if there is not less than 10 per cent between 1½-inch and 2-inch sizes.

For fine aggregates there should be of the coarser material not less than 15 per cent between the coarser size and the next smaller screen opening. Thus, if a fine aggregate is to be classed as ¼-inch size there should be not less than 15 per cent between the ⅛-inch screen and the ¼-inch screen.

With the ¼-inch sand down, the one usually specified, and with the coarse aggregate varying from that held on a No. 4 sieve to that passing a 1½-inch opening, the usual proportions of 1 : 2 : 3 were taken and, with a workable plasticity or practical consistency, such a mixture produces a concrete with a crushing strength at twenty-eight days of 3000 pounds per square inch in the form of 6×12-inch cylinders. All of the other proportions and combinations are computed to give the same strength concrete as 1 : 2 : 3 mixture.

TABLE III

QUANTITY OF MIXING WATER REQUIRED FOR CONCRETE

Mix Cem.-Agg. by Vol.	Gallons of Water per Sack of Cement* Using Aggregates of Different Fineness Moduli											
	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00
Relative Consistency—(R) = 1.00												
1–12	23.5	21.4	19.5	17.8	16.4	15.2	13.9	12.9	12.0	11.1	10.4	9.8
1–9	18.1	16.7	15.2	14.0	12.9	12.0	11.0	10.2	9.6	9.0	8.4	7.9
1–7	14.7	13.5	12.3	11.4	10.6	9.9	9.1	8.6	8.0	7.6	7.2	6.7
1–6	13.0	12.0	11.0	10.2	9.5	8.9	8.3	7.7	7.3	6.8	6.5	6.2
1–5	11.2	10.4	9.5	8.9	8.3	7.8	7.3	6.9	6.4	6.1	5.8	5.5
1–4	9.5	8.9	8.2	7.7	7.2	6.8	6.3	6.0	5.7	5.4	5.2	5.0
1–3	7.8	7.2	6.7	6.3	6.0	5.7	5.4	5.1	4.9	4.6	4.5	4.3
1–2	6.0	5.7	5.4	5.1	4.9	4.7	4.5	4.3	4.1	4.0	3.9	3.8
1–1	4.3	4.1	3.9	3.8	3.7	3.6	3.5	3.4	3.3	3.2	3.2	3.1
Relative Consistency—(R) = 1.10												
1–12	25.8	23.6	21.4	19.6	18.1	16.7	15.3	14.2	13.2	12.2	11.4	10.8
1–9	19.9	18.4	16.7	15.4	14.2	13.2	12.1	11.2	10.6	9.9	9.2	8.7
1–7	16.2	14.9	13.5	12.5	11.7	10.9	10.0	9.5	8.8	8.4	7.9	7.4
1–6	14.3	13.2	12.1	11.2	10.5	9.8	9.1	8.5	8.0	7.5	7.2	6.8
1–5	12.3	11.4	10.5	9.8	9.1	8.6	8.0	7.6	7.0	6.7	6.4	6.1
1–4	10.5	9.8	9.0	8.5	7.9	7.5	6.9	6.6	6.3	5.9	5.7	5.5
1–3	8.6	7.9	7.4	6.9	6.6	6.3	5.9	5.6	5.4	5.1	5.0	4.7
1–2	6.6	6.3	5.9	5.6	5.4	5.2	5.0	4.7	4.5	4.4	4.3	4.2
1–1	4.7	4.5	4.3	4.2	4.1	4.0	3.9	3.7	3.6	3.5	3.5	3.4
Relative Consistency—(R) = 1.25												
1–12	29.4	26.8	24.4	22.2	20.5	19.0	17.4	16.1	15.0	13.9	13.0	12.3
1–9	22.6	20.9	19.0	17.5	16.1	15.0	13.8	12.7	12.0	11.2	10.5	9.9
1–7	18.4	16.9	15.4	14.3	13.2	12.4	11.4	10.7	10.0	9.5	9.0	8.4
1–6	16.3	15.0	13.8	12.8	11.9	11.1	10.4	9.6	9.1	8.5	8.1	7.7
1–5	14.0	13.0	11.9	11.1	10.4	9.8	9.1	8.6	8.0	7.6	7.2	6.9
1–4	11.9	11.1	10.2	9.6	9.0	8.5	7.9	7.5	7.1	6.8	6.5	6.2
1–3	9.8	9.0	8.4	7.9	7.5	7.1	6.8	6.4	6.1	5.8	5.6	5.4
1–2	7.5	7.1	6.8	6.4	6.1	5.9	5.6	5.4	5.1	5.0	4.9	4.8
1–1	5.4	5.1	4.9	4.8	4.6	4.5	4.4	4.3	4.1	4.0	4.0	3.9

The table contains in the upper line of each block the proportion of cement, fine and coarse aggregate to be combined, while immediately below in each square are given the quantities that are required for a cubic yard of concrete, the cement quantity being given in barrels and hundredths of barrels and the quantities for fine and coarse aggregates being given in hundredths of cubic yards.

It should be borne in mind that the quantities shown in the table are for a cubic yard of concrete as determined from laboratory measurements and that for the purpose of ordering materials or making estimates of the total cost of materials for a given piece of work these quantities should be increased from the amounts shown by such estimate of waste for the aggregates as experience in handling the work, according to the particular method to be employed, has indicated as necessary.

The following example will make clear the use of the table:

It will be supposed that one sand is that usually specified, from ¼-inch down, and must be shipped in at a cost of $2 per cubic yard and that one coarse aggregate, varying from ¼-inch to 2 inches, must also be shipped in at a total cost of $3 per cubic yard; that there is available locally a supply of sand and coarse aggregate, each being rather fine, the sand varying from ⅛-inch down which costs $1.50 per cubic yard, while the coarse aggregate varies from ¼-inch to 1 inch and may be secured at a cost of $2.50 per cubic yard. The cement in each case is assumed to cost $3 per barrel. The cost of a cubic yard of concrete using the materials to be shipped in would then be as follows:

1.52 barrels cement....................	at $3.00 =	$4.56
.43 cubic yard of sand................	at $2.00 =	.86
.81 cubic yard of coarse aggregate......	at $3.00 =	2.43
Total cost of materials for 1 cubic yard concrete		$7.85

Using local materials the cost would be:

1.72 barrels cement....................	at $3.00 =	$5.16
.46 cubic yard of sand................	at $1.50 =	.69
.66 cubic yard of coarse aggregate......	at $2.50 =	1.65
Total cost of materials for 1 cubic yard concrete......		$7.50

Thus the local aggregate, in this instance, although fine and requiring more cement, will produce a yard of concrete at less cost. In general it will be found that the use of finer sand or finer aggregate increases the amount of cement, the opposite being true for coarser sizes. Thus a coarse aggregate with all of the fine material removed, varying from 1 inch to 3 inches in size, combined with sand varying from ¼ inch down, uses 1.49 barrels of cement; whereas an aggregate varying from 1 inch to ¼ inch combined with the same sand, ¼ inch down, requires 1.67 barrels of cement for a cubic yard of concrete.

If the producer of aggregate materials can say what are the sizes of aggregates he can furnish they can be used to make a concrete of a given strength. Should concrete of a strength other than 3000 pounds per square inch be desired, then another table would be calculated with the proportions and quantities required accordingly, but the table given here is confined to the use of concrete for concrete roads where a better quality and greater strength are required than is necessary for concrete for many other structures.

Edwards' Surface Area Method.—L. N. Edwards proposed a method[1] of proportioning concrete, in 1918, on the theory that "The strength of mortars is dependent upon (1) the quantity of cement in relation to the surface areas of the aggregates, and (2) the consistency of the mix; that the strength of mortars of uniform consistency containing sand aggregates of varying granulometric composition is directly proportional to the quantity of cement they contain in relation to the surface area of the aggregate."

Mr. R. B. Young[2] has determined a series of diagrams for getting the relation of the surface area and the grading. From these diagrams Mr. Edwards' method may be applied without extended computations.

Some Proportions Used in Practice

A concrete pavement laid at Bellefontaine, Ohio, in 1893, had a 4-inch base of one part Portland cement to four parts gravel. The top course 2 inches thick was one Portland cement to one of clean sand.

Richmond, Ind., in 1903 laid a 5-inch base of 1 : 2 : 5 mixture and 1½-inch wearing surface of either 1 part cement to 1 part coarse sand or 1 part cement to 1 part sand to 1 part stone screenings.

Lemars, Iowa, 1904, 5-inch base 1 : 6 gravel; 1½-inch wearing surface 1 : 2 sand.

Independence, Mo., crushed stone and sand mixed in the proportion of 1 : 7 for 5½-inch base and 2 : 3 for 1¾-inch top.

Mason City, Ia., 1 : 2 : 5 mixture for 5-inch base and 1 : 2 for 2-inch wearing surface.

[1] Proceedings, American Society for Testing Materials, Vol. XVIII, Part II.

[2] Engineering News-Record, Vol. LXXXIV, Jan., 1920.

Sioux City, Ia., one course 5 inches thick. Mixed to overfill voids 5 per cent. If voids were not determined a 1 : 3 : 4½ was used.

Wayne County, Mich. Roads constructed in 1911 consist of the single course type; the concrete being 1 : 1½ : 3, depth 7 inches.

Scotia-High Mills road, Schenectady, N. Y., 1 : 1½ : 3. (1914). Other New York road same proportions.

Tupelo-Saltillo, Lee county, Miss., 1 : 2 : 3. (1914.)

Macon, Ga., 1913, 1 : 2 : 3. 5 to 7 inches thick.

Pennsylvania Highway Commission, 1916. 1 : 2 : 3.

Dupont Road, Delaware. This is a very carefully constructed road. A testing laboratory was maintained on the work and constant tests made of all materials. The proportion was changed frequently to conform to the materials used.

Proportioning the Very Fine Aggregate.—Not much attention has been paid to this part of the concrete. On the other hand, with asphalt pavements very great attention is given to the fine sand and stone dust used even to the portion which passes a No. 200 sieve. Sufficient tests and studies have been made, however, to prove that the addition of fine material, such as clay or hydrated lime, will improve lean concretes. This fine material not only fills the voids and makes the mortar denser but improves its plasticity. Hydrated lime, no doubt, adds some cementing properties and is therefore better than stone dust or clay. But tests of strength and density and the increased cost must be the determining factors for its use.

Quantities of Materials.—Fuller's rule for quantities is as follows: [1]

Divide 11 by the sum of the parts of all the ingredients, and the quotient will be the number of barrels of Portland cement required for 1 cubic yard of concrete.[2]

To express this rule algebraically

Let c = number of parts cement;

s = number of parts sand;

g = number of parts coarse aggregate.

[1] Taylor and Thompson's "Concrete, Plain and Reinforced," p. 16, Wiley & Sons, New York.

[2] The constant 10.3 is also used; see Mills' "Materials of Construction," p. 177. John Wiley & Sons, N. Y.

Then $\frac{11}{c+s+g}=P=$ number of barrels Portland cement required for 1 cubic yard concrete.

Since a barrel of cement is now reckoned as 4 bags and a bag of cement weighing 94 pounds as 1 cubic foot, there results:

With the proportions

$$\text{cement : sand : gravel or stone} = c : s : g,$$

1 cubic yard of concrete will require

$$\text{Cement, barrels,} = P = \frac{11}{c+s+g}$$

$$\text{Sand (cu. yd.)} \quad = P \times s \times 4/27$$

$$\text{Coarse aggregate (cu. yd.)} \quad = P \times g \times 4/27$$

Problem: A roadway is to be paved 18 feet wide, 6 inches thick for a distance of ¼ mile. Required, the quantities for a 1 : 2 : 3 concrete.

Solution: Total number of yards of concrete required

$$= \frac{18}{3} \times \frac{6}{36} \times \tfrac{1}{4} \text{ of } 1760$$

$$= 440 \text{ cubic yards}$$

$$P = \frac{11}{1+2+3} = \frac{11}{6} = 1.83$$

$$\text{Cement} = \frac{11}{6} \times 440 = 805 \text{ barrels}$$

$$\text{Sand} \quad = \frac{11}{6} \times 2 \times \frac{4}{27} \times 440$$

$$= 239 \text{ cubic yards}$$

$$\text{Coarse aggregate} = \frac{11}{6} \times 3 \times \frac{4}{27} \times 440$$

$$= 359 \text{ cubic yards.}$$

If the coarse aggregate is screened to a uniform size, about 5 per cent should be added; if graded from coarse to fine, so as to be quite dense, deduct 5 per cent.

Taylor and Thompson's Rule.—Taylor and Thompson [1] have worked out quite a complete formula which they have simplified to the following working formula for average materials:

$$B = \frac{27}{2.61 + 0.723S + 1.08(1-v)G},$$

[1] "Reinforced Concrete," p. 224.

where B = number of barrels cement per cubic yard of concrete;
S = volume of loose sand in cubic feet;
v = absolute voids [1] in stone determined by weight method;
G = volume of broken stone or gravel or cinders in cubic feet.

Now if c, s, and g represent the proportional parts of cement, sand and stone in the mixture, as before,

$$\text{Cement in barrels} = B$$

$$\text{Sand in cubic yards} = B \times s \times 4/27$$

$$\text{Stone in cubic yards} = B \times g \times 4/27$$

Applying this formula to the same problem with average limestone rock having absolute voids of 40 per cent:

The proportions are 1 : 2 : 3;

[1] The method of finding the voids is made as follows:

Pour into a 16-quart pail 31 pounds 2 ounces of water and mark the level of the surface. The pail up to this mark contains ½ cubic foot of any material.

Weigh the empty pail.

Fill the pail to the required level with the material.

Weigh and deduct the weight of the empty pail. Call the net weight of a cubic foot of the material S.

Dry a sample—about 10 pounds—of the material at a temperature of boiling water, 212° F., until there is no further loss. Calculate the loss in weight or moisture in percentage of the original moist weight. Express this as p.

R = weight of solid rock per cubic foot = weight of a cubic foot of water multiplied by the specific gravity of the rock = 62.46 × specific gravity of the rock.

Then $$v = \left(1 - \frac{S - Sp.}{R}\right) 100$$

AVERAGE SPECIFIC GRAVITY OF VARIOUS AGGREGATES

Material	Specific Gravity	Weight of Solid Cubic Foot of Rock, lb.
Sand	2.65	165
Gravel	2.66	165
Conglomerate	2.6	162
Granite	2.7	168
Limestone	2.6	162
Trap	2.9	180
Slate	2.7	168
Sandstone	2.4	150
Cinders (bituminous)	1.5	95

therefore if cement be taken as 1 barrel

$$S=2 \text{ barrels}=8 \text{ cubic feet, and } G=12 \text{ cubic feet}$$

$$B=\frac{27}{2.61+0.724\times 8+1.08\ (1-.40)\ 12}$$

$$=\frac{27}{2.61+5.784+7.776}=\frac{27}{16.17}$$

$$=1.67$$

Then for the whole job will be required

Cement (barrels) 440×1.67	=735
Sand (cubic yards) 735×2×4/27	=218
Stone (cubic yards) 735×3×4/27	=32

PROBLEM.—If Mills' rule were used, what would be the quantities? If Abrams' Table?

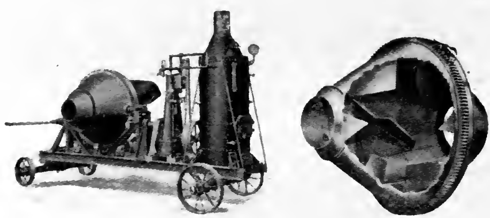


FIG. 136.—Tilting Drum Mixers.

The Specification of the Concrete Institute, that a cubic yard of concrete in place shall contain not less than 1.7 barrels of cement falls between Fuller's rule (1.83) and Taylor and Thompson's rule (1.67), and agrees with Mills' rule (1.71), but all are greater than the quantity given in Abrams' Table (1.61).

Mixing the Concrete.—The method of hand mixing was explained in Chapter X, p. 207. Machine mixing only will be considered here.

Mixers.—A number of different mixers have been placed upon the market and these have been generally classified as "batch mixers" and "continuous mixers." In the batch mixer measured quantities of the several ingredients are placed in the mixer, these mixed together and removed; then a second charge or batch is mixed and removed; and so on indefinitely. In the continuous mixer the materials are fed into the machine in a continuous stream in presumably right proportions at one place and the mixed concrete is continuously discharged at another. The difficulty of thorough control of the feeding due to choking valves, pipes, irregularities of the materials or laziness of workmen have brought engineers and contractors to favor

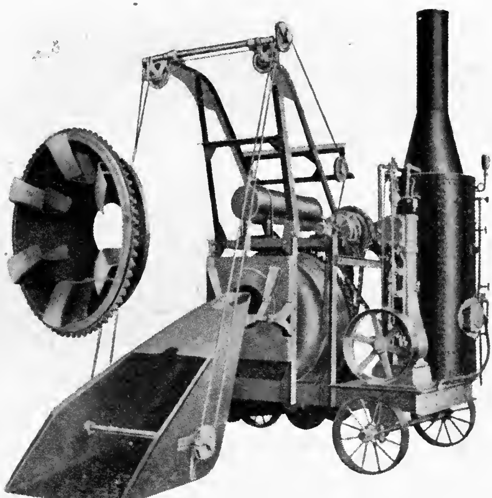


FIG. 137.—Showing Interior of Drum, and Loading Skip.

generally the batch mixer. If the feeding could be made automatic and absolutely regular there would be some advantages in the continuous mixer With the batch mixer the quantities are measured out beforehand and all put in the mixer at once. The homogeneity of the product depends on the character and time of mixing, which is easily regulated.

Mixers are further classified as **Rotary, Paddle,** and **Gravity.** A rotary mixer is essentially a chamber, drum, box or barrel into which the materials to be mixed are introduced. The chamber is rotated on trunnions and the tumbling of the materials thoroughly mixes them together. All of the modern mixers, except those used for dry mixing, are open at the ends of the drum to facilitate examination of the mixing concrete and that they may be charged and discharged without stopping. Blades or cleats on the inside of the chamber, Figs 136 and 137, carry the materials up the side and as they pour off the blades and drop to the bottom of the drum, they are deflected, cut and kneaded in such a way that a very thorough mixing, com-

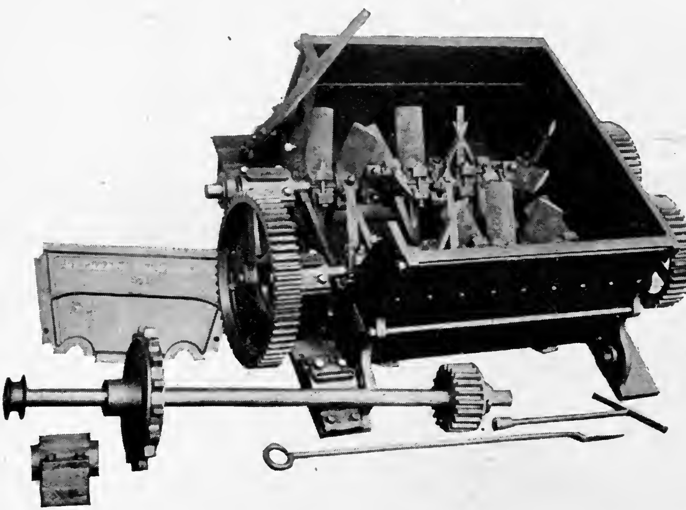


Fig. 138.—Paddle Mixer.

mingling and coating is accomplished. The larger machines have loading skips, Fig. 137, so arranged that the materials may be dumped into the skip while a batch is being mixed; as soon as the mixing chamber is discharged the loaded skip is mechanically emptied into it. The loading of the skip and the mixing going on together makes the loss of time due to charging and discharging a minimum.

Paddle Mixers.—Fig. 138 shows a paddle mixer. It consists of an open box in which revolve in opposite direction two shafts having attached to them the paddles. It is placed on a platform and the materials introduced at the top by shovels, barrows or otherwise. The mixed concrete is discharged through an opening in the bottom through the platform into barrows, wagons, carts or other conveyors. It may be used either as a batch or continous mixer by proper arrangement of the paddles and exit valve. Other paddle mixers have but a single shaft with the paddles arranged in a spiral along it so that the materials entering at one end are pushed along and mixed and then finally discharged at the other end. Such a mixer is of the continuous type. Fig. 139 shows a portable concrete mixer of the paddle type.

Gravity Mixers.—Gravity mixers require no power to

Fig. 139.—Paddle Type Mixer, Portable.

operate them, the mixing being done by dropping the material down a vertical trough or chute, Fig. 140, in which are obstructions or baffles. These baffles throw the material from side to side of the chute mixing it as it falls. Water is introduced through convenient pipes. Iron gratings serve to cut up any cement balls that might form. Other forms of gravity mixers have been designed, but as this type of mixer is little used for road work they will not be described.

Measuring the Materials.—The 94-lb. bag of cement is ordinarily considered to be one cubic foot. With sand and stone loose measurements are usually assumed. A measuring box was described in Chapter X, page 207, which can be used for measuring or checking as desired. Wheelbarrows, Fig. 141, are now so made that they may be struck off smooth on top and contain exactly three, or four, cubic feet. With such barrows the quantities can be measured with reasonable accuracy.

Automatic Measuring Devices have not proven entirely satisfactory owing to their liability to become clogged or choked. One of them consists of a series of cylinders in vertical positions with their open bottoms above and slightly separated from revolving disks. As the disks revolve the materials in them flow out on to the disks in cone-shaped masses. An adjustable blade is arranged to peel off from the cone a definite amount.

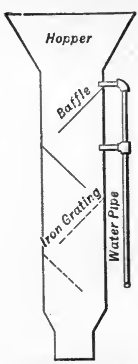


FIG. 140.

FIG. 141.—Measuring Barrows.

Other devices have a roll, and others a moving belt to drag out from an adjustable opening at the lower end of a hopper the material.

Weighing Devices.—It is entirely feasible to proportion by weight. This has been done for years in the construction of bituminous pavements. The stone and sand are elevated from the screen to bins above a hopper which rests on a scale having a number of weighing beams. A poise is moved out on one of the beams until it comes to a stop clamped at a place to indicate the amount of one of the ingredients of the mixture. The valve in a bin spout is opened, the material flows until the beam raises, the valve is closed. Another poise is run out to its stop, another bin is opened, and so on until all the ingredients and grades are in the hopper. The valve in the bottom of the hopper is now opened and the whole charge in exact proportions is dropped into the mixer. Improvements have been made on these scales so that now the stops may be placed at the proper places and the beam locked up; a pointer only shows on the outside. A man in authority has the key; no one else can change the proportions.

Consistency.—The United States Bureau of Standards has six different consistencies for concrete as follows:

Dry.—Containing just sufficient water to cause the cement and sand to adhere after tamping and removal of the molds.

Moist.—A mean between the dry and plastic consistencies.

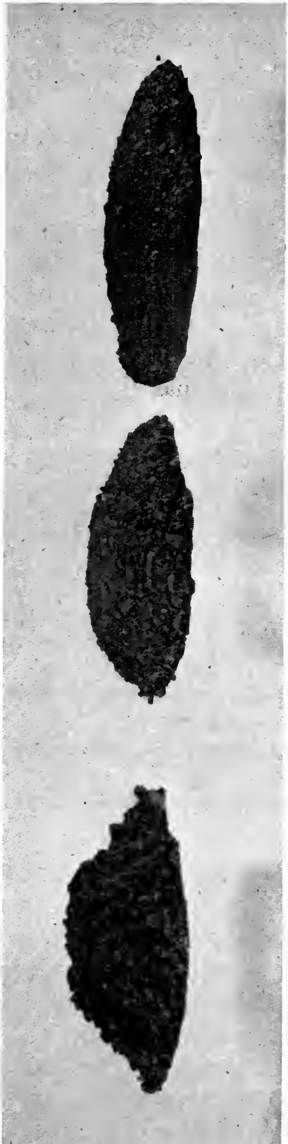
Plastic.—Containing the maximum of water which allows the removal of forms immediately after molding. The surface of the mass shows web-like marks of neat cement and water.

Quaking.—A stiff mixture upon which water can be brought to the surface by light tamping. The mass should not flow readily.

Mushy.—A soft mushy mixture which is not watery, but can be spaded and readily worked into place to the form.

Fluid.—A watery mixture which flows readily into place in the form with little or no mixing.

Fig. 142 shows three batches to illustrate the consistencies "quaking," "mushy," and "fluid." In forming the piles the concrete was allowed to slide from the shovel and drop only a few inches. "Quaking" to "mushy" would be the proper consistency for road work. The specification of the Association of American Portland Cement Manufacturers is, "The materials shall be mixed with sufficient water to produce a concrete which when deposited will settle to a flattened mass, but shall not be so wet as to cause a separation of the mortar from the coarse aggregate in handling."



Quaking. Mushy. Fluid.

FIG. 142.—Consistency of Concrete, Courtesy of U. S. Bureau of Standards.

Slump Test for Consistency.—This consists in withdrawing the mold from a cylinder or a truncated cone of concrete immediately after casting and noting the amount it decreases in height —slumps.

Cylinder Slump.—Professor Abrams in his work used a 6×12-inch cylindrical form, one of the regular molds for casting test pieces, made of steel gas pipe sawed longitudinally along one side. A clamp holds the edges of the saw kerf tightly together while the form is being filled. As soon as the freshly made concrete is mixed it is packed into the form, the clamp loosened and the form removed by a steady upward pull. For a relative consistency of 1.00 (normal consistency, or consistency for maximum strength) there should be a slump of $\frac{1}{2}$ to 1 inch. A relative consistency of 1.10 gives a slump of 5 to 6 inches; of 1.25, 8 to 9 inches.

Truncated Cone Slump.—Mr. F. L. Roman, Testing Engineer, Illinois State Highway Department, suggests that a truncated cone is better than a cylinder for making the slump tests.[1] The form recommended is shown in Fig. 143. It is made of 24-gauge galvanized iron and, manufactured locally, costs about $2.50 each. For convenience the molds are provided with handles and foot holds of strap iron. The top and bottom is turned on ½-inch wire and care is taken that the cone is circular and smooth throughout. Mr. Roman's statement is:

When making a slump test the base of the truncated cone mold is placed on a flat horizontal surface, and filled with the concrete, care being taken to tamp or rather arrange the mixture in the apparatus to obtain dense concrete and avoid stone pockets, as large voids or stone pockets tend to cause the concrete specimen to slump on one side rather than vertically. The mold is removed as nearly vertically as possible and the "slump" or vertical settlement (height of molded specimen minus height of concrete after settlement) is determined. Usually the concrete settles and comes to rest almost as quickly as the mold is removed, but it is advisable to take all readings about one minute after the mold is removed.

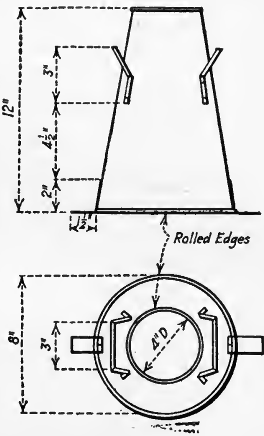


Fig. 143.—Truncated Cone Mold.

Experience in determining the consistency of concrete with the truncated cone apparatus would indicate the following "slumps"; very dry consistency, no "slump"; fairly dry consistency, ½ to 1 inch; medium to wet consistencies, 1 to 4 inches; wet to sloppy consistencies, 4 to 8 inches; very sloppy consistencies, above 8 inches. It should be noted, however, that crushed stone concrete will show somewhat less slump than gravel concrete of the same consistency due to the fact that angular fragments will, to some extent, be held in place mechanically and will not rearrange themselves as readily as the round pebbles. The difference in slump due to different aggregates is at least apparent at the drier consistencies, and for future state highway work in Illinois one general requirement only is made, that all concrete for pavements shall have a slump of ½ to 1 inch.

The quantity of water necessary to bring the concrete to the proper consistency depends on the temperature and humid-

[1] See "An Apparatus for Determining the Consistency of Concrete," by F. L. Roman, in *Engineering and Contracting*, March 3, 1920.

ity of the atmosphere and the character and condition as regards moisture of the materials. It must be determined each day, and thoughout the day, by those in charge.

Laboratory experiments show that a dry mixture, well-tamped, makes the strongest concrete. But as tamping is hard work and the probability that it will not be done well is always present, concrete men usually prefer a wetter mixture as more likely to be homogeneous. It is also slightly cheaper as the services of the tampers are eliminated. Professor Duff A. Abrams, Professor in Charge, Structural Materials Research Laboratory, Lewis Institute, Chicago, says:

> The only safe rule to follow with reference to water in concrete is to use the smallest quantity of mixing water which will give a plastic or workable mix, then provide plenty of moisture for the concrete during the period of curing which follows setting and hardening of the cement.[1]

Duration and Speed of Mixing.—Where the materials are mixed in a batch mixer the mixing should continue until all the particles of aggregate are completely coated and the concrete of proper consistency. Forty-five seconds after the materials are in the drum is considered enough. The recommended speed at which the drum should revolve is given in the following table:[2]

Rated Capacity Cubic Feet Unmixed Material	Capacity Bags of Cement in 1 : 2 : 3 Mixtures	Revolutions per Minute of Drum	
		Minimum	Maximum
7 to 11	1	15	21
12 to 16	2	12	20
18 to 23	3	12	20
24 to 29	4	11	17
30 to 33	5	10	15

[1] See Abram's table, p. 255.

[2] Extracted from "Report of Committee on Mixing and Placing Materials," National Congress on Concrete Road Building, 1914, Chicago.

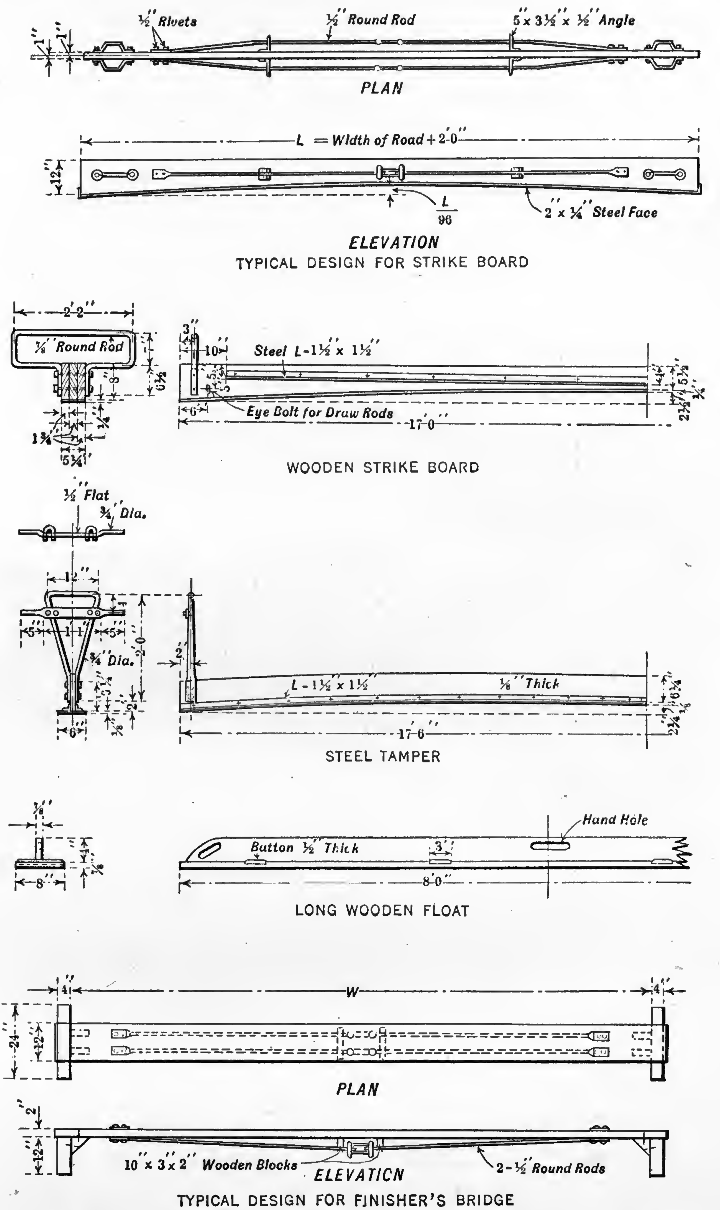


Fig. 144.—Typical Designs for Strike Boards, Bridge Float and Tamper. From Bul. 249, U. S. Dept. of Agriculture.

Retempering mortar or concrete is not allowable and all materials should be emptied from the drum before mixing the next batch.

Placing the Concrete.—Before placing, the subgrade, which has been carefully prepared in advance, drainage looked after, rolled and compacted, should be brought to an even surface. It should be damp but not muddy. Concrete laid on a muddy surface may take up enough muddy water, alkali water or acid water to refuse to set up and harden normally.

The concrete should be deposited upon the subgrade as

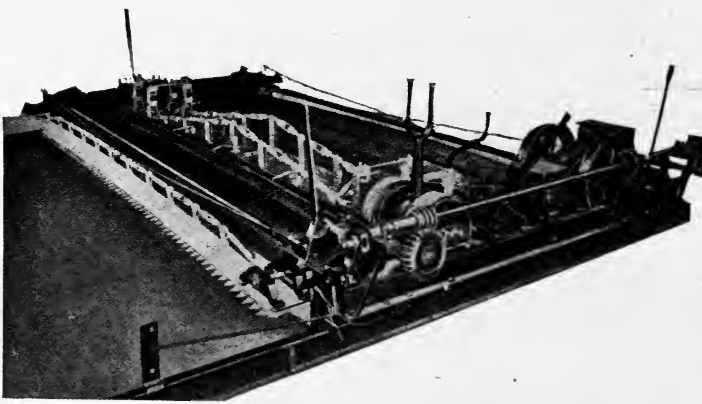


Fig. 145.—Baker Concrete Road Finisher.

soon as possible after mixing. Successive batches being near enough together so that they will join into one monolithic mass. Otherwise there will be weak places which may afterward induce cracks. The whole width of the roadway should be deposited to the required depth in a continuous operation. Should the machine break down it is recommended that hand-mixed concrete be used to complete the section to the next joint.

Striking Off, Templates.—The surface of the concrete should be struck off with a template or strike board. This may be a single plank curved on the bottom to allow for the crown or it may be of much more elaborate construction, Fig. 144. If a single strike board, it will be moved forward with a combined forward and transverse motion. When within 3 feet of the transverse joint, the board is lifted to the joint and the roadway struck by moving the board away from the joint. Templates may be made of two planks fastened parallel to each other about 2 feet apart and drawn along the roadway. Extra concrete is kept in the space between the planks which, flowing under the second plank, fills any low places left by the first.

Much more elaborate templates are being made up of steel I-beams or channels bent to the proper cross-section curve and held at a uniform distance apart by steel spreaders. They rest on rollers or carriages at the end with finished bearings packed in hard oil. They are drawn forward by a block and tackle or by a cable wrapped about a drum operated by the mixer engine. Fig. 145 shows such a template.

A Joining Straightedge with a $1\frac{1}{2}$-inch slot cut upward 3 inches at its middle point is recommended by the State Highway Commission of Wisconsin to prevent the slabs on opposite sides of the joint being out of alignment. The straightedge is constructed from a $1\frac{1}{8} \times 8$-inch plank, 6 feet long; the edge is beveled and shod with sheet metal.

Forms.—The forms along the outside of the roadway are placed exactly at grade and on them the strike board is drawn. These forms may be wooden plank against stakes or they may be steel angles, channels or rails.

Finishing.—After being brought to the proper grade by the strike board the surface is usually finished with wooden floats from the bridge. The bridge is arranged so that no part of it touches the concrete surface. The finished surface should be true to shape, not varying more than $\frac{1}{4}$ inch from the true contour. At Sioux City, Ia., the surface is worked to a pasty mass by *long-handled wooden floats,* Fig. 146. The floats are $14 \times 16 \times 2$ inches. The concrete is laid wet and worked smooth. Then a dry mixture of

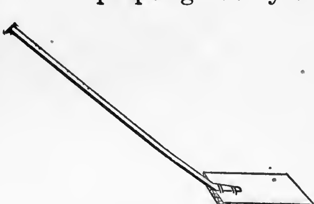


FIG. 146.

equal parts of cement and sand is sprinkled on the surface to absorb the surplus water. The floating is continued until the

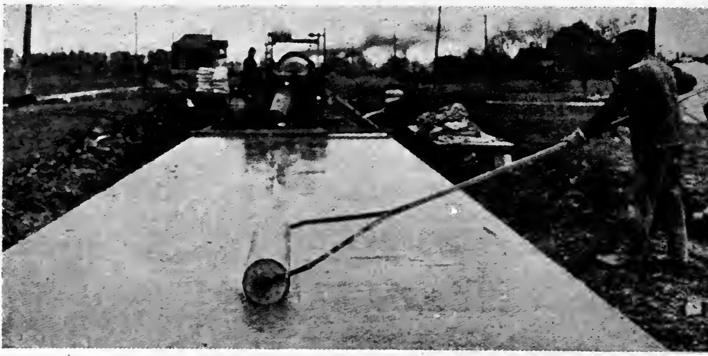


Fig. 147.

pasty adhesive mass is slightly drawn along with the float. The resulting surface is rough but not sharp.

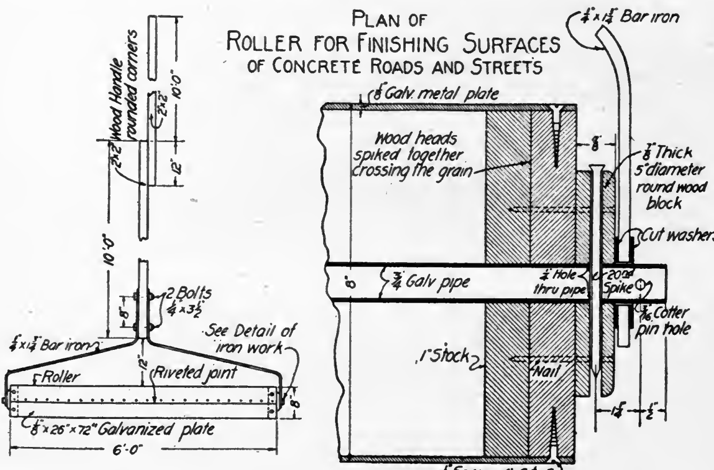


Fig. 148.

A Canvas or Rubber Belt from 6 to 12 inches wide with sticks nailed across the ends for handles is used for finishing by having a man on each side of the roadway take the belt by the handles and see-saw it along the pavement. *A Light Roller* may be drawn by means of long handles or ropes backward and forward over the pavement. It compresses the concrete, reduces the voids and forces out surplus water, Figs. 147, 148. *Wood Tamping Templates*, Fig. 149, for one or two men are employed.

Reinforcing.—In case it is thought necessary to place reinforcing, and this is frequently done when the pavement is more than 20 feet wide, it is placed not less than 2 inches from the finished surface and extends to within 2 inches of all joints, but should not cross them. The adjacent widths of fabric are to be lapped not less than 4 inches. The reinforcing fabric may be either woven wire or expanded metal, but the cross-sectional

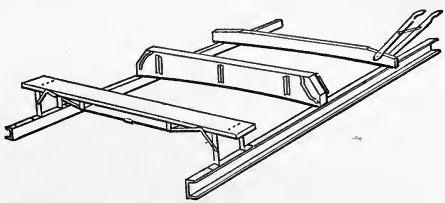


FIG. 149.—Wood Tamping Templates and Light Bridge for Furnishing Concrete Roads.

area running parallel to the center line of the roadway, according to standard specifications should amount to at least 0.038 square inch per foot of pavement width, and the cross-sectional area of reinforcing which is perpendicular to the center line of the roadway should be at least 0.049 square inch per foot of pavement length.

Curing and Protection.—Concrete must be kept damp for some time after depositing in order to harden properly. Spraying or sprinkling as soon as it is hard enough not to pit is recommended unless the temperature should be below 50° F., when, in the discretion of the engineer, it may be omitted. In warm sunshiny weather a canvas placed over the new pavement until it is hard enough to be covered is customary. As soon as permissible the roadway should be covered with earth about 2 inches deep; this is allowed to remain on the road for about ten days or two weeks and kept moist. Traffic should not be allowed on the road until the pavement is well cured. Two weeks in warm weather and longer in cool weather is the minimum. A month is much better.

The method of ponding is a common practice in California. Shallow earth dams are placed along the edge and across the pavement; the small ponds or reservoirs thus formed are filled with water. Excellent results are reported from this method of curing.

Freezing Weather.—Although some people think concrete can without injury be deposited in freezing weather, the best practice is not to permit it. And even if the temperature gets nearly to freezing, the aggregates and water should be heated before mixing, and precautions taken to protect the work from freezing for at least ten days. Straw and manure have been used successfully for protection.

Two-course Work.—With two-course work the only practical difference is that the lower course may be made leaner and the wearing surface is made of finer stone. Standard specifications require for the foundation course 1 bag of Portland cement to not more than $2\frac{1}{2}$ cubic feet of fine aggregate (passing $\frac{1}{4}$-inch screen), and not more than 4 cubic feet of coarse aggregate (passing $1\frac{1}{2}$-inch screen, retained on $\frac{1}{4}$-inch). The leanest allowable then is

$$\text{cement} : \text{sand} : \text{stone} = 1 : 2\tfrac{1}{2} : 4.$$

The wearing course consists of two parts material specified above as fine aggregate and three parts clean, hard durable crushed rock or gravel, free from dust, soft particles, loam, vegetable, or other deleterious matter, and passing when dry a screen having $\frac{1}{2}$-inch openings and retained on a screen having $\frac{1}{4}$-inch openings. The mortar is to be mixed in the proportions of 1 bag of Portland cement and not more than 2 cubic feet of aggregate for wearing course just described. That is a mixture of

$$1 \text{ cement} : 2 \text{ wearing course aggregate} =$$

$$1 \text{ cement} : 4/5 \text{ sand} : 6/5 \text{ small stone.}$$

A cubic yard of lower course in place should contain at least 1.4 barrels (5.6 bags) of cement; and a cubic yard of wearing surface, 2.97 barrels (11.9 bags).

It is not necessary to strike off the lower course with a template. The concrete is deposited to approximately the thickness of the wearing course below the grade line of the finished surface.

Expansion and Contraction Joints.—Just how frequently expansion joints should be placed is a matter on which there is considerable difference of opinion. Some think every 200 or 300 feet is sufficient; others say every 30 to 50 feet. Recommended practice [1] would place them not more than 50 feet apart transversely and along each curb. In California, where the range of temperature is considerably less than in most of our Northern States, miles of roadway are constructed without any expansion and contraction joints. When they have a well-drained and compacted subgrade they give no trouble whatever. The standard width of the joint is one-fourth inch. Joint filler made of tarred felt which may be placed in position before the concrete is deposited is now on the market. Where such cannot be obtained a well-greased sheet of steel is set in the joint until the concrete is hard, then removed and the joint filled with heavy tar or hot asphalt. Care must be taken that the tarred felt or sheet of steel is secured against deflection. The joint should remain a true vertical plane to prevent the tendency of one section rising above the other.

Joint-protection Plates.—An effort to prevent the chipping of the concrete at the joint edge has led to several kinds of joint protection. The tendency of present practice, according to the second "Concrete Road Conference," Chicago, 1916, is toward the omission of metal protection plates for joints. It is possible that their value depends somewhat on the character of the aggregate used, and it is considered that they are more essential in street pavements than in country highways. Metallic joint-protection plates are usually made of steel securely anchored to the concrete. But even such are not entirely

[1] National Conference Concrete Road Building, 1914 Proceedings.

satisfactory because the steel does not wear down at the same rate as the concrete. An uneven surface results, which eventu-

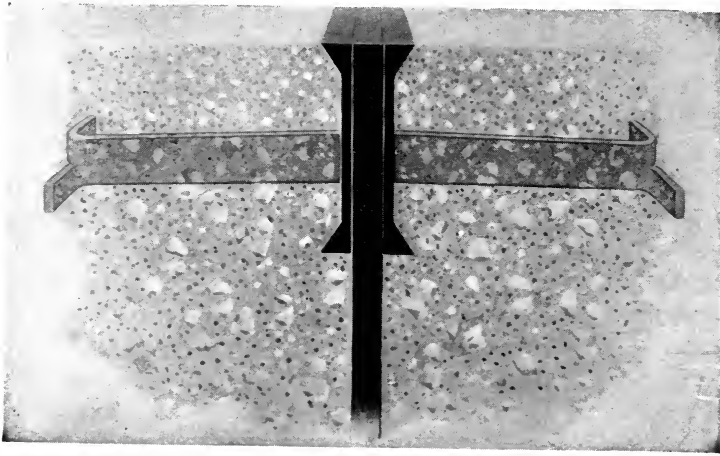


FIG. 150.—Kahn Armored Joint.

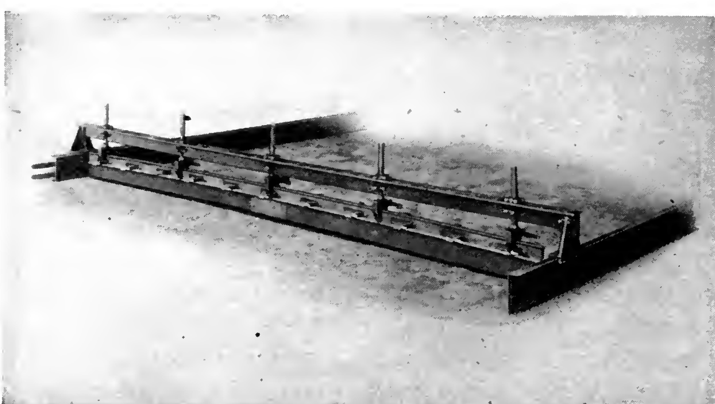


FIG. 151.—Machine for Placing Expansion Joint.

ally becomes a pot hole or rut. Fig. 150 shows one of the forms on the market. Special devices are made for installing fillers,

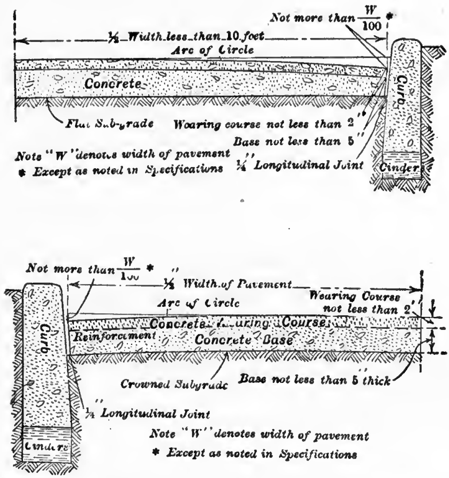
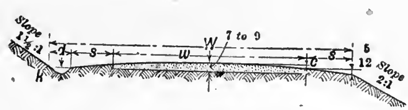
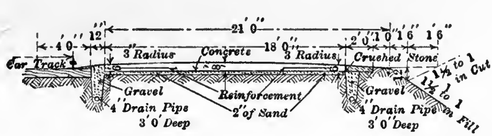


Fig. 152. Typical Concrete Road and Street Cross-sections with Curb and Gutter.



Typical Section of Concrete Roadway.

Side ditches should be of sufficient size to dispose of all drainage; C may vary from $\frac{W}{96}$ to $\frac{W}{72}$, when w exceeds 20 feet make joint in center and crown subgrade; k varies from 6 to 12 inches.



Commonwealth Avenue Road, Duluth

Fig. 153.—Typical Concrete Road Cross-sections.

Fig. 151. By these the joint filler, a tarred felt, with or without the plates, are held securely in place and free from deflection while the concrete is being deposited.

Cross-section.—Figs. 152, 153, show recommended cross-sections for concrete roadways. The *thickness* is controlled by several factors, such as the character and drainage of the subgrade, the character and amount of the traffic, the width and crown of the roadway. Drainage and consolidation of subgrade are extremely important items in all road-making and no less so under a concrete pavement. Unequal settlement is sure to produce a cracked surface. With better roads will naturally come an increased use of heavy motor trucks and tractors. The thickness must be such that the concrete will not break under the heaviest load. It is recommended that roads having a crown be made thicker in the middle than on the edges; while roads with an inverted crown (lower in the middle than on the sides) used in alleys and in narrow cuts where rain-water is liable to wash out the side ditches, and those on side hills with the slope all in one direction, be made the same thickness throughout. Practice seems to vary from 5 to 8 inches. The concrete Road Conference recommends a minimum of 6 inches. An analysis of the statistics of paving construction for 1915 published in "Engineering and Contracting," April 5, 1916, will show that of 125 different localities covering the entire United States,

50 places, 40.0 per cent, constructed concrete pavements 6 inches thick.
49 places, 39.2 per cent, constructed concrete pavements 7 inches thick.
10 places, 8.1 per cent, constructed concrete pavements 8 [1] inches thick.
6 places, 4.8 per cent, constructed concrete pavements 5 inches thick.
5 places, 4.0 per cent, constructed concrete pavements $6\frac{1}{2}$ inches thick.
1, $6\frac{1}{4}$, 1, $7\frac{1}{4}$; and 2, $7\frac{1}{2}$ inches thick.

Width.—A desirable width of pavement for a single-track roadway is 10 feet; for double-track roadway 20 feet. In case of a single-track roadway an earth roadway of equal width or shoulders of 5 feet each should be kept alongside. For a

[1] Several of these were thinner at the outside edges, as thin as 6 inches.

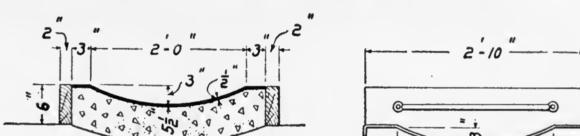
double-track paved way the shoulder need be used for turnout purposes only in cases of congestion.

The **crown** or slope of the paved way should be not less than one-hundredth, nor more than one-fiftieth its width. Except in unusual cases the lower crown is to be preferred.

FIG. 154.

Integral Curb.—If a curb is desired it may be constructed as curbs already described for other pavements or built integrally with the concrete. The latter is preferable. Precaution should be taken that it is thoroughly bonded to the pavement proper. Figs. 154 and 155 illustrate integral curbs with method of construction.

Maintenance.—Here, as in all other roads, constant attention will diminish the need of extensive repairs. The proper maintenance of a concrete road consists in filling cracks and potholes as soon as possible after their appearance. In Wayne County, Michigan, a crew consisting of seven men and a team



TYPICAL CROSS SECTION OF CONCRETE GUTTER AND DESIGN FOR A TEMPLATE TO BE USED IN ITS CONSTRUCTION.

FIG. 155.

is utilized for maintaining their numerous concrete roadways.[1] A foreman is paid $5 a day, the team and driver $5 a day, the "tar man" $3 a day, two laborers at $2.50 each, and two laborers at $2.25 each. The tools used are two-wire bristle brooms, a wheelbarrow, a couple of shovels and a tar bucket with a round spout. The cracks are swept clean with the wire

[1] Report of Committee VI. Edward N. Hines, Chairman, Proceedings National Conference on Concrete Road Building, Chicago, 1914, p. 110.

brooms and filled with a heavy tar (Tarvia X) at 225° F. An excess of tar is poured so that it extends beyond the edge of the crack. After standing a few minutes, dry, coarse sand is spread with a shovel over the crack and into the tar; this is left for the traffic to iron out. The excess tar is worn away, leaving a smooth even surface. The work is preferably done on hot, dry days, and once a year, they think, often enough to go over the work. Small pot-holes are treated in the same manner. Of course, asphalt may be used in place of tar.

Repairs.—In case of large pot-holes or places removed for water pipes, telephone conduit or other purposes, more extensive repairs than those mentioned in the report will be necessary. The edges of the concrete should be trimmed to make the walls vertical, the subsoil carefully replaced and tamped. Concrete of the same character as the original roadway is used to fill the opening and then finished as before. In time cracks may appear between the new concrete and the old, they will be treated as other cracks.

Seal Coat or Carpet.—Since a bituminous material has been satisfactorily used for filling cracks and small holes there has arisen the idea of covering the entire pavement with a *seal coat*, *squeegee coat* or *carpet.* The hot bituminous asphalt cement, refined tar, or tar-asphalt is spread from sprinklers and swept over with brooms or applied with "squeegees." A thin layer, $\frac{3}{8}$ to $\frac{1}{2}$ inch, of coarse sand or crushed stone screenings is spread upon the hot bituminous matter. Sometimes this latter is rolled with a light roller, sometimes not. The main difficulty has been to get the bituminous coat to adhere thoroughly to the concrete. Dust or too much moisture in the concrete will prevent. A little moisture is said to assist and a very light application of a thin oil is claimed to be beneficial. It is also said that two applications of the material with a pressure machine of $\frac{1}{4}$ gallon per square yard each is better than a single application of $\frac{1}{2}$ gallon.

Cost of Concrete Roads.—It is difficult to give in general terms the cost of a concrete road. The particular factors that enter into the cost of the individual road should be taken into account. Type, that is, one-course, two-course, bituminous top, or reinforced; thickness; location; extent and contractor's guarantee are some of these factors. Without taking any of these into account an analysis of the statistics for the concrete pavements constructed in 1915 [1] shows that of the 136 localities reported, distributed generally over the United States, 21 per cent paid from $1.20 to $1.30 per square yard. While 40 per cent of the localities come within the limits of $1.10 to $1.40; and 74 per cent within the limits of $1.00 to $1.70. The lowest

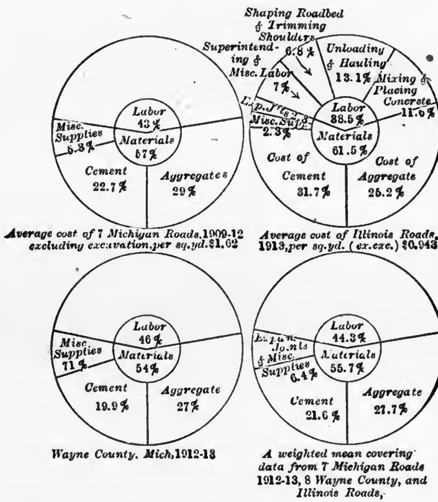


FIG. 156.—Concrete Pavement Costs.

reported price is $0.66 and the highest $2.65 per square yard. Fig. 156 is a graphical representation of concrete pavement costs.

Data prepared by Committee XII of the National Conference on Concrete Road Building, A. N. Johnson, Chairman,[2] give an average cost of a one-course concrete road to be $1.24 and a weighted average of $1.19. The diagrams in Fig. 156 were also presented by the same committee.

[1] For statistics see *Engineering and Contracting*, April 5, 1916.
[2] Proceedings, 1914, p. 142.

Miscellaneous Methods. Grouting.—The Hassam pavement is made by placing a layer of broken stone ranging in size from $1\frac{1}{4}$ to $2\frac{1}{2}$ inches and rolled as in macadam construction to a thickness of 4 inches. A grout, 1 part cement to 3 parts sand, is poured over this, care being taken continually to agitate the grout, in order to prevent segregation, until deposited. Rolling is continued during the pouring of the grout to force it into the interstices of the stone. When the voids are filled a second course of broken stone is laid. This may be of a harder tougher rock and about 2 inches thick. It is grouted and rolled but with a thinner grout, 1 : 2. The surface is finished by brooming and brushing into it a thick grout composed of 1 part cement, 1 part sand and 1 part pea-size trap rock. This process is patented.

Oil-cement Concrete.—Fluid residual petroleum is added to the concrete in the mixer in the proportion of 10 to 18 per cent of the weight of the cement. The addition of oil, while it weakens the cement, is supposed to make it more waterproof. Some experimental roads have been built but the process has not otherwise been used.

Organization

As the cost of a pavement depends upon the efficiency of the working crew the following extracted from Bulletin 249, U. S. Office of Public Roads, by C. H. Moorefield and J. T. Voshell, will be of interest to the concrete road maker:

Preliminary Planning.—The work of mixing and depositing should be as nearly continuous as practicable after it is once begun. To effect this the order and progress of the work should be carefully planned beforehand. This means that provision should be made for completing the drainage structures, the grading and the preparation of the subgrade well ahead of the mixer, as well as supplying the mixer with necessary materials.

The drainage structures should preferably be completed in advance of the grading. However, there are places where it will be more advantageous to do otherwise.

The work of preparing the subgrade and setting the forms should preferably proceed sufficiently far in advance of the mixer to allow for two or three days' run. The prepared subgrade will usually dry out more quickly after a rain than the unprepared road. It may need re-rolling after a rain.

Selecting the Concrete Mixer.—Two-size mixers are in general use. The smaller capable of mixing a batch containing two bags of cement; the larger, three bags. Where the materials can be economically obtained only at a slow rate, or where the expense of providing facilities for handling large quantities would be excessive, the smaller size mixer is more economical

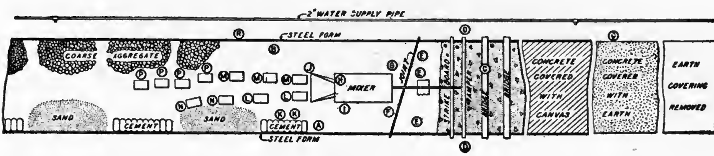


FIG. 157*a*.

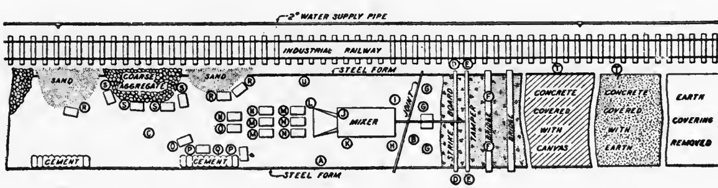


FIG. 157*b*.

to use. Either mixer should mix, ordinarily, from 400 to 450 batches in a working day of eight hours. The diagrams, Fig. 157, illustrate mixer organizations for the two sizes of mixers.

Handling Materials.—One of the difficult problems to be solved is that of handling the materials. The different kinds of materials required must be delivered to the mixer in definite proportions at the same time; the location of the materials influence the transportation methods. Consider, for example, a "three-bag mixer." If the work is to progress normally, the quantities of materials required each day will be approximately, for a 1 : $1\frac{1}{2}$: 3 mixture, as follows:

Cement, barrels	320
Sand, cubic yards	70
Coarse aggregate, cubic yards	140
Water, gallons	8800

In addition to this, if the mixer runs continuously, about 10,000 gallons of water will be required each day for keeping wet that part of the pavement which will have been laid during the two preceding weeks. This makes a total weight of water which may be required each day of 75 tons, and the total weight of all materials combined of about 420 tons per day.

CHAPTER XIII

BITUMINOUS ROADS

Road surfaces, the binding material of which is a cement composed chiefly of bitumen, constitute an important part of the pavements of cities and villages, and, in some forms, have extended to a considerable extent to rural highways. Since the design of such road surfaces is a highly technical operation requiring much space for adequate treatment, and since there are many good books dealing with the details of asphalt and other bituminous pavements,[1] it has been thought best to describe the subject but briefly in this text.

Materials.—Bituminous roads are constructed of a mineral aggregate bound together by a bituminous cement, that is, one

[1] Abraham's "Asphalts and other Allied Substances," D. Van Nostrand Co., N. Y.

Blanchard's "American Highway Engineers' Handbook," Wiley & Sons, N. Y.

Blanchard and Drowne's "Highway Engineering," Wiley & Sons, N. Y.

Baker's "Roads and Pavements," Wiley & Sons, N. Y.

Boorman's "Asphalts," Wm. T. Comstock, Chicago.

Danby's "Natural Rock Asphalts and Bitumens," Constable & Co., N. Y.

Hubbard's "Dust Preventives and Road Binders," Wiley & Sons, N. Y.

Hubbard's "Highway Inspectors' Handbook," Wiley & Sons, N. Y.

Hubbard's "Laboratory Manual of Bituminous Materials," Wiley & Sons, N. Y.

Harger and Bonney's "Handbook for Highway Engineers," McGraw-Hill Book Co., N. Y.

Tilson's "Street Pavements and Paving Materials."

Richardson's "Modern Asphalt Pavement," Wiley & Sons, N. Y.

Whinery's "Specifications for Street Roadway Pavements," McGraw-Hill Book Co., N. Y.

having as an essential constituent, bitumen. The forms in which the bitumen occurs bear various names, the asphalts and the tars being the most important for road purposes.

Classification.—The sub-types of bituminous roadways are: (1) Bituminous Earth, (2) Bituminous Macadam, (3) Bituminous Concrete, (4) Sheet Asphalt, (5) Rock Asphalt, (6) Bituminous and Bituminized Block.

Definitions.—Some terms are continually recurring in a discussion of bituminous roads and it may be well to give their technical meaning at the beginning. Most of these definitions have either been adopted or have been proposed by committees for adoption, by such organizations as the American Society of Civil Engineers and the American Society for Testing Materials.

Bitumens.—Mixtures of native hydrocarbons and their non-metallic, derivatives which may be gases, liquids, viscous liquids, or solids and which are soluble in carbon disulphide.[1]

Asphalts.—Solids or semi-solid native bitumens, solid or semi-solid bitumens obtained by refining petroleum, or solid or semi-solid bitumens which are combinations of the bitumens mentioned with petroleums or derivatives thereof, which melt upon the application of heat and which consist of a mixture of hydrocarbons and their derivatives.[1]

Flux.—Bitumens, generally liquid, used in combination with harder bitumens for the purpose of softening the latter.[1]

Asphalt Cement.—A fluxed or unfluxed asphalt specially prepared as to quality and consistency for direct use in the manufacture of bituminous pavements and having a penetration at 25° C. (77° F.) of between 5 and 250, under a load of 100 grams applied for five seconds.[1] This is usually spoken of by the workmen as A.C. (See penetration below.)

Rock Asphalt.—Sandstone or limestone naturally impregnated with asphalt.[1]

Tars.—Bitumens which yield pitches upon fractional distillation and which are produced as distillates by the destructive distillation of bitumens.[1]

[1] Report of Special Committee A. S. C. E. Proceedings, 1914; Am. Soc. for Testing Materials. Year Book, 1915.

Coal Tar.—Tar produced from the destructive distillation of coal.

Gas Coal Tar.—Tar produced in the gas-house retorts from bituminous coal.

Water-gas Tar.—Tars produced by cracking oil vapors at high temperature in the manufacture of water gas.[1]

Pitches.—Solid residues produced in the evaporation or distillation of bitumens, the term being usually applied to residues produced from tars.[1]

Refined Tar.—Tar freed from water by evaporation or distillation, or a product produced by fluxing tar residuum with tar distillate.[1]

Penetration.—A term to define the solidity or consistency of bituminous material. It is measured by the distance expressed in tenths of a millimeter which a weighted standard cambric needle under standard conditions will penetrate the sample.

Viscosity.—The measure of the resistance to flow of a bituminous material, usually stated as the time of flow of a given amount of material through a given orifice. This time of flow divided by the time of flow of the same volume of water at 25° C. (77° F.) is designated as the *specific viscosity*, volume and temperature stated.

Sources of Bituminous Materials

Native Asphalts.—Asphalts are found native as solid or semi-solid bitumens in various places, but especially in Venezuela. On the island of Trinidad is a pitch lake of 115 acres, 135 feet deep at the center and on the mainland the Bermudez lake of about 1200 acres with a maximum depth of 10 feet, and the Maracaibo deposits near the Gulf of Maracaibo. Trinidad asphalts contain as found about 39 per cent bitumen soluble in carbon disulphide; Bermudez and Maracaibo about 72 per cent. When " refined " by heating in kettles to drive off the water, remove floating foreign substances and reduce to a

[1] Report of Special Committee A. S. C. E. Proceedings, 1914; Am. Soc. for Testing Materials. Year Book, 1915.

uniform consistency, the percentages are increased for Trinidad to about 56 and Bermudez to 94.

Deposits of native asphalt are found also in Cuba (Cuban), California (Alcatraz) and in Utah and Colorado (Gilsonite). Gilsonite is found in veins and is about 99 per cent soluble bitumen.

Petroleum Asphalts.—Asphalts are obtained from refining the asphaltic oils of California, Mexico, Southern Illinois, Texas, Oklahoma, and Wyoming. Eastern petroleum oils have a paraffin base with very little asphalt, the extreme western oils have an asphaltic base with little paraffin, while those from the intermediate districts have both in varying degrees. No asphalt is obtained from Pennsylvania oils, but large quantities are prepared from the California asphaltic oils and the Texas semi-asphaltic oils. The asphalt remains after the volatile oils have been distilled off by use of saturated steam, or after they have been partially distilled and the remainder driven off by blowing air through the residue. The quality of the asphalt depends on the character of the crude oil and also on the maxiimum temperature attained in the process of refining. Air blowing is claimed to keep the temperature below the destructive cracking or decomposition limit.

Road tars and pitches are obtained from the destructive distillation of coal in illuminating-gas manufacturing plants or coke ovens. This tar is refined by distilling off the water and volatile oils. The process is carried only so far as is necessary to produce the consistency wanted. For light or surface tars the water only is removed; for the heavier tars the distillation may be prolonged; for the very heavy tars or pitches steam is blown through the kettles. This carries off the heavier oils at a sufficiently low temperature to prevent damaging the pitch; also, the destruction of the still by depositions of carbon and local heating is avoided.

Various grades of road tars are used as well as combinations of asphalts and tars.

Physical and Chemical Tests

A great many physical and chemical tests have been devised for controlling the properties of asphalts and tars. A very few of these will be mentioned. For detailed methods as well as other tests the reader is referred to the standard tests of the American Society of Civil Engineers, and the American Society for Testing Materials.

Consistency Test-penetration Method.—Fig. 158 shows an apparatus for making this test—a pentrometer. It consists of a machine for applying a weighted needle to the sample and measuring the distance it penetrates. A standard No. 2 cambric needle weighted, ordinarily with 100 grams, is used and the depth of penetration reported in tenths of a millimeter. The sample is maintained at 25° C. (77° F.) during the test by keeping it in an open tin box of prescribed dimensions and the tin box completely submerged in a glass cup of water.

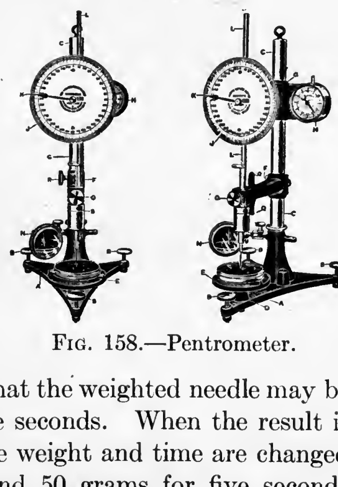


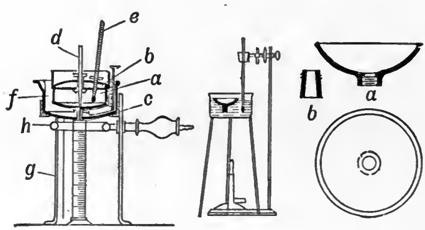
Fig. 158.—Pentrometer.

The pentrometer is so arranged that the weighted needle may be employed for the exact time, five seconds. When the result is less than 10 or more than 350 the weight and time are changed to 200 grams for one minute and 50 grams for five seconds respectively. When practical, penetration tests are made as follows, the second being most important and is what is meant by "penetration," if no mention is made of temperature or time:

At 4° C. (39° F.) with a weight of 200 grams for one minute,
At 25° C. (77° F.) with a weight of 100 grams for five seconds,
At 46° C. (115° F.) with a weight of 50 grams for five seconds.

The object of the test is to secure that consistency or hardness which experience has shown is required for a pavement that will not be unduly soft in the summer time and will not crack in the winter time. Uniformity, an important element in road materials, is to a greater or less degree regulated by the test. Other tests for consistency are also used, and especially for tars whose surface tension is so high the penetration method cannot be relied upon.

Consistency by Viscosimeter Method.—There are two viscosimeters in standard use, Fig. 159. With the Engler the time required for a given quantity of the material at a given temperature to flow through a small orifice compared with the time it will take water to flow through the same orifice, is the measure



Engler viscosimeter. New York testing laboratory float apparatus.

FIG. 159.—Apparatus for Determining Consistency.
(From Bulletin No. 38, Office of Public Roads, U. S. Dept. of Agr.)

of viscosity. The size and shape of apparatus and orifice, temperatures, and charge have all been standardized. The same is true of the other tests herein mentioned.

New York Testing Laboratory Float Test for Consistency.—This consists of an aluminum float or saucer in the bottom of which is screwed a conical brass collar, Fig. 159. The brass collar is filled with the samples to be tested and screwed into the float and the whole placed on the surface of the water bath. The plug of bituminous material becomes warm and fluid by the heat of the water, which is maintained at the temperature required for the test, and is gradually pushed upward and out of the collar. Water gains entrance to the saucer and the apparatus sinks. The time in seconds, between placing the saucer on the water and the sinking of the float is taken as a measure of the consistency of the material under examination.

Melting-point, Cube Method (Used with Tars).—A small cube of the bituminous material is suspended by a No. 10 brass wire in a beaker of water or vegetable oil at least 40° F. lower than the fusing-point of the substance, Fig. 160. The water is gradually warmed and its temperature noted by a thermometer fastened in such a manner that its bulb is just

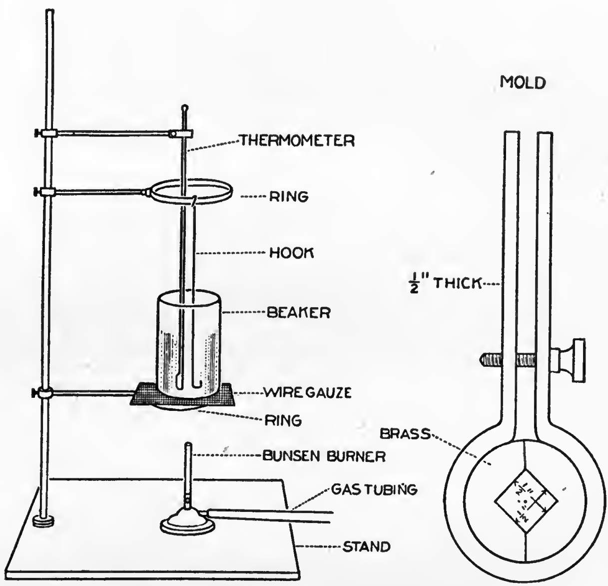


Fig. 160.—Melting-point Apparatus

beside the cube. The cube has its bottom edge at the start 1 inch from the bottom of the beaker. Under the heat of the water the substance will run down and when it has just touched the bottom the temperature of the liquid is taken as the melting-point of the sample.

Melting-point, Ring and Ball Method (Used with Asphalts).[1] —The apparatus consists of a brass ring, ⅝-inch in diameter,

[1] Proceedings A. Soc. Testing Materials, 1917.

$\frac{1}{4}$-inch deep, $\frac{3}{32}$-inch wall, suspended 1 inch above the bottom of a 600 c.c. (approximately) beaker. The ring is filled with melted material which is allowed to harden and the excess removed; then suspended in the beaker containing approximately 400 c.c. of water at a temperature of 5° C. (41° F.); the thermometer is placed on a level with, and within $\frac{1}{2}$ inch of the ring; heat is applied at the rate of 5° C. (9° F.) per minute (the rate is important); the temperature is recorded at the starting-point and every minute thereafter until the test is completed. The softening-point is the temperature at which the specimen has dropped 1 inch.

The melting-point is of value when the penetration or grouting method of constructing bituminous macadam is followed. Too high a melting-point means rapid solidification and consequently insufficient penetration of the interstices of the stone. Tars for this purpose should not have a melting-point exceeding 25° C. (77° F.) and a blown oil not over 35° C. (95° F.).

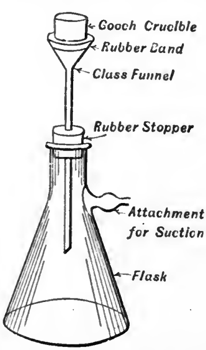
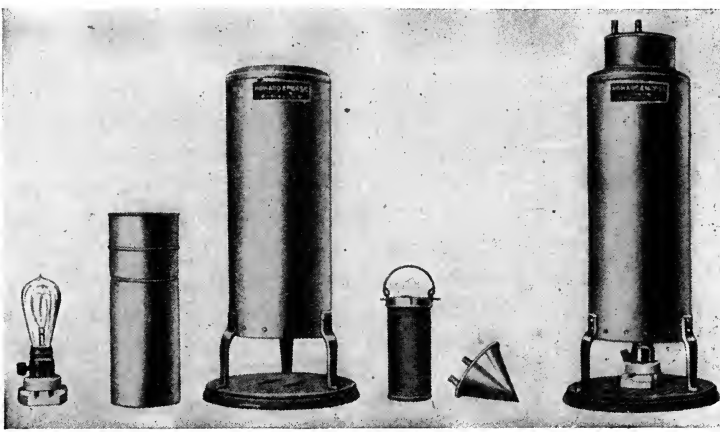


FIG. 161.—Apparatus for Determining Soluble Bitumen.

Solubility.—This is considered to be one of, if not the most, important tests of bituminous materials. It consists in a very carefully standardized method of determining the percentage of the sample that will be dissolved in carbon disulphide (CS_2). This test may be made on the original asphalt or tar or, of greater importance, on the mixed product taken from the road, Figs. 161, 162. When made on the mixed product it shows the amount of binding material in that product and after that has been extracted the aggregate may be examined for proper gradation in size by sieve analysis.

Solubility tests are sometimes made in carbon tetrachloride (CCl_4) and in petroleum naphtha. The former merely takes the place of the carbon disulphide, while the latter has a different object. The residue or insoluble part in petroleum naphtha is largely the part from which come the binding properties of asphaltic oils and cements. The character of the soluble part is, nevertheless, of interest and value to the roadmaker.

Fixed Carbon.—A gram of bituminous material is placed in a platinum crucible having a tightly fitting cover, Fig. 163. This is heated first gently then more violently until no smoke or flame issues from the crucible. It is then heated for seven



(a) (b) (c) (d) (e) (f)

FIG. 162.—New York Testing Laboratory Extractor for the Analysis of Paving Mixtures Containing Broken Stone. Five hundred grams of the sample is placed in the wire basket (*d*). About 200 c.c. of CS_2 is placed in the inside vessel (*b*). The carbon lamp (16 c. p.) furnishes heat to evaporate the CS_2. Cool water is circulated through the cone (*e*), which is also the cover. The evaporated CS_2 is condensed on the cone, drips on the sample and dissolves out the carbon. After extraction the solvent matter is burnt to recover any fine particles which may have passed into the extract.

minutes in the full heat of the Bunsen burner to drive off the most volatile products; then cooled and weighed; then ignited over a Bunsen burner until only ash remains. It is again weighed and the difference in weights represents the fixed carbon (coke) in the original material. Like the naphtha-insoluble bitumen it is a measure of the mechanical stability of an oil.

Other tests nave been standardized as follows: Specific gravity, flash point, loss on evaporation, distillation, ductility and paraffin. The character of these tests are indicated by their names.

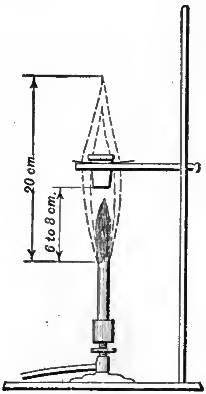


FIG. 163.—Apparatus for Determining Fixed Carbon. (From Bulletin No. 38, Office of Public Roads, U. S. Dept. of Agr.)

BITUMINOUS EARTH ROADS

Oiled Earth Roads.—Some engineers look upon oiling earth roads merely as a means of mitigating the dust; others, as a means of maintenance. Since the construction of oiled roads consists mainly in distributing oil upon the road surface in place, their description will be deferred until the next chapter, which deals with surface treatments.

Bituminized Earth Roads.—A method of heating, pulverizing, mixing with asphalt cement, and laying clay or loam upon any suitably prepared foundation has been developed and patented and employed on roadways under the trade name of National Pavement. The clay or loam, which may be taken from the roadway in grading, is placed in a specially designed machine which dries, beats and thoroughly pulverizes it. The finely divided particles presenting a large surface to be covered with cement can absorb a greater quantity of asphalt, it is claimed, than any other type of pavement. When the beaten clay is heated with the asphalt it is said to resemble a pulverized rock mixture. The hot material (200 to 300° F.) is hauled to the roadway and dumped on a spot outside the space on which it is to be spread, shoveled into place and uniformly spread by raking with hot rakes. It is then compressed by light rolling or tamping. The rolling is continued with a roller weighing not less than 260 pounds per inch of width of tread at a rate of not more than 200 square yards per hour per roller, until a satisfactory compression is obtained. This type of roadway has not been in use sufficiently long to afford a definite statement of durability.

Bituminized Sand.—The Massachusetts Highway Commission has constructed a number of miles of roadway by mixing by hand or in a suitable machine, hot local sand with oil asphalt and then spreading the mixture on the prepared roadway. The pavement has a thickness of about 4 inches at the middle and 3 inches at the sides of an 18-foot roadway. The asphalt finally adopted was an oil-asphalt having a penetration of 80 (a penetration of not less than 60, or viscosity of 500 seconds at 100° C., Lawrence Viscosimeter, is specified). The sand is to be clean, sharp, and fairly coarse, not over 52 per cent passing a 50-mesh sieve. The amount of oil used is as ordered, but not less than 15 gallons nor more than 20 gallons per cubic yard of loose sand. The temperature of the oil as used varies according to its nature from 121 to 191° C. The hot mixture is dumped at one side, shoveled to place and spread uniformly by rakes; after cooling it is compressed by rolling with a horse roller weighing about 1 ton. The surface during the rolling is shaped with a road machine or other scraper and finally rolled with a steam tandem roller. After the sand and oil mixture has been shaped and rolled a seal coat of asphaltic oil is distributed with a pressure distributor on the surface in two applications of $\frac{1}{4}$ gallon per square yard. Each application is covered with a thin layer of sand and rolled in.

The Layer Method of Construction.—By this method about $\frac{3}{4}$ gallon of a light grade of oil which will continue to mix with the sand during the summer weather was used per square yard of surface, and immediately covered with $\frac{1}{2}$ inch of sand. On this a second $\frac{3}{4}$ gallon of oil was applied followed by a second $\frac{1}{2}$-inch coating of sand. After this had thoroughly soaked in the roadway was reshaped and a third application of oil, $\frac{1}{2}$ gallon, was made, upon which was spread 1 inch of sand. The final application was thought, by the Massachusetts Commission, to give better results if applied after the road had been used through a winter.

Bituminized sand roads are suitable for light traffic only and must be constantly looked after, for when once started they very quickly go to pieces. Better results were obtained when the sand subsoil had been hardened by an application of loam or clay.

Bituminized Gravel.—The fact that gravel has a very small interlocking property but depends almost wholly for its stability on the cement, natural or artificial, filling the interstices, makes it rather unsuitable for a bituminous-bound roadway. Unless the gravel is very cheap in comparison with broken stone it will hardly pay to use it. When used it is recommended that more than 95 per cent should pass the 1-inch screen and less than 15 per cent the $\frac{1}{4}$-inch screen. A seal coat should be applied.

Bituminous Broken-stone Roads

Broken-stone roads bound together by bitumen may be differentiated by the manner in which the cement is applied. Those in which the wearing surface is laid like a macadam roadway and filled by " penetration " are designated as *bituminous macadam;* those in which the stone, or other mineral aggregate, is incorporated with the cement by mixing similar to cement concrete are defined as *bituminous concrete.*

Bituminous Macadam

Drainage and Foundation.—These items require the same attention as for a water-bound macadam or any other type of pavement. If the roadway is to carry heavy trucks, a cement concrete foundation of sufficient thickness should be provided.

The mineral aggregate should be composed of good macadam stone subscribing to tests according to the traffic; a coefficient of wear of not less than 5 for light, and not less than 10 for heavy; and a toughness (impact) of not less than 5 for light, and not less than 10 for heavy. The stones interlock best when angular and are strongest when length, breadth and thickness are approximately equal. The following stipulations were recommended by the conference of State Highway Testing Engineers and Chemists and published by the U. S.

Office of Public Roads, and are here given not to be used generally but as a guide for making up proper specifications:

General.—The broken stone shall consist of angular fragments of rock excluding schist, shale, and slate, of uniform quality throughout, free from thin or elongated pieces, soft or disintegrated stone, dirt or other objectional matter occurring either free or as a coating on the stone.

Physical Properties.—The stone shall meet the following requirements: French coefficient of wear, not less than 7. (Toughness, Hardness and Absorption may be added if desired.)

Chips.—That portion of the product of the crusher which, when tested by means of laboratory screens, will meet the following requirements:

Passing 1-in. screen, not less than	95%
Retained on ¼-in. screen, not less than	85

Coarse Stone.—That product of the crusher which, when tested by means of laboratory screens, will meet the following requirements:

Passing 2-in. screen, not less than	95%
Total passing 1½-in. screen	25 to 75
Retained on 1-in. screen, not less than	85

Alternate Type Specifications.—When several kinds of materials are available and for good results these materials require different treatments it is becoming customary to write a separate set of specifications to cover the use of each. This is done for two reasons: (1) To insure uniformity; (2) To secure the widest possible competition. Uniformity is a very important factor entering into the durability of a paved roadway. Without it the wear is uneven, and unevenness itself increases wear, hence with lack of uniformity deterioration proceeds in geometric ratio. To make a blanket specification to cover all materials would result in one so open that uniformity would not necessarily be secured. To make a single specification so close as to secure uniformity with a given class, sort, kind, grade or type of material might keep out other equally desirable materials and thus limit competition to that person or those persons having access to the one kind of material. By writing separate specifications for the several materials uniformity is insured no matter which one is finally accepted and the fullest competition is encouraged.

Specifications for Bituminous Cement.[1]—The following points, or so many of them as are applicable or desirable to secure uniformity of product, are usually covered by the specifications:

1. *Homogeneity.*—"The asphalt cement (refined tar) shall be homogeneous and shall not foam when heated to . . . °."

2. *Specific Gravity.*—Usually taken at 25° C. (77° F.) for both substance and water.

3. *Melting-point.*—Method to be stated—cube or ring and ball.

4. *Flash Point.*—" . . . . not less than . . . . °."

5. *Consistency.*—The penetration method is ordinarily used for asphalts for viscosimeter and float methods for soft asphalts, tars, and petroleum oils. Temperatures are specified for which the tests shall be made.

6. *Volatility.*—"Loss by distillation at . . . . ° for . . . . hours not over . . . . per cent." The penetration and specific gravity of the residue are also specified.

7. *Solubility.*—(*A*) Carbon disulphide. "The total bitumen soluble in carbon disulphide shall be not less than . . . . per cent."

(*a*) Organic matter insoluble, not over . . . . per cent.

(*b*) Inorganic matter insoluble, ... per cent to . . . . per cent

(*B*) Carbon tetrachloride. Per cent soluble in.

(*C*) Paraffin naphtha. Per cent insoluble in 86° B. naphtha . . . . to . . . .

8. Fixed Carbon. " . . . . per cent to . . . . per cent."

9. Ductility. " . . . . ° C. not less than . . . . centimeters."

Occasionally other tests may be specified.

The following table shows a number of typical specifications:

CONSTRUCTION

The subgrade, drainage and foundation course require the same careful attention as for any other type of pavement. In fact, since the bituminous cement is plastic and the surface will bend to fit any depression that may come in its supporting course, there is practically no bridging property in the upper course. Modern practice prefers cement concrete foundations

[1] Tentative or standard specifications have been issued by such authorities as: The Office of Public Roads, Dept. of Agriculture, Washington, D. C.; The American Society for Municipal Improvements; The American Society of Civil Engineers; Several State Highway Departments; and the American Society for Testing Materials.

Points	Asphalt A Suitable for Gilsonite and Asphaltic Oil	Asphalt B Suitable for California and Texas Oil Asphalts	Asphalt C Suitable for Mexican Oil Asphalt	Asphalt D Suitable for Bermudez Asphalt	Refined Tar E Suitable for Water-gas Tar	Refined Tar F Suitable for Coal Gas Tar
1	177° C.	177° C.	177° C	177° C.	121° C.	121° C.
2	960–1.000	1.000–1.045	1.025–1.045	1.035–1.060	1.150–1.200	1.180–1.300
3	Cube method n. l. t. 60° C.	Cube method n. l. t. 30° C.	Cube method n. l. t. 40° C.		Cube method n. m. t. 75° C.	Cube method [1] n. m. t. 75° C.
4	n. l. t. 205° C.	n. l. t. 205° C.	n. l. t. 205° C.	n. l. t. 163° C.		
5	Penetration 100–120	Penetration 90–110	Penetration 110–130	Penetration 130–160 Float method 66° C., 120–180 sec.	[1] Float method 50° C., 120–150 sec.	[1] Float method 50° C., 150–180 sec.
6	50 g. at 160° C. for 5 hr. n. m. t. 2% Penetration of residue not less than ½ original	50 g. at 163° C. for 5 hr., n.m.t. 2% Penetration of residue not less than ½ original	50 g. at 163° C. for 5 hr., n. m. t. 2% Penetration of residue not less than ½ original	50 g. at 163° C. for 5 hr., n. m. t. 3% Penetration of residue not less than ½ original	170° C., n. m. t. 0.5% 270° C., n. m. t. 12% 300° C., n. m. t. 25%	170° C., n. m. t. 0.5% 270° C., n. m. t. 10% 300° C., n. m. t. 20%
7	n. l. t. 99.5%	n. l. t. 99.5%	n. l. t. 99.5%	84 to 98%	n. l. t. 95% n. m. t. 0.2% ash[2]	80–95% n. m. t. 0.2% ash [2]

[1] Pitch residue after distillation to 300° C.

[2] Insoluble residue shall show not more than ......

such as have been treated in a previous chapter. Old macadam and broken-stone foundations are in use. In wet and yielding soils telford or Missouri types may be resorted to. Upon ordinary good subsoil, well drained, coarse macadam which passes over a $1\frac{1}{2}$-inch screen and through a $2\frac{1}{2}$-inch screen, or over a $2\frac{1}{2}$- and through a $3\frac{1}{2}$-inch screen, depending on the character of the soil in the subgrade, is spread in one or more courses and each thoroughly rolled until interlocked. Some

Fig. 164.—Constructing Bituminous Macadam Roads.

engineers cover each course with screenings and finish by rolling wet. These courses combined will be from 6 to 10 inches in thickness, according to the kind and amount of traffic the road is intended to carry.

Wearing Surface.—A number of different methods of constructing the wearing surface are in use. Without going deeply into details some of them may be described briefly as follows:

Crusher Run.—The entire product of the stone of the crusher, with the exception of the screenings sometimes, is spread uniformly and rolled lightly to bring it to grade. The bituminous cement properly prepared is then applied by hand pouring or by mechanical distributors, Fig. 164, and the rolling continued until the required compression and locking of stone is obtained. Dampening or oiling the rollers may be necessary to prevent sticking. A thin layer of stone chippings or sand is spread over the bituminous cement and rolled into the surface; $1\frac{1}{2}$ to $2\frac{1}{2}$ gallons of bituminous cement is required per square yard.

Uniform Stone.—A uniform product of stone, over a $1\frac{1}{2}$- and through a $2\frac{1}{2}$-inch screen, is used. This is spread and rolled, the cement applied and covered with a layer of fine stone chips or of sand, and the rolling continued to completion; $1\frac{1}{2}$ to 2 gallons of bituminous cement per square yard is required.

Partially Filled Voids.—The stone of the wearing course having been spread and smoothed the voids are partially filled by brooming and rolling in fine materials. Any surplus material is swept off and the bituminous cement applied. This is covered with stone chips or pea-gravel and thoroughly rolled. One and one-fourth to two gallons of bituminous cement per square yard is used.

Mechanically Mixed Filler.—The stone of the wearing course is spread and rolled to smooth. The voids are then filled with a mixture of hot sand and bituminous cement in practically equal parts by measurement. Tar pitch has been successfully used for the cement. The sand cement thoroughly stirred is poured by hand and broomed in, after which a layer of stone chips or gravel is spread and rolled in.

Sand-cement Mastic Layer.—A layer of sand is spread loosely upon the under course the voids of which have been filled. Upon the sand is distributed about 1 gallon per square yard of bituminous cement and the stone for the upper course immediately spread. This is then rolled to compact it and to force the mastic upward into the interstices. Bituminous cement is then applied to the surface (1 to $1\frac{3}{4}$ gallons per square yard), covered to a depth of $\frac{3}{4}$ inch with $\frac{3}{8}$-inch stone chips and rolled.

Seal Coat.—A seal coat of thin bituminous cement is often spread over the finished surface, covered lightly by a layer of stone chips to absorb the excess bituminous material, and rolled. One-third to one-half gallon per square yard will be required.

Maintenance.—Pot holes, worn places or depressions caused by the settling of the foundation may be cut out and filled with ready-mixed material or by layers of broken stone and bituminous cement. Bleeding will require a covering of dry stone chips. Where there is insufficient bitumen it should be sprinkled on with a covering of stone chips. Where there are several miles of roadway a patrol and repair gang with truck and materials constantly on the job will be found to give best results. When the continuous method of maintenance is not advisable, the roadway will occasionally have to be scarified and new stone added, smoothed and rolled, then bituminous cement applied as for new construction. The quantity of cement, however, need not be as great.

Bituminous Concrete

Definition.—A bituminous concrete road is one whose wearing surface is "composed of broken stone, broken slag, gravel or shell, with or without sand, Portland cement, fine inert material or combinations thereof, and a bituminous cement incorporated together by a mixing method."[1]

Classification.—The committee proposing the definition divided bituminous concrete pavements into three classes: (A) Those "having a mineral aggregate composed of one product of a crushing or screening plant"; (B) Those "having a mineral aggregate of a certain number of parts by weight or volume of one product of a crushing or screening plant"; and (C) those "having a predetermined mechanically graded aggregate. . . ."

Patented Mixtures.—Many patents for mixtures of bituminous concrete have been allowed by the United States Patent Office and by foreign governments. Some of these

[1] Proposed by a special committee of the A. S. C. E.

have been upheld by the courts; it is well, therefore, before using bituminous concrete for road purposes to be satisfied as to future expense for royalties or lawsuits. Blanchard [1] states in effect that the history of litigation cases indicates that the construction of bituminous pavements of class (A) will probably not lead to litigation; but that the construction of unpatented bituminous pavements of class (B) in large quantities will probably lead to an infringement suit; and, with the exception of the "Topeka Specification," the construction of class (C) pavements in large quantities will usually lead to litigation.

Materials.—Broken stone suitable for water-bound macadam roads may be used for bituminous concrete. Broken slag, gravel, and oyster shells have also been used. Trap rock and certain kinds of slag seem best suited to heavy traffic. A stone having an abrasion loss—French coefficient of wear—not less than 6 for light traffic and 8 for heavy, and a toughness—impact—not less than 6 for light traffic and 8 for heavy ought to prove satisfactory. For class A pavements stone that will pass a $1\frac{1}{4}$-inch screen such that from 3 to 10 per cent will pass a $\frac{1}{4}$-inch screen, has been recommended as suitable in size. For class B pavements one specification stipulates run of crusher stone passing a $1\frac{1}{2}$-inch screen, having not more than 5 per cent of dust; clean coarse sand to be used as a filler in proportions found necessary to fill the voids. The mixture would contain from 53 to 62 per cent stone, 30 to 37 per cent sand, and 8 to 10 per cent asphalt cement. For class C, good stone or slag, sand, and stone dust are recommended. The aggregate is carefully separated into several different sizes and recombined according to some predetermined formula, the object being to obtain the densest possible mixture with the materials at hand.

Bituminous Cement.—Refined tars and asphalts, as in the case of bituminous macadam, have been used singly and in combination. Alternate type specifications are necessary for the different classes and for modifications and variation of materials under the several classes. The following table shows characteristics extracted from several specifications:

[1] "American Engineers' Handbook," Wiley & Sons, New York.

Points	Asphalt A	Asphalt B	Asphalt C	Asphalt E	Refined Tar F	Refined Tar G
1	177° C.	177° C.	177° C.	177° C.	150° C	150° C.
2	.970–1.000	1.000–1.030	1.030–1.040	1.040–1.060		
3	Cube method n. l. t. 55° C.	Cube method n. l. t. 50° C.	Cube method n. l. t. 45° C.		Cube method n. m. t. 75° C.	Cube method n. m. t.
4	n. l. t. 205° C.	n. l. t. 205° C.	n. l. t. 205° C.	n. l. t. 205° C.	n. l. t. 165° C.	
5	Penetration 75–90	Penetration 90–100	Penetration 70–90	Penetration 140–160 Float method 66° C., 120–180 sec.	[1] Float method 50° C., 140–170 sec.	[1] Float method 50° C., 140–170 sec.
6	50 g. at 163° C. for 5 hr. n. m. t. 2% Penetration of residue not less than ½ original	50 g. at 163° C. for 5 hr., n.m.t. 1% Penetration of residue not less than ½ original	50 g. at 163° C. for 5 hr., n. m. t. 2% Penetration of residue not less than ½ original	50 g. at 163° C. for 5 hr., n. m. t. 1% Penetration of residue not less than ½ original	170° C., none 270° C., n. m. t. 7% 300° C., n. m. t. 20%	170° C., none 270° C., n. m. t. 10% 300° C., n. m. t. 20%
7	n. l. t. 99.5%	n. l. t. 99.5%	n. l. t. 99.5%	93–98%	n. l. t. 95% n. m. t. 0.2% ash [2]	75–90% n. m. t. 0.2% ash [2]

NOTE: n. l. t. = not less than. n. m. t. = not more than.

[1] Pitch residue after distillation to 300° C.

[2] Insoluble residue shall show not more than ....

The following are six optional materials. Additional stipulations are usually required for some of them:

Proportioning.—The designing of a proper mixture from the different sizes of stone and sand and bituminous cement is not an easy proposition. Some engineers work out the mixture by cut-and-try method. The stone having been separated in various sizes is remixed in varying proportions and that selected which gives the densest mixture, as determined by weighing a given volume. Others attempt to secure by calculation those proportions which will give a product as near to a predetermined formula, or to one which has proved to be satisfactory in actual use, as is practicable. Others combine the two methods, employing the second method for a trial mix and modifying it to get a satisfactory mixture. The quantity of cement which the aggregate will carry is determined by visual inspection of the matrix, or by softening tests in an oven in the laboratory. The inspector will gain ability to judge of this through experience. The mixture must be such that the roadway will not be too soft in the summer time nor so hard as to crack in the winter. While the mix for every job should be worked out on its own merits a few representative designs are given for purposes of comparison:

	Single Product Crusher Run	Topeka Specifications	As used Riverside Drive, N.Y.	As used Ontario	Omaha (Dundee) Specifications	Spokane Specifications	Bitulithic Specifications	Warrenite Specifications	Wash., D.C. Tests of Pavements laid
Bitumen, %	5–7	7–11	8.9	9.7	8–10	7–10	7–9½	.....	7–8
200-mesh sieve	....	5–11	11.9	8.3	6–8	4–8	4–7	5–10	
100-mesh sieve	....	....	....	....	....	5–10	....	.....	3–10
80-mesh sieve	....	....	14.5	13.0	10–30	10–20	....	15–20	0.5–2
40-mesh sieve	....	18–30	18.6	46.5	15–30	15–30	....	.....	3–6
10-mesh sieve	....	25–55	18.9	9.0	5–40	25–40	24–32	5–10	15–30
$\frac{1}{8}$-inch screen	1–5	....	....	....	....	....	....	.....	0.5–3
$\frac{1}{4}$-inch screen	3–10	8–22	19.1	6.0	5.20	15–40	....	5–10	3–20
$\frac{1}{2}$-inch screen	30–45	0–10	18.1	7.5	9–30	0–10	8–12	10–20	15–25
1-inch screen	10–25	....	....	....	....	....	26–35	40–60	15–30
Retained on 1-inch screen	1–10	....	....	....	....	....	36–50		0–20

CONSTRUCTION

Foundation.—Any good foundation may be used. Portland cement concrete is considered best, but old macadam, old brick,

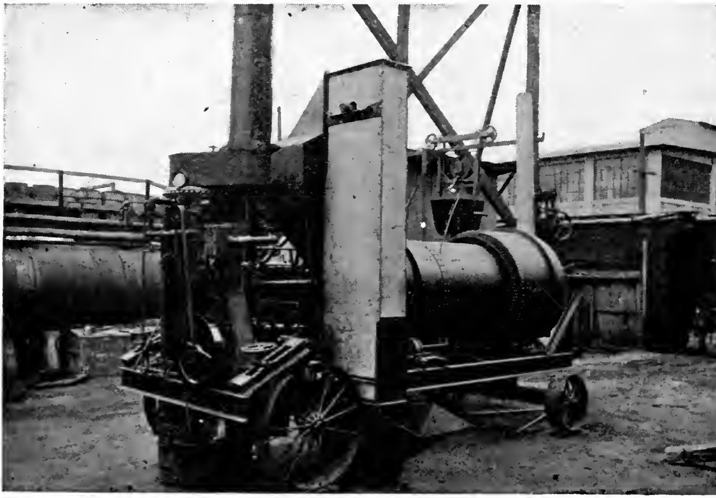


FIG. 165.—Asphalt Mixer (Courtesy of Warren Bros. Co.).

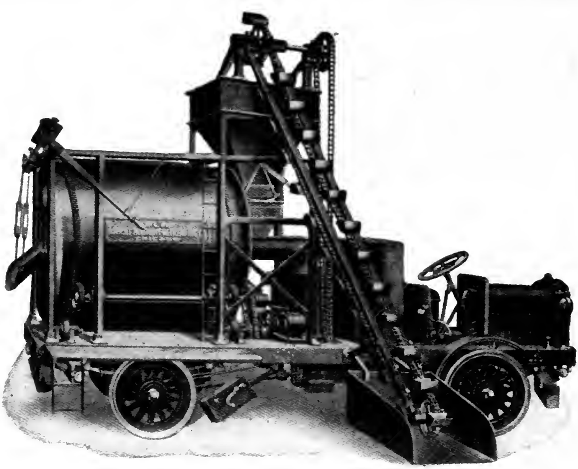


FIG. 165*a*.—Asphalt Ready Mixer (Courtesy of Asphalt Retreating Co.).

and stone block have been successfully used. Naturally, the heavier the traffic the stronger the foundation required. Of course the subsoil and drainage must always be taken into account.

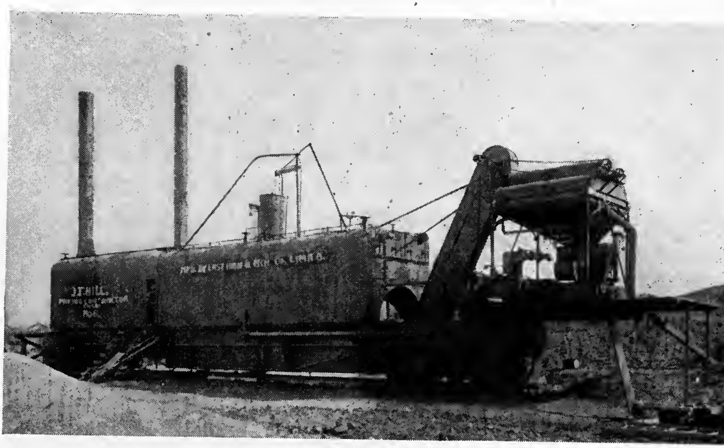


FIG. 166.—A Portable Bituminous Paving Plant.

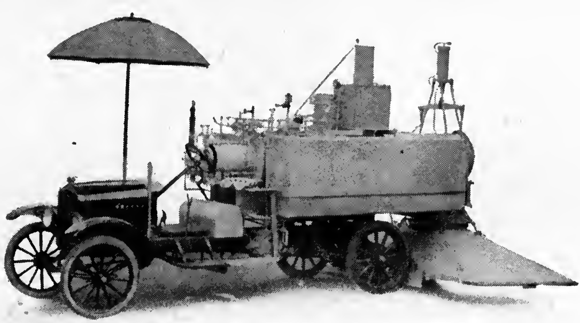


FIG. 166*a*.—Asphalt Pavement Retreader (Courtesy of Asphalt Pavement Retreading Co., Chicago).

Mixing.—Hand mixing is seldom resorted to nowadays except for patching or where very small amounts are to be laid. In such cases the mixing is done on a board with shovels or hoes in a manner similar to the mixing of cement concrete, except that the tools work better if heated. There are many types of plants, Figs. 165, 166, for mechanical mixing with and without heaters, dryers, separating sieves and melting kettles. Mixing in ordinary cement mixers, as well as hand mixing, of unheated materials can be done to advantage only in warm weather and with a soft bituminous cement. Sometimes the sand and stone are heated by piling over a drum in which a fire is kept burning. Special, but simple furnaces, are also in use for this purpose. The more elaborate mixers have appliances for heating the aggregate, separating it into several sizes, elevating and storing these in suitable bins from which they can be drawn by gravity into a hopper scale, the proportions weighed accurately and dropped into a mixer, usually of the pug type. Attached to the same plant, or a part of it, are large kettles for heating and softening the bituminous cement, with proper appliances for stirring it so that it will not burn to the kettles. Measured portions of the cement are poured upon the stone in the mixer and the whole pugged until of uniform consistency when it is dropped into a waiting wagon and hauled to the roadway.

Temperature of Mixture.—In best practice the mixture is required to be placed upon the roadway at a temperature not less than 66° C. (150° F.), therefore it must leave the plant at a somewhat higher temperature. Specifications usually require this to be not less than 135° C. (275° F.) and not more than 277° C. (350° F.) for asphalt, and not less than 95° C. (200° F.) and not more than 135° C. (275° F.) for refined tar. Any cement heated beyond the maximum limits should be rejected.

Laying.—The surface of the foundation being thoroughly clean and dry the prepared bituminous concrete is hauled and dumped upon platforms or upon the foundation a short distance from where it is to be finally spread by hot shovels and raked smooth with hot iron rakes. The usual thickness after compression is from 2 to 2½ inches.

Rolling.—Immediately after spreading the bituminous concrete is tamped and rolled. The rollers should weigh from 8 to

12 tons or from 200 to 300 pounds per lineal foot of roller. Rolling should begin at the outside and proceed toward the center of the roadway, lapping generously upon that which has already been rolled. If wide enough the pavement is cross and diagonally rolled. Some builders prefer a very light roller for the first time over followed by an 8-ton roller and finished with a 12- to 15-ton roller. Rolling, or tamping in places inaccessible to the roller should continue until the surface shows no further compression.

Seal Coat.—A seal coat of asphalt cement is immediately distributed over the dry smooth surface and uniformly spread by squeegees or brooms. Some authorities say the seal coat should be made of the same kind of cement as the body of the wearing surface, while others prefer asphalt cement even on a tar concrete. The cement should be distributed at a temperature between 135° C. (275° F.) and 177° C. (350° F.) and immediately covered with a thin layer of stone chips or sand and rolled twice by the roller. Sowing the stone chips by hand or distributing by shovel or machine are practical methods. In one machine distributor the sand falls on a revolving cone from which it is thrown off in such a manner as to spread it quite uniformly over the surface.

Maintenance.—An occasional surface coating of tar or asphalt cement and stone chips will keep the roadway in good condition and at the same time serve as a dust layer. When, however, the roadway has been broken by the excessive weight of a truck, a fracture of the foundation, or cut away for pipes or under repairs, or otherwise disturbed, it may be necessary to cut out the damaged places and refill with the same sort of material, preferably, as the original pavement, or by cold mixtures in layers, tamping them or leaving them to be compacted by traffic. The cut edges of the pavement should be painted by bituminous cement before the patching material is applied. In case cracks appear due to contraction in cold weather they may be cleaned out and filled with hot tar or asphaltic cement. These should not occur if the original bituminous cement is of right quality and consistency and receives proper treatment throughout, assuming, of course, that the design of the mixture is correct.

Sheet Asphalt

Definition.—A sheet asphalt pavement is "one having the wearing course composed of asphalt cement and sand of predetermined grading, with or without the addition of fine material, incorporated together by the mixing method."[1] It usually consists of three courses, a foundation of cement concrete, a binder course of bituminous concrete, and a wearing course of asphalt cement, sand and stone-dust.

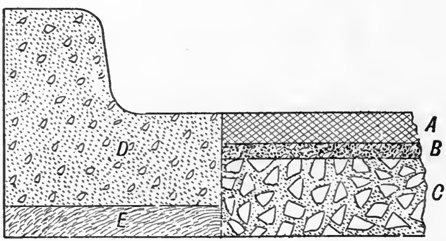


Fig. 167.—Cross-section of a Sheet Asphalt Pavement.

A = Asphalt wearing surface.
B = Binder course.
C = Concrete base.
D = Concrete curb and gutter.
E = Cinders, sand or gravel for drainage.

Foundation.—Since the mineral particles in this type, Fig. 167, of pavement are fine and have little mechanical stability, and since the bituminous cement is more or less viscous, the surface course will easily conform to any movements of its supporting course; therefore it is absolutely necessary to have a strong and rigid foundation and a well-drained subsoil. A foundation course 5 inches thick of a 1 : 3 : 6 Portland cement concrete is a common specification. With the increase of heavy motor transportation, however, double this thickness may soon be advisable.

[1] Proposed by the special committee, "Materials for Road Construction," Am. Soc. Civil Engineers.

Binder Course.—This is an intermediate course of lean asphaltic concrete which furnishes a horizontal stability to the wearing course and serves to even up the irregularities of the cement foundation. The wearing course and the binder become inseparably cemented together in the finished pavement. Binder is usually composed of asphalt cement and cubically broken stone or slag with or without sand or other fine material. Ninety-five per cent of the stone should pass a screen with circular openings having a diameter three-fourths the thickness of the course; none of it should exceed in largest dimensions the thickness of the course. There are two types of binder known as open and closed, the preference being for the latter. The *open binder* does not have added to the stone used sand or other fine mineral matter to help fill the voids. The voids are later closed during the process of laying and rolling with the "topping"; its advocates claim this forms a more perfect union of the two courses. *Closed binder* in order to reduce voids requires a graded aggregate. The following is recommended in addition to the dimensions given above for open binder: Passing 10-mesh sieve, 15 to 35 per cent; passing $\frac{1}{2}$-inch circular opening and retained on 10-mesh sieve, 20 to 50 per cent; total passing $\frac{1}{2}$-inch screen, 35 to 85 per cent. Advocates of the closed binder claim it is more economical and just as good. Old asphalt surfaces have been used for the filler, new asphalt cement being added in sufficient quantity to cover each particle.

The binder is hauled to the work and spread while hot so that it will roll to the required thickness, 1 to $1\frac{1}{2}$ inches. The upper surface of the rolled binder should be approximately parallel to the surface of the finished pavement. General traffic should not be allowed on the binder course, neither should any great amount of time intervene between its laying and that of the wearing course.

Wearing Course.—This course consists of asphaltic cement and mineral aggregate. The cement is prepared by fluxing native or petroleum asphalt with residues from distillation of petroleum oils or with heavy oils. The suitable fluxes vary so much that a definite statement of proportions would be

TYPICAL SPECIFICATIONS FOR ASPHALT CEMENT

	Northern United States			Southern United States		
	Suitable for Oil Asphalts	Suitable for Fluxed Bermudez Asphalt	Suitable for Fluxed Trinidad Asphalt	Suitable for Oil Asphalts	Suitable for Fluxed Bermudez Asphalt	Suitable for Fluxed Trinidad Asphalt
Specific gravity 25° C.	1.020+	1.050–1.070	1.200–1.250	1.020+	1.055–1.075	1.210–1.270
Flash point (open cup) ° C.	175+	175+	175+	177+	175+	175+
Melting-point (R. & B.) ° C.	40–60	45–55	45–55	45–65	45–55	50–60
Penetration at 25° C.	50–60	50–60	50–60	40–50	40–50	40–50
Volatilization—5 hours loss at 163° C.	1%–	3%–	3%–	1%–	3%–	3%–
Penetration of residue at 25° C.	30+	25+	25+	25+	20+	20+
Soluble in carbon disulphide, per cent	99.5+	94.0+	68.0+	99.5+	94.0+	65.0+
Organic insoluble, per cent	0.2–	....	....	0.2–		
Inorganic insoluble, per cent	....	2.5–4.0	20–30	....	2.5–4.0	22.–32

impossible. Each case should be worked out by trial mixes in the laboratory, and varied at the plant as occasion may require. The mineral aggregate consists of graded sand according to a predetermined formula and impalpable dust. The design of the mixture that will be sufficiently hard and stable in hot weather, will not crack in cold weather, is non-volatile in hot weather, and will not disintegrate rapidly in wet weather requires an expert knowledge of the theory of bituminous pavements, the character and properties of the several ingredients used, and the best construction practice. There is not space here to go into these matters and brief mention only can be made.

Typical Specifications.—The table, p. 316, shows some of the important characteristics required by typical specifications.

Mineral Aggregate.—Since approximately 90 per cent of the wearing course of a sheet asphalt pavement is made up of sand and stone-dust the character and grading of the mineral aggregate is an important element.

Sand.—The sand used should be clean and moderately sharp. Some authorities [1] prefer a rounded grain, as it seems to compress better than the sharp. Quartz and feldspar sands are to be preferred. It is important that a large percentage of the grains should be small, but some coarse grains are highly desirable. The researches of many students of bituminous paving have led to standard designs, p. 318, for sheet asphalt sand gradings, which are to be used with such modifications as may be demanded by local materials and conditions.

Filler.—A very fine powder is used to fill the voids of the sand. This mixes with, absorbs and holds the asphalt cement, possibly because it greatly increases the surface area of the mineral aggregate to be painted. The asphalt cement is permanently held by adhesion and does not act as a lubricator and the pavement as a whole becomes hard and unyielding. Limestone dust, having large adhesive power for asphalt cement, is commonly used. Portland cement, or Portland cement combined with limestone dust, is by some

[1] Richardson's "Modern Asphalt Pavement," Wiley & Sons, New York.

STANDARD GRADINGS OF SAND FOR SHEET ASPHALT PAVEMENTS

Sieve Numbers	For Heavy Traffic		For Light Traffic	
	Design [1]	Limiting Values [2]	Design [1]	Limiting Values [2]
Passing 10-mesh and retained on 20-mesh, %.	5	2– 8	10	5–12
20-mesh and retained on 30-mesh,	8	5–10	10	10–15
30-mesh and retained on 40-mesh,	10	10–15	15	10–20
Total coarse sand............	23	17–30	35	25–40
Passing 40-mesh and retained on 50-mesh,	13	5–30	15	10–30
50-mesh and retained on 80-mesh,	30	5–40	30	10–40
Total medium sand...........	43	....	45	
Passing 80-mesh and retained on 100-mesh,	17	10–20	10	6–15
100-mesh and retained on 200-mesh,	17	10–25	10	10–15
Total fine sand...............	34	25–40	20	18–25
Passing 200-mesh......................	0	0– 5	0	0– 5

[1] Richardson's "Asphalt Construction," McGraw-Hill Book Co., N. Y. Richardson allows a variation of ±5 from standard values.

[2] Blanchard's "Highway Engineers' Handbook," Wiley & Sons, N. Y.

considered better but the cost is greater. Other stone dusts, marl, clay, etc., have been used with success. Since only the impalpable powder can enter the voids of the fine sand grains the stone-dust should be ground so that at least two-thirds will pass a 200-mesh sieve. That failing to pass acts as so much sand and should be taken into account in the design of the mixture. Some native asphalts, such as Trinidad, contain a considerable proportion of mineral matter which authorities agree may be considered as part of the necessary filler.

Complete Topping Mixture Design.—Richardson [1] considers the points to be especially regraded in designing the wearing course of an asphalt pavement to be: 1st, The Fine Sand; 2d, The Coarse Sand; 3d, The Filler; and 4th, The Bitumen. From his experience he gives the following as a "correct surface mixture" for heavy traffic:

[1] "Modern Asphalt Pavement."

ASPHALT SURFACE MIXTURE

Correct Surface Mixture 100%	Bitumen, 10.5% (4th point)				
	Mineral aggregate 85.9% (1st point) (2d point) (3d point)	Filler + 200-mesh sand 13.0% (3d point)			
		Sand 76.5% (1st point) (2d point)	Mesh		
			100	13.0	26.0%
			80	13.0	
			(1st point)		
			50		23.5%
			40		11.0%
			30	8.0	16.0%
			20	5.0	
			10	3.0	
			(2d point)		

Construction.—The wearing course mixture (topping) is prepared in a plant similar to that used for bituminous concrete (Figs. 165, 166). The sand is either fed into the drying drum from sources such that the mixture when elevated to the bin will be according to the predetermined design, or it is dried and screened separating it into several portions in order that it may be remixed in proper proportions. The sand after heating is stored in a hopper bin above the measuring or weighing device into which it may be drawn by gravity and dropped into the mixer. Carefully measured hot asphalt cement and stone-dust, usually cold, are put in the mixer with the sand and the whole turned until uniformly mixed. It is then transported to the roadway in wagons. The mixture leaves the plant at a temperature not exceeding 177° C. (350° F.) and reaches the roadway at a temperature not less than 110° C. (230° F.), preferably about 150° C. (302° F.). The wagons are dumped on the binder course just ahead of the work or on platforms. The mixture is shoveled to place and raked smooth by hot iron rakes, after which it is rolled and tamped until satisfactorily compressed. A small tandem roller (about 8 tons) is first used then a heavy one (about 12 tons). Hot tampers are used along the edges or in places inaccessible to the rollers.

Maintenance.—The ordinary maintenance consists in repairing pot holes and other defects that may appear due to wear, excessive pressure by vehicles, rotting under the influence of dampness from beneath or on top, openings for pipes or underground work, or imperfect design and construction. Even if the wear is uniform there will come a time when the whole top will have to be replaced. When defects occur two methods of procedure are available. In one the surface is heated by hot pans drawn over it or by flames projected against it and the surface thus softened scraped away $\frac{3}{4}$ to 1 inch in depth and replaced by new topping. In the other method the wearing and binder courses are cut through vertically making a rectangular opening to the foundation and this filled with new binder and topping, and tamped or rolled to place. The edges, especially in old pavements, should be uniformly painted with a thin coating of asphalt cement to insure the adherence of the new and old work. Cracks are usually widened and new material tamped in. Tar or asphalt cement may be used to fill them but as these have a tendency to soften the surrounding surface they may do more harm than good. If the design of the pavement is suitable to the traffic, small cracks will be closed automatically by the pounding and kneading of hoofs and vehicles.

Rock Asphalt.—Sandstone or limestone naturally impregnated with asphalt is known as rock asphalt. This stone is quarried and broken into fragments and used as macadam, or, it is pulverized, heated and spread like sheet asphalt. The principal objection to its use is lack of uniformity in the bitumen content, which varies from 3 to 10 per cent, with no assurance that contiguous parts of the roadway will be anywhere near the same. If some easy method could be devised to mix the broken or pulverized rock in large quantities and so thoroughly that it would have a uniform bitumen content, increased by adding asphalt cement if necessary, rock asphalt, would no doubt prove highly successful for roads near the quarries where freight charges would not be a barring factor.

Asphalt Blocks.—Blocks about 12 inches long, 5 inches wide, and 2, $2\frac{1}{2}$ or 3 inches deep made up of a mixture approaching in composition the Topeka formula (p. 309), are molded hot in the factory under a pressure of 30,000 to 50,000 pounds per square inch. These are then transported, after cooling, to the roadway and laid on a concrete or other firm foundation in a similar manner to brick or stone blocks. They are laid as closely together as possible and no allowance need be made for expansion. A thin layer of sand over the newly laid blocks will fill the joints.

CHAPTER XIV

SURFACE TREATMENTS TO MITIGATE AND PREVENT DUST

It has already been stated that impalpably fine dust (clay and rock powder) is the cement which finally binds broken stone road metal into a comparatively monolithic mass. The same is true of gravel and in a much less degree of sand-clay and earth. The cementing of stone and gravel is probably due to chemical action while the stability of earth and sand-clay may depend almost wholly upon the physical properties of cohesion, friction, and the surface tension or adhesion of the moistening water for the earth particles. All of these properties seem to function better in the presence of moisture; therefore when the water is dried out the roadway under the action of traffic soon begins to disintegrate and becomes dusty. Dust is defined by the Century Dictionary as "earth or other matter in fine dry particles so attenuated that they can be raised and carried by the wind." The roadway is the most fertile source of dust, and dust, being a carrier of disease germs and an irritant of delicate tissues, is well known to be a menace to the health of man, horses, cattle, and other animals, besides being very uncomfortable. Also, when it settles upon the leaves of plants it gives them a bad appearance and hinders their growth by interfering with their natural functions.

Road dust, while instrumental in preserving a roadway, is seen to be at the same time a nuisance. The problem then is so to treat the road surface that the dust nuisance may be mitigated or prevented and the bond of the roadway at the same time retained or bettered.

Cause of Dust.—Hubbard, after stating the cause of dust to be wear, classifies the dust-making agencies under three heads:[1] chemical, physical, and mechanical. Water and weak acids carried in water act upon rocks to decompose their mineral constituents and break them down, chemically, into fine particles.[2] The disrupting effect of frost, the attrition of falling rain, the transporting power of water and the action of wind comprise the physical agencies; while the mechanical are abrasion, impact, local compression, and shear. To combat the dust nuisance it will be necessary either to prevent the formation of dust, to treat the roadway with something which will retain the dust on the surface, or to remove it by some mechanical means such as sweeping and washing. The last method is employed for pavements in cities but is not practical for the ordinary rural roads.

Earth is an unstable material when very wet and an extremely friable one when very dry, but forms a comfortable and reasonably good road surface for light traffic when in just the right condition of moisture. Hence the logical maintenance of an earth road is to crown and smooth it so that excessive water will readily run off; at the same time the work on the surface should be such as to cause it to become so dense that it takes up the water slowly and dries out slowly, thus retaining for a considerable time the necessary moisture to hold it together.

The same statement may be made of sand-clay roads for, indeed, ordinary earth or loam is a mixture of sand and clay but probably not in the best proportion for road surfaces.

When there is intermixed such a proportion of pebbles that the road may be considered a gravel road, strength and power to resist wear is given by both the chemical binding action and the mechanical stability due to the coarser materials. But here again too great an amount of water and too little water are both detrimental. The ideal road can only be maintained

[1] "Dust Preventives and Road Binders," by Prevost Hubbard, Wiley & Sons, New York.

[2] See U. S. Department of Agriculture, Bureau of Chemistry Bulletins, 85, 92, and 28, by Page, Cushman and Hubbard, on the "Cementing Power of Road Materials," "The Effect of Water on Rock Powders," and "The Decomposition of Feldspars."

with a mean between these extremes or by an artificial bonding cement.

With a water-bound broken stone road similar conditions apply, but the stone being angular there is still greater stability and when wedged firmly together by the roller will withstand well the mechanical disrupting factors, while the moist disintegrating rock powder settling between the stones serves further to cement them together into a more or less monolithic mass. Excessive water in addition to softening the subgrade washes away the " fines "; with insufficient moisture, though there may be plenty of dust, cementation and recementation cannot take place.

With still more stable roadways an artificial cement takes the place of the natural " dust cement," as in concrete and bituminous pavements; or, definitely shaped blocks—brick, stone, wood, etc., are carefully laid so as to resist, quite effectually, the destructive action of traffic.

But roadways can not always be in ideally moist condition. And even if they could be and no wear at all took place, dirt would be tracked, blown and washed upon them from outside. Twigs and leaves from trees, droppings from animals, soot from chimneys, debris from mills, and many other things furnish material for street litter. This litter is ground up into dust which when raised by the wind becomes a nuisance. If this dust would remain on the surface, even though it had no binding power, and much of it has not, it would serve as a cushion to prevent further wear. But, under the action of traffic and wind the road may be depleted of its dust, which, while decreasing the dust nuisance, leaves the roadway without its natural protective and repair agency, and hence subject to continued and more harsh and violent usage.

Palliatives and Preventives

Those substances which when applied to the roadway temporarily lay dust are technically known as *palliatives;* those whose effect is more permanent, good for six months to two years, are called *preventives.*

Palliatives. Water.—The use of water as a dust layer is universal, and when properly applied is effective. The principal objections to its use are its temporary nature and that the roadway immediately after application is muddy and slippery. The usual method of applying water is by means of horse-drawn sprinkling carts. These are tanks mounted upon wagons having suitable valves and orifices for spreading the water. It has been pretty well demonstrated that efficient sprinkling will materially prolong the life of a road under horse-drawn iron-tired traffic, but it will not prevent damage by rapidly moving motor cars.

The cost of water sprinkling will depend on the character of the road, the climate, the cost and efficiency of labor, and the cost and availability of water. Country roads could hardly be treated continuously with water.

Sea water, because it contains some hygroscopic magnesium salts, can in some places be used with success. Objection has been raised to the residue of white salt scale that appears when the water dries out. Except when the water is easy to obtain it will not pay to use it.

Oil and water, mechanically mixed in a tank by whirling blades then immediately forced upon the roadway, has been used to some extent. The theory being that when the water evaporates a very thin film of oil will be left.

Deliquescent salts such as common table salt (a mixture of sodium chloride and magnesium chloride) and calcium chloride have also been used somewhat. These may be spread dry or dissolved in water and sprinkled from a water wagon. Being hygroscopical they will attract moisture from the air and keep the road from drying out for a considerable time, depending on the character of the road and the climate and weather conditions. About 1 to 1½ pounds to the square yard is recommended for a first application of calcium chloride in its dry state upon a macadam or gravel road. A farm lime spreader may be used advantageously for distributing. This treatment is followed in periods of one or two months by applications one-half as great. In very dry weather it may be necessary to sprinkle with water occasionally. The wet method which is recommended for hard surfaced roadways consists in dissolving salt in water and sprinkling it on the surface. One pound of salt to a gallon of water is recommended. Subsequent applications to be made every three or four weeks, depending on the weather.

Emulsions.—Water and soap or other saponifying agents such as potash, ammonia, soda, or carbolic acid, are mixed with mineral oil, or tar agitated until emulsified, and sprinkled upon the road. Good results cannot be obtained with paraffin oils. They are too greasy and non-adhesive. With asphaltic oils repeated applications may produce a carpet or mat of appreciable thickness which acts both as a dust layer and as a road protector. Emulsions may be purchased or made up in concentrated form, shipped or hauled to the place of use, there diluted with water to secure the desired strength and applied. A Boston method is to dissolve 25 to 30 pounds of cottonseed soap in 100 gallons of hot water; to this solution is added 200 gallons of emulsion oil and the mixture agitated for twenty minutes. This forms a concentrated solution. It is reduced about one of solution to four of water for first application and about one to eight for subsequent applications. One gallon of the diluted mixture will cover about 6 square yards of surface. In a week or ten days after the first application a second application should be made. Succeeding applications will be required at periods of two to six weeks, depending on the type of roadway, weather and climatic conditions.

Organic substances such as waste from sugar factories and paper mills are used as palliatives. These products being more or less sticky form with the dust a thin mat.

Sugar Waste.—A poor grade of molasses diluted with water to make it thin enough to run from the sprinkler and reduce its stickiness so that it will not adhere to the wagon wheels has been found helpful to the roads near sugar factories. However, the loads of beets and sugar cane are so heavy that they soon cut up any road but the very best.

Paper Mill Waste.—Waste sulphite liquor from the manufacture of wood pulp has been used to a considerable extent. The dispensers of a preparation of this character, under the trade name of Glutrin, claim that it acts upon the silica of the stone-dissolving it and forming a bond insoluble in water. The liquor is shipped to the place of use in concentrated form, there mixed with water and sprinkled on the surface.

Light Oils.—Crude petroleum and petroleum distillates are

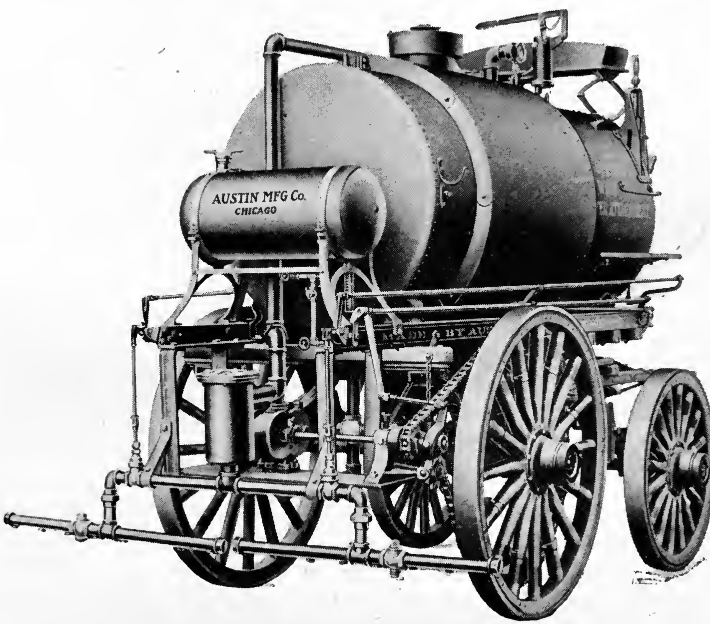


Fig. 168.—Oil Distributor.

largely used as dust palliatives. Only those oils having an asphalt base (35 per cent or more asphalt) are considered of real value for this purpose. Non-asphaltic oils are temporary in their effect but not being sticky do not require covering with sand. The residual oils from the petroleum refineries have been most successful in California where the long dry season makes the main traveled untreated earth roads extremely dusty and uncomfortable.

Earth roads will require three or four treatments to keep them in the best condition. They are first properly shaped with the road machine and the light oil sprinkled on the surface to the amount of about ½ gallon per square yard. Subsequent applications, if made before the roadway has become rutted or out of shape, will require about half that amount of oil. It is recommended that the road be sprinkled with water, if very dry, before application. After a light rain is a good time to apply the oil.

Macadamized and other hard-surfaced roadways should first be swept clean; dry, if that removes the dirt, if it does not then wet followed by another sweeping after it has dried. The oil is applied at the rate of ½ to ¾ gallon per square yard and after two or three hours covered lightly with sand or dry earth. Gravity or pressure distributors, Fig. 168, are more efficacious than hand-pouring cans, although the latter are useful for small jobs and for patching.

Heavy residual oils are frequently cut back by a flux and applied in the same manner as the light oils. The flux soon evaporates, leaving the heavier asphalt thinly but uniformly spread over the surface.

Tars.—Light tars of various kinds are used in the same manner as oils. Pressure distributors are recommended as spreading the tar most evenly. Light tars are usually applied cold in warm weather but may be heated if too viscous to flow well. Crude and refined tars are used; refined tars are considered better but are of such a consistency that they have to be heated. It may pay, however, to use the refined and heavier tars, as the number of applications per season will be reduced. From five to ten hours is allowed to elapse before covering the tarred surface with stone screenings or sand.

Animal and Vegetable Oils.—These are sometimes mixed with an alkali to form a soap which can be used later to make an emulsion with a mineral oil. If used alone they are short lived and act as a dust layer similar to, though more lasting than, water.

Preventives, Bituminous Surfaces

The so-called preventives are practically all made up of mixtures or compounds containing bitumen as its binding ingredient. Oils and tars when applied frequently may produce surfacings of appreciable thickness which have sufficient permanency to be called preventives. The point where palliatives disappear and preventives begin cannot be definitely defined. Bituminous surfaces are road preservatives as well as dust preventives; in fact, that may and often is their primary significance. They are classified either according to the materials used, as, oil, tar, asphalt; or according to their thickness—a *coating*, if less than ½-inch thick and a *carpet* or *blanket* if more.

Materials.—The most satisfactory materials for these surfaces are: (*a*) petroleum residual oils having an asphaltic base, (*b*) cut-back asphalts, (*c*) refined coal tars, (*d*) refined water-gas tars, (*e*) cut-back coal tar pitches, and (*f*) combinations of tars and asphalts. The residual oils are ordinarily used on earth roads; tars and cut-back asphalts and pitches on gravel, broken stone or paved surfaces. Which is better, the tars or petroleum products, is a disputed question. And while the heavy materials carry more bitumen, build up mats quicker and last longer, they should not be too viscous for ready application.

Specifications.—Since these will depend upon local conditions as well as the materials used, and are highly technical in character detailed specifications are omitted. Specimen specifications may be obtained from most of the state highway departments or from the Office of Public Roads, United States Department of Agriculture. The table on page 330 gives the characteristics required by typical specifications.

Oiled Roads.—The desire to eliminate the dust nuisance at a cost less than sprinkling with water led, in California, to the use of heavy residual petroleum oil. The asphaltic base of the oil cemented the particles of earth and sand together, making a rubbery coating over the road surface. This proved to be so much better than the original earth surface, in dry weather

BITUMINOUS MATERIALS FOR SURFACE TREATMENT[1]

Material	Oil and Asphalt Products				Tar Products		
	Heavy Distillate	Heavy Crude or Cut-back	Cut-back Asphalt	Residual	Light Refined	Refined or Residual	Cut-back
Use	Dust Palliative	Cold Surface Treatment	Cold Surface Treatment	Hot Surface Treatment	Cold Surface Treatment	Hot Surface Treatment	Cold Patching
Specific gravity 25° C.	0.940 –	0.935–0.970	0.890 +	0.980 +	1.100–1.180	1.130 +	1.100–1.200
Flash point, open cup	100°C.+	50° C. +	…	80° C. +			
Specific viscosity, 25° C	10 –	80–120	25–35				
Specific viscosity, 40° C	…	…	…	…	10–35	…	40–70
Specific viscosity, 100° C	…	…	…	60 –			
Float test, 32° C	…	…	…	60 sec. +	…	60–150	
Loss 163° C., 5 hours per cent	15	30	30–40	15			
Float 50° C. on residue	Liquid	90 sec +	…	110 sec +			
Penetration 25° C., of residue	…	…	50–85				
Total distillate to 170° C. per cent	…	…	…	…	5 –	1 –	2 –
Total distillate to 270° C. per cent	…	…	…	…	30 –	15 –	15–25
Total distillate to 300° C. per cent	…	…	…	…	40 –	25 –	30 –
Solubility in carbon disulphide, per cent	99.8 +	99.5 +	99.5 +	99.5 +	90 +	85 +	80 +
Insoluble in 86° B naphtha	…	6.0 +	…	6.0 +			
Sp. gr. distillate to 200° C	…	…	0.73–0.78				

[1] After Hubbard, "Highway Inspectors' Handbook," Wiley & Sons, N. Y.

eliminating the dust and in wet weather the mud, that many miles of road were systematically oiled. While a very great improvement, they are not sufficiently durable under moderately heavy traffic to commend their general use for country roads. They are being replaced as circumstances demand by more durable types. But just as earth roads will always be with us, and under favorable circumstances are the cheapest and best road for certain localities, so there will be need for the oiled road.

Construction.—The road surface is plowed up to a depth of

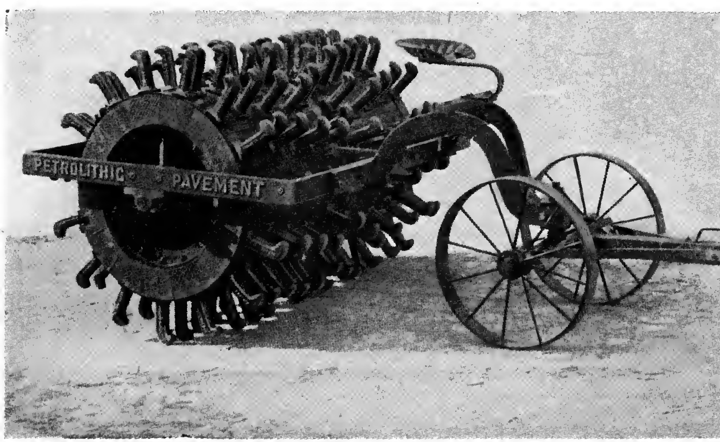


FIG. 169.—Sheep's Foot Roller.

about 6 inches and thoroughly pulverized with disk and tooth harrows. Oil, with an asphaltic base, is distributed over the surface to the amount of about 1 gallon per square yard. This is allowed to stand for a short time to soak in when the road is brought to the proper crown with a road machine. It may be necessary to sprinkle on a little dry soil from the side where the oil remains sticky. The roadway is then rolled thoroughly. When a sheep's foot or tamping roller, Fig. 169, is used, the impregnated soil is rolled until the tampers on the roller which, at the beginning sink in full depth, fail to penetrate the surface materially. The roadway is then smoothed up with the road machine and rolled with a heavy roller. Roads built in this manner have proved to be quite satisfactory. A surface treatment of screened gravel and asphaltic oil is sometimes given the wearing surface.

Oil.—In all petroleum-oiled roads it is quite essential that the oil used has an asphaltic base. Residual oil, that is, that remaining after the lighter oils, naphtha, benzine, gasoline, kerosene, and lubricants have been driven off is considered best as the percentage of asphalt, which constitutes the binding power, is then greatest. Care must be observed that the oil has not been heated to that point which will destroy the tenacity, ductility and adhesiveness of the asphalt.

CHAPTER XV

REVENUE, ADMINISTRATION AND ORGANIZATION

Revenue.—The revenues for the construction and maintenance of roads are usually derived from taxes. A few roads have been built by private corporations and operated by exacting tolls. The tendency is for these to be taken over by the public and made free highways. New additions to cities often have the streets graded and paved, as a promotion proposition before the plats are filed for record. Occasionally, a wealthy man or firm builds a road and gives it to the public. The most notable example is the Dupont road in Delaware. No better way for erecting a lasting memorial can be imagined than the endowment of a fund for constructing and maintaining a well-traveled road. Of late years there is a growing tendency to license automobiles and devote the revenue derived therefrom for the use of highway improvement or for the maintenance of a State highway department.

Taxes, Direct.—Direct taxes are levied upon persons and property. When levied upon persons they are called poll or capitation taxes. Poll taxes are usually levied upon persons of a prescribed class: For example, "all able-bodied males between the ages of 21 and 50 inclusive," or "all voters under 55 years of age." Taxes are levied upon property (1) in proportion to its value or (2) because of nearness, or other reasons, it is especially benefited by the improvements. The former is usually known as a *property tax* and the latter as a *special tax*. In most States the laws require property taxes to be levied uniformly over the entire taxed district which usually coincides with some civil district such as city, township or State.

Special taxes, on the contrary, are not levied uniformly over the taxed district. They are levied to defray the cost of a special improvement and can be used for nothing else. The improvement must be demanded by public interest and the taxes are levied upon property especially benefited and in direct proportion to the benefits accruing to the property. Ordinary **property taxes** are levied in proportion to the value of the property, that is, presumably, according to the ability of the owner to pay, and not in proportion to special benefits derived from taxation.

Labor taxes are direct taxes which are to be paid in labor. They may be either poll or property taxes. Road taxes from the earliest levying of such to within very recent times have been largely labor taxes. But as lines of work become more specialized the tendency is to do away with labor taxes altogether, to pay the taxes in cash and employ men versed in road-making and maintenance to care for the public highways.

General taxes are often levied over a county or State for the use of the roads of the county or State as a whole. The funds arising are not expended uniformly upon all the roads but at such places as the proper officers may direct. They may also be used for county or State aid, of which more will be said under the head of Administration.

Indirect Taxation.—Where money is derived from national aid for road purposes it comes from indirect taxation. State aid, if the State taxes be collected in one general fund, may likewise be classed as indirect taxation, although the State tax is itself a direct tax. Another form of indirect tax comes from the employment of convicts for road building, the convicts themselves being cared for from a fund for that purpose and not specially raised for road work.

Bonds.—Bonding a district is a method of borrowing money and spreading the payment over a series of years in order that the levy of any one year shall not be excessive. This method of financing road projects has been quite popular. The total of such bonds according to the U. S. Office of Public Roads up to January 1, 1914, was $286,557,073.[1] The amount of out-

[1] Bulletin, 136, U. S. Dept. of Agriculture, "Highway Bonds," by Hewes and Glover.

standing local highway bonds January 1, 1913, was approximately \$202,007,776. The grand total of all highway bonds State, county, township, municipal and district, reported to the Office of Public Roads, to January 1, 1914, was \$445,147,073.

Kinds of Bonds.—Bonds may be classified according to the manner of payment as sinking-fund, serial and annuity.

Sinking-fund.—These are straight terminal bonds, the interest being paid annually upon the principal, which is the face value of the issue, or at some other fixed regular period. In order to pay the bonds, a sinking-fund is established. There is theoretically paid into this sinking-fund annually a certain sum. The sinking-fund is then loaned. The payments and interest are together such that they will amount to the face of the bond at its maturity. The interest which the sinking-fund draws may not be as large as that of the bond. Even though the nominal interest rate is the same, there is always time lost between the collection of the tax and its investment. For this reason and from the fact that a sinking-fund may be easily drawn upon for other purposes than that for which it was created makes this the least desirable class of bonds.

The sinking-fund which must be raised to amount to P dollars in n payments at an interest rate of i per cent may be obtained by the formula—

$$\text{Sinking-fund} = \frac{i}{(1+i)^n - 1} \cdot P$$

EXAMPLE

What sinking-fund must be raised to discharge a debt of \$10,000 in five years at 4 per cent annual interest?

Solution:

$$S = \frac{.04}{(1+.04)^5 - 1} \cdot \ \$10{,}000$$

$$\begin{aligned} \text{Log } 1.04^5 &= 5 \log 1.04 \\ &= 5 \times 0.017033 \\ &= 0.085165 \\ 1.04^5 &= 1.2166 \\ (1+.04)^5 - 1 &= 0.2166 \end{aligned}$$

$$\log S = \log .04 + \log 10{,}000 - \log 0.2166$$
$$= (8.602060 - 10) + 4.0 - (9.335658 - 10)$$
$$= 3.266402$$
$$S = \$1846.27.$$

Interest, annuity, and sinking-fund tables are published and may be seen at almost any bank or money brokers'. The sinking-fund table gives the value of the fractional coefficient in the formula, or the sinking-fund which will amount to 1 in n years. Such a table is printed in Bulletin 136, U. S. Department of Agriculture. Here in the column marked 4 per cent and the limit five years, is found 0.1846271; this multiplied by $10,000 gives the same result as obtained above.

The following tabular statement shows the growth of the fund:

TABLE I

Year	Sinking-fund at Beginning of Year	Interest during Year	Annual Payment into Sinking-fund	Total S. F. End of Year
1	0	0	$1,846.27	$1,846.27
2	$1,846.27	$73.85	1,846.27	3,766.39
3	3,766.39	150.66	1,846.27	5,763.32
4	5,763.32	230.53	1,846.27	7,840.12
5	7,840.12	313.61	1,846.27	10,000.00
	Totals......	$768.65	$9,231.35	

If this loan bore $4\frac{1}{2}$ per cent interest the cost to the borrower would have been $10,000 principal + $2250 interest less $768.65 interest on sinking-fund = $11,481.35; or, Interest on loan $2250 + Sinking-fund payments ($1846.27 × 5) = $11,481.35.

Serial Bonds.—The serial method retires a fixed annual amount of the principal each year. Usually the amount so retired is an aliquot part of the whole. The annual payment, therefore, is the fixed payment of principal plus the interest on the unpaid principal.

Here, if the principal is P, the annual payment is $\frac{P}{n}$, the interest for the kth year is $\left(P+(1-k)\frac{P}{n}\right)i=Pi\left(1+\frac{1-k}{n}\right)$ and the payment for the same year is $P\left(\frac{1}{n}+i\left(1+\frac{1-k}{n}\right)\right)$. The total amount of interest paid up to the end of the kth year is $Pik\left(1+\frac{1-k}{2n}\right)$; and the total amount of interest and principal paid up to the end of the kth year is

$$\frac{Pk}{n}+Pik\left(1+\frac{1-k}{2n}\right)=Pk\left[\frac{1}{n}+i\left(1+\frac{1-k}{2n}\right)\right].$$

By substituting n for k, the grand total of interest, and interest and principal, paid is readily found to be

$$\text{Total interest in } n \text{ years} = \frac{(n+1)i}{2}\cdot P$$

$$\text{Total to discharge debt} = P\left(1+\frac{(n+1)i}{2}\right).$$

The following table shows how a \$10,000 loan at $4\frac{1}{2}$ per cent interest could be paid by five serial payments:

TABLE II

Year	Principle at Beginning of Year	Interest for Year	Principal Repaid at End of Year	Total
1	10,000	\$450	\$2,000	\$2,450
2	8,000	360	2,000	2,360
3	6,000	270	2,000	2,270
4	4,000	180	2,000	2,180
5	2,000	90	2,000	2,090
	Totals.....	\$1,350	\$10,000	\$11,350

Annuity bonds are those wherein a uniform periodic payment will discharge the debt in a given time. The necessary annual payment to discharge a debt P, interest rate i, in n years is given by the formula

$$\text{Annual payment} = \frac{i}{1-\frac{1}{(1+i)^n}} \cdot P = \frac{i}{1-(1+i)^{-n}} \cdot P$$

EXAMPLE

Find the annual payment which will discharge a debt of $10,000 in five equal payments, the rate of interest being $4\frac{1}{2}$ per cent.

Solution:

$$(1+i)^{-n} = 1.045^{-5}$$
$$\text{Log } 1.045 = 0.019116$$
$$-5 \log 1.045 = -0.095580$$
$$= 9.904410-10$$
$$\text{Log}^{-1} (9.904410-10) = 0.802449$$
$$1-.802449 = 0.197551$$
$$\text{Log (Annual payment)} = \log i - \log 0.197551 + \log P$$
$$= \log 0.045 - \log 0.197551 + \log 10{,}000$$
$$= (8.653213-10)-(9.295679-10)+4.000000$$
$$= 3.357534$$
$$\text{Annual payment} = \$2277.916$$

The following table shows the progress of the repayment of the loan of $10,000 by annual payments of $2277.92.

TABLE III

Year	Principal Owing at Beginning of Year	Interest for Year	Principal Repaid at End of Year	Total Payment for Year
1	$10,000.00	$450.00	$1,827.92	$2,277.92
2	8,172.08	367.74	1,910.18	2,277.92
3	6,261.90	281.79	1,996.13	2,277.92
4	4,265.77	191.96	2,085.96	2,277.92
5	2,179.81	98.09	2,179.81	2,277.90
	Totals.....	$1,389.58	$10,000.00	$11,389.58

In making up bonds it is desirable and customary to have them in some number of hundreds and the interest in dollars only. This requires some adjustments from the theoretical amounts. Various adjustments can be made which will keep the annual payments near the theoretical amount. One for the above loan is shown in the following schedule:

TABLE IV

Year	Principal Owing at Beginning of Year	Interest for the Year	Principal Repaid at End of Year	Total Payment for Year
1	$10,000	$450	$1,800	$2,250
2	8,200	369	2,000	2,369
3	6,200	279	2,000	2,279
4	4,200	189	2,000	2,189
5	2,200	99	2,200	2,299
	Totals.....	$1,386	$10,000	$11,386

Comparison.—The total expense of a loan under the sinking-fund plan is usually greatest and under the serial plan least. Table V shows the relative cost for a $100,000 20-year loan.

TABLE V[1]

TOTAL COST OF A $100,000 LOAN FOR 20 YEARS INTEREST COMPOUNDED ANNUALLY

Annual Interest on Bonds	Sinking-fund Bond Compounded Annually at			Annuity Bond	Serial Bond
	3%	$3\frac{1}{2}$%	4%		
4	$154,431	$150,722	$147,163	$147,163	$142,000
$4\frac{1}{2}$	164,431	160,722	157,163	153,752	147,250
5	174,431	170,722	167,163	160,485	152,500
$5\frac{1}{2}$	184,431	180,722	177,163	167,359	157,750
6	194,431	190,722	187,163	174,369	163,000

[1] From Bulletin 136, U. S. Dept. of Agriculture.

Licenses.—Licenses for the operation of vehicles may be classed under the heading of indirect taxation. Many States are adopting this method of raising money for road purposes. Illinois has recently (1919) bonded the State for $60,000,000 to build trunk lines roads the whole of which is to be paid eventually from motor vehicle licenses. In some of the States the license fee is an arbitrary amount placed on all cars alike, in others it is based on the rated horse-power of the car, and in others on the weight of the loaded car. Differentiation in fees are usually made for the several classifications of vehicles and drivers. Motor-cycles are taxed from $2 to $5 per year; a 35-h.p. pleasure car weighing 3000 pounds, for example, from $3 to $35, with an average of about $12; trucks and commercial cars, if light, about the same as pleasure cars, while the heavier ones go as high as $250; chauffeurs and owner operators are in some States also licensed, the fees being from $1 to $5; dealers in most States are taxed, the license fee ranging from $5 to $50.

Administration

Development of Road Systems.—While roads have been built since the earliest history of the world, it is only within comparatively modern times that systematic road systems have been developed. Herodotus speaks of an Egyptian road requiring 100,000 men a period of ten years to build. The Babylonians, the Carthaginians, the Chinese, and even the Peruvians built roads in the dim vistas of the past, many of them magnificent structures, but if they developed any systematic methods of administration, these methods have been lost.

The great Roman roads, of which the Appian Way extending from Rome to Capua, 142 miles long, afterwards lengthened to Brundisium, a total of 360 miles, was perhaps the most famous of the military roads radiating from the capital city. It is said these roads, about thirty, extended throughout the entire empire, which dominated a large part of the then known world. The Roman construction was massive and, notwithstanding they were used for hundreds of years and then neglected after the fall of the empire, many are yet in such a state of preservation that their method of construction, consisting of four successive courses placed upon the prepared subgrade, may be still seen. Under what organization the Romans worked, if known, is of no particular interest at the present day.

During the Dark Ages, road building in Europe fell into desuetude; there was even a premium upon bad roads in places for the robber barons had enacted laws providing that the vehicle, together with its load, which broke down should become the property of the person upon whose land the accident occurred. They also exacted excessive tolls or tariffs for passing over their domains. Even in England, according to Macaulay, the conditions were extremely bad, the roads were not only poor, but highway robbery flourished. A prince of France visiting in England had to have footmen go ahead with lanterns to light the way while others followed with poles to pry the carriage from the numerous mud holes encountered.

In the last quarter of the eighteenth and the first quarter of the nineteenth centuries road building received considerable impetus. This has resulted in fine paved roads throughout France, Great Britain, Switzerland, Germany, and most of the other European countries.

The United States.—While some progress was made during colonial times, it was usual merely to clear away the brush and blaze the trees that the way might be followed by horseback riders. The settlements were mostly near the water—sea, river, or lake, upon which by boat commerce was carried. The York road between New York City and Philadelphia was laid out in 1711. During the French and Indian War some military roads were established across the Allegheny Mountains. George Washington laid out one in 1754, over which passed Colonel Fry's army. In 1755 General Braddock followed approximately the same trail.

Constitutional Provision.—The framers of the Constitution provided for governmental construction and management of post roads. But the government did nothing to that end until the construction of the National or Cumberland road. Mean-while a number of private corporations were chartered by the several States to build turnpikes. These were allowed to exact toll for the privilege of traveling upon them.

The Lancaster Turnpike, which extended from Philadelphia to Lancaster, Pa., is supposed to have been the first macadam road in the United States. It was built in 1792 of stones of all sizes thrown together and covered with earth. Later it was reconstructed of stones none of which would not pass a 2-inch ring. Many other toll roads adopted this system. By 1811 317 turnpikes had been chartered in New York and the New England States, being about 4500 miles of road with a combined capital of $7,500,000. By 1828 there had been 3110 miles of chartered turnpike in Pennsylvania completed at a cost of over $8,000,000.

The Cumberland Road.—Congress appropriated $30,000 which on March 29, 1806, was approved by President Thomas Jefferson, to be used for the survey and construction of a road leading from a point on the Potomac at or near Cumberland to the Ohio River at or near the town of Steubenville. This measure was sponsored by such men as Henry Clay and Albert Gallatin. It provided that the road be cleared for a width of 4 rods, and that no grade exceed 5%. In 1820 $10,000 was appropriated by Act of Congress to lay out a road from Wheeling, Va., to the Mississippi River near St. Louis. This was a continuation of the Cumberland or National Road, and was laid out 80 feet wide. Appropriations were made from time to time for this highway, the last direct appropriation being made for a portion west of the Ohio, May 25, 1838. The total appropriations amounted to $6,824,919.33. The money came largely from the sale of public land. From 1835 to 1850, little by little the government gave over the management of the road to local turnpike companies. At the present time it has practically all been taken into the State highway systems. This ambitious road-building project by the nation ended, after the advent of the steam railway, upon the prairies of Illinois. It had been surfaced to Columbus and west of there in places. Had it not been for the phenomenal growth of the railways and their ability to transport goods and passengers quicker and cheaper than the highways there is no doubt but what large systems of the latter covering the entire settled portion of the country would have been developed.

Later Developments.—The United States government has since done little in actual road-building. Some roads have been constructed in the island possessions and some in the national parks and forest reserves. The Federal Aid Road Bill became a law on July 11, 1916. By this law the sum of $85,000,000 is made available for the construction of rural roads in the United States. The sum of $75,000,000 is to be expended for the construction of rural post roads under co-operative arrangements with the highway departments of the various States, and $10,000,000 is to be expended for roads and trails within or partly within the national forests. The act limits the Federal Government's share in road work in co-operation with the states to 50 per cent of the estimated cost of construction. Federal aid is extended to the construction of rural post roads, excluding all streets or roads in towns having a population of 2500 or more, except the portion of such streets or towns in which the houses are on an average, more than 200 feet apart. Five million dollars is made available for expenditure during the fiscal year ending June 30, 1917, and thereafter the appropriation is increased at the rate of $5,000,000 a year until 1921, when the sum provided is $25,000,000, making a total of $75,000,000. In addition an appropriation of $1,000,000 a year for ten years makes up that part to be devoted to roads within the forest reserves.

The act provides that after making necessary deductions for administering its provisions in not to exceed 3 per cent of the appropriations for any one fiscal year—the Secretary of Agriculture shall apportion the remainder of each year's appropriation in the following manner:

One-third in the ratio which the area of each State bears to the total area of all the States.

One-third in the ratio which the population of each State bears to the total population of all the States.

One-third in the ratio which the mileage of rural delivery routes and star-routes in each State bears to the total mileage of rural delivery routes and star-routes in all the States.

The Secretary of Agriculture promulgated rules and regulations [1] for carrying out the act which provide for a very close supervision by the Office of Public Roads and Rural Engineering for the expenditure of the money. Any State, county or district making application for aid must present a "Project Statement" to enable the Secretary to ascertain (*a*) whether the project conforms to the requirement of the Act; (*b*) whether adequate funds, or their equivalent, are or will be available by or on behalf of the State for construction; (*c*) what purpose the project will serve and how it correlates with the other highway work of the State; (*d*) the administrative control of, and responsibility for, the project; (*e*) the practicability and economy of the project from an engineering and construction standpoint; (*f*) the adequacy of the plans and provisions for maintenance of roads; and (*g*) the approximate amount of Federal aid desired." Forms of contract together with all documents referred to in them must also be submitted. Projects are to be recommended in the order of their application. Rules are also established for plans, sketches, maps, estimates, and other things. It also provides that the materials should be tested before use, that no part of the right of way shall be paid for by government funds, that complete records and cost data shall be kept, and the method of payments is specified.

State Aid

The State aid principle has been in use in Europe for upwards of a century but was first adopted in the United States in 1891. At a mass-meeting of farmers and others interested in roads called by the State Board of Agriculture of New Jersey, in 1887, a committee was appointed to examine the laws of their own State, of other States and foreign countries, and report

[1] Rules and Regulations for Carrying out the Federal Aid Road Act, Circular No. 65, U. S. Dept. of Agriculture.

such amendments as in their judgment would best serve the interests of the commonwealth. The committee held meetings and studied many laws; after careful consideration, they recommended the abolishment of the office of road-overseer. As a result the board of agriculture had a bill prepared and presented in the State legislature of 1888 to that effect. Through the influence of the overseers this bill was defeated; it was again introduced in 1889 and again defeated; and met with a similar fate in 1890. But in 1891 its friends succeeded in securing its passage. The plan of placing the roads under the township committees proved so successful that the opposition was not only unable to effect its repeal, although a trial was made, but the State went farther in the line of centralization by entering upon an entirely new departure. This new law, passed in 1891 and made operative in 1892, is what is commonly called the State Aid Law, a law which has influenced legislation in nearly all the States of the Union. The following quotation from the first state aid law gives the salient features:

> That whenever there shall be presented to the board of chosen free holders of any county a petition signed by the owners of at least two-thirds of the land . . . fronting on any public road . . . praying the board to cause such to be improved and setting forth that they are willing the peculiar benefits conferred . . . shall be assessed thereon in proportion to the benefits conferred to an amount not exceeding 10 per centum of the entire cost of improvement . . . it shall be the duty of the board to cause such improvements to be made . . . That one-third of the cost of all roads constructed under this act shall be paid for out of the state treasury.

Under this first act the abutting property holders paid one-tenth the cost, the State one-third and the county the remaining $56\frac{2}{3}$ per cent. The friends of the law demanded its enforcement, the opponents as strenuously objected and carried the matter into the courts, but the law was upheld. A few changes only have been made in the law, these tending to its more efficient administration, the most important being the authorization of a State highway commissioner.

In 1893 Massachusetts adopted a similar law. Under this law the State bears 75 per cent and the county 25 per cent of the cost of improvement. In 1895 Connecticut adopted the State aid principle, and New York in 1898. Without mentioning further dates it may be said that the State aid principle in some one of its various forms is in operation in nearly all the States in the Union. A great many States supply cash aid in varying amounts, others supply engineering services, plans, specifications, or give aid in the use of convicts.

State Highway Departments

While the details of carrying out State aid differ with different States, all have State highway departments. Some consist of a single salaried commissioner, or engineer, appointed by the governor, or elected by the people; others an unsalaried commission either appointed or ex-officio heads of departments of State or State educational institutions; and in others a salaried commission of three or more persons appointed or elected. A centralized administration makes for efficiency. Authority for doing things is placed upon one, or at the most, a few persons. There is no chance to escape responsibility. Systematic organization is likewise essential for best results. Every under officer down to road caretaker should know exactly what is expected of him and how far his authority extends.

Powers.—State highway departments are usually empowered to map the various soil areas of the State, to study the character of each for road purposes, to devise means of construction and maintenance best adapted to the different soils, to determine whether or not a mixture of soils from different areas would be advantageous, to seek out and test gravel, stone, and other materials available to the several portions of the State and to publish the results of the investigations. In some States the department furnishes uniform or standard plans for road construction, maintenance, culverts, bridges, guard rails, railroad crossings, etc. This makes it possible to compare unit costs, a thing highly desirable, and to prevent overcharge and scandal.

State Highway Laws

While each of the several States has its own peculiar problems and laws, space will not permit of separate treatment. The tendency seems to be toward a classification of highways into main and less traveled roads. The main roads may be denominated "State" highways in contradistinction to "county" and "township" for those less traveled. In order that the main traveled roads may be combined into a comprehensive system so connecting the various parts of the State that lines of travel may be as direct as is consistent with other conditions, it is the duty of the State to provide for some centralized authority over the main traveled roads, leaving to local control those of less importance. This idea has led to the formation of highway commissions and more or less complete and complex organizations under them.

State Highway Commissions.—In a number of the States the highway commission consists of a single person, in others of several persons forming a board of commissioners. In at least one State the highway commissioner is elected by the voters "in the same manner as justices of the supreme court." In many States the commissioners are appointed by the governor, with or without the consent of the Senate. In others the commission is made up ex-officio of other State officers, of specified members of the faculty of the State university, or of both combined.

While there are arguments favoring centralizing authority for the sake of efficiency in a single person, local conditions may make this inconvenient, and where considerable money is being handled it is usually more satisfactory if two or more persons are made responsible for its management. However, good work is being done under all these forms of organization.

State Highway Engineer.—Where there is a board of commissioners, they usually deal personally only with matters of general policy, leaving the details to a State highway engineer, who, in some States is appointed for a specified term, in others holds office at the pleasure of the commission.

Typical Laws for the Formation of Highway Departments, quoted from the statutes of two States, illustrate the one-person commission and the multiple-person commissions.

From the Ohio Laws:

The State highway commissioner shall have general supervision of the construction, improvement, maintenance and repair of all inter-county highways and main market roads, and the bridges and culverts thereon. He shall aid the county commissioners in establishing, creating and preparing suitable systems of drainage for highways, and advise with them as to the construction, improvement, maintenance and repair of highways; and he shall approve the design, construction, maintenance and repair of all bridges, including superstructure and substructure, and culverts or other improvements on inter-county or main market roads; and in the case of bridges and culverts on other roads, when the estimated cost thereof exceeds $10,000, the plans therefor shall be submitted to and approved by him, before contracts are let therefor. He shall cause plans, specifications and estimates to be prepared for the construction, maintenance or repair of bridges and culverts when so requested by the authorities having charge thereof, and he shall cause to be made surveys, plats, profiles, specifications and estimates for improvements whether upon State, county or township roads. He shall make inquiry in regard to systems of road and bridge construction and maintenance whenever he may deem it advisable, and conduct investigations and experiments with reference thereto, and make all examinations, in his opinion, advisable, as to materials for road construction or improvement.

From the North Carolina laws:

The State highway commission shall consist of the governor, three citizens of the State of North Carolina to be appointed by the governor, one from the eastern, one from the central, and one from the western portion of the State, one of whom shall be a member of the minority political party, the State geologist, a professor of civil engineering of the University of North Carolina and a professor of the North Carolina Agricultural and Mechanical College, said professors to be designated by the governor. The members of the commission shall be appointed and serve for four years, and until their successors are appointed; the members of the commission shall, when employed in any manner required of them under this act, receive their actual expenses. The governor shall fill all vacancies in the commission caused by death or otherwise, and he shall have the power to remove any member for due cause.

Duties of Highway Departments.—From a review of the legislation concerning State highway departments by R. Walton Moore is taken the following: [1]

Miscellaneous Duties. (*a*) Lease offices; (*b*) purchase furniture and office and engineering supplies; (*c*) engage assistants, employ skilled and unskilled labor, and utilize convicts and prisoners; (*d*) maintain facilities for testing materials used in road and bridge construction, and investigate sources and properties of such materials; (*e*) issue permits for occupation of State and State-aid roads by trucks, pole lines, conduits and other structures; (*f*) collect automobile fees and issue regulations governing the use of vehicles on public roads; (*g*) issue regulations for use of State and State-aid roads by traction engines, motor omnibuses and trucks; (*h*) institute suitable legal proceedings to stop violations of highway and bridge statutes; (*i*) conduct investigations and collect statistics of traffic; (*j*) keep detailed records of the expenditure of all State road and highway bridge funds; (*k*) give names to through routes and mark them or permit them to be marked by colors and signs; (*l*) to acquire toll roads, bridges and ferries.

Educational Duties. (*a*) Collect information relating to roads and highway bridges in the State; (*b*) investigate the suitability of different types of road and bridge construction for use in the State; (*c*) hold public meetings to explain the desirability of road and bridge improvements; (*d*) hold meetings with county and township road officials to discuss the improvement and maintenance of roads and bridges; (*e*) publish annual reports of the department's work and bulletins on subjects relating to the construction and maintenance of roads and bridges; (*f*) notify local officials of road and bridge work which is being done in a wasteful manner, and if the wasteful methods are continued report them to the governor; (*g*) prepare standard plans and specifications for roads and bridges.

State Road Duties.—(*a*) Determine the main roads of the State and prepare maps of them; (*b*) designate the order in which main roads shall be improved with State funds; (*c*) acquire rights of way by contract or condemnation proceedings; (*d*) prepare plans and specifications for roads and bridges built by State-aid and supervise their construction; (*e*) make contracts for State road and bridge improvements and maintenance; (*f*) carry on construction and maintenance of State roads and bridges with day labor, both free and convict; (*g*) buy or hire machinery, tools, materials, teams and supplies needed in carrying the work of the department.

Co-operative Duties.—(*a*) Prepare or aid in preparing plans for road or bridge improvements by local officials; (*b*) supervise or assist in supervising construction and maintenance of roads under local officials; (*c*)

[1] "Review of Legislation Concerning State Highway Departments," by R. Walton Moore, published by the American Highway Association, 1916, Washington, D. C.

apportion among the counties or other subdivisions State funds for co-operative road and bridge work; (*d*) act with local authorities in designating road and bridge work on which State funds shall be spent; (*e*) approve contracts for road and bridge work made by local officials; (*f*) hold competitive examinations for positions of county highway superintendents or engineers to furnish lists of capable men from which counties must select such officials; (*g*) approve plans for road and bridge improvements submitted by local officials; (*h*) determine when State-aid roads are improperly maintained, in case the law prohibits further State aid to counties where State-aid roads are not kept in satifactory condition by the counties; (*i*) inspect annually all bridges exceeding 30 feet in length and advise local authorities of their condition; (*j*) prepare and distribute directions and forms for accounting for local road funds and recording all official actions of local road authorities.

These cover compactly the duties delegated to the highway departments in the United States. Perhaps no one State would burden its department with all of them but only with such as are appropriate to the local conditions in that State.

Organization Charts.—An organization chart is a graphical representation of the total business into its component parts and is built up somewhat after the manner of a genealogical tree. A complete chart indicates exactly through whom authority reaches from the head to the lowest subordinate, and each person knows to whom he shall look for instructions and to whom he in turn shall give instructions. It assists in avoiding conflicts of authority or the short-circuiting of orders. The making of such a chart in itself is a long step toward systematizing the work of a department, and system means efficiency and economy.

Each State highway department will work out its own chart compatible with its own needs and limitations. A few such charts are given as examples, pp. 351–354.

County and Township Organization

County and township road organization varies so greatly in the several States that it is not possible to generalize with any degree of accuracy. In many States the local road administration is under a county board of supervisors or commis-

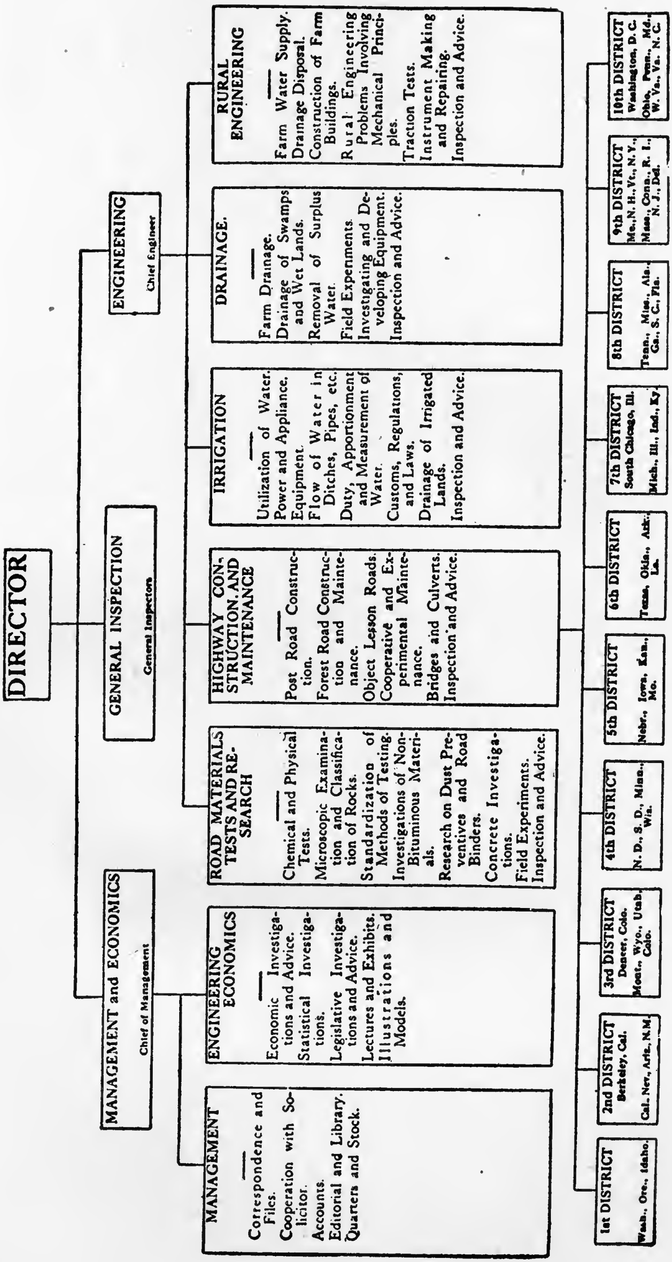


FIG. 170.—Chart of Organization of U. S. Office of Public Roads and Rural Engineering, 1917

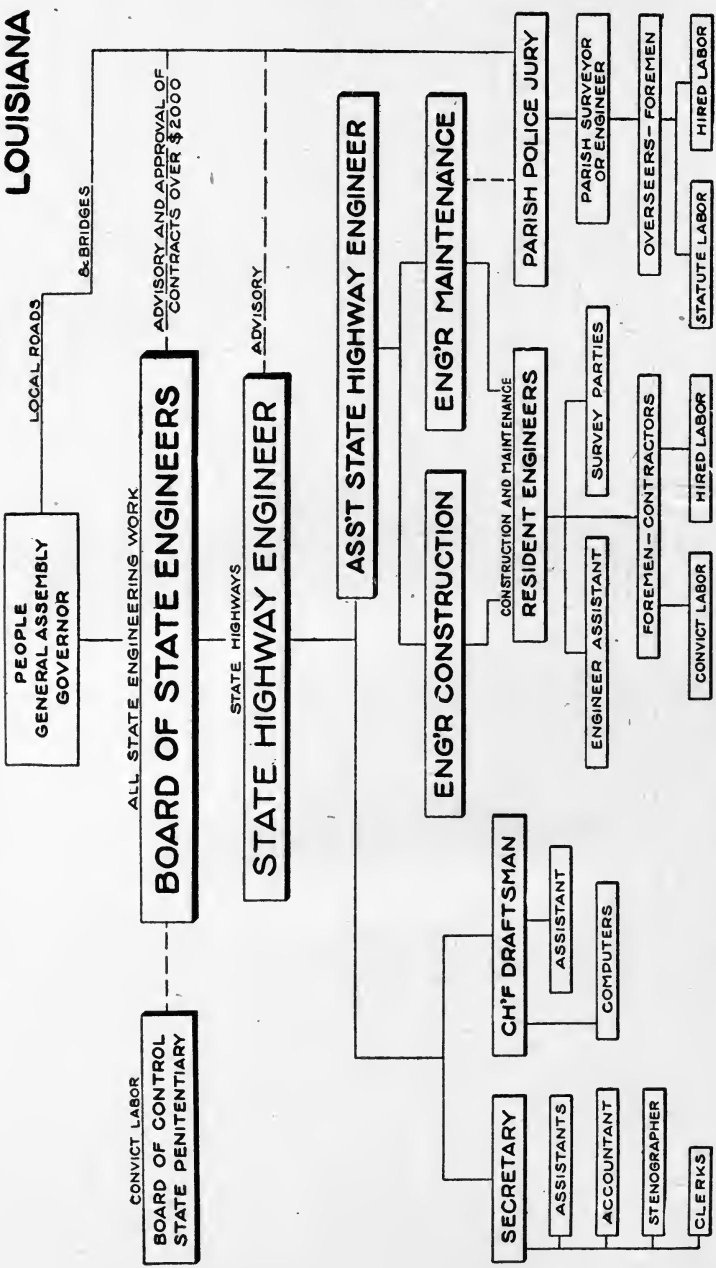


FIG. 171.—Organization Chart of the Louisiana Highway Department

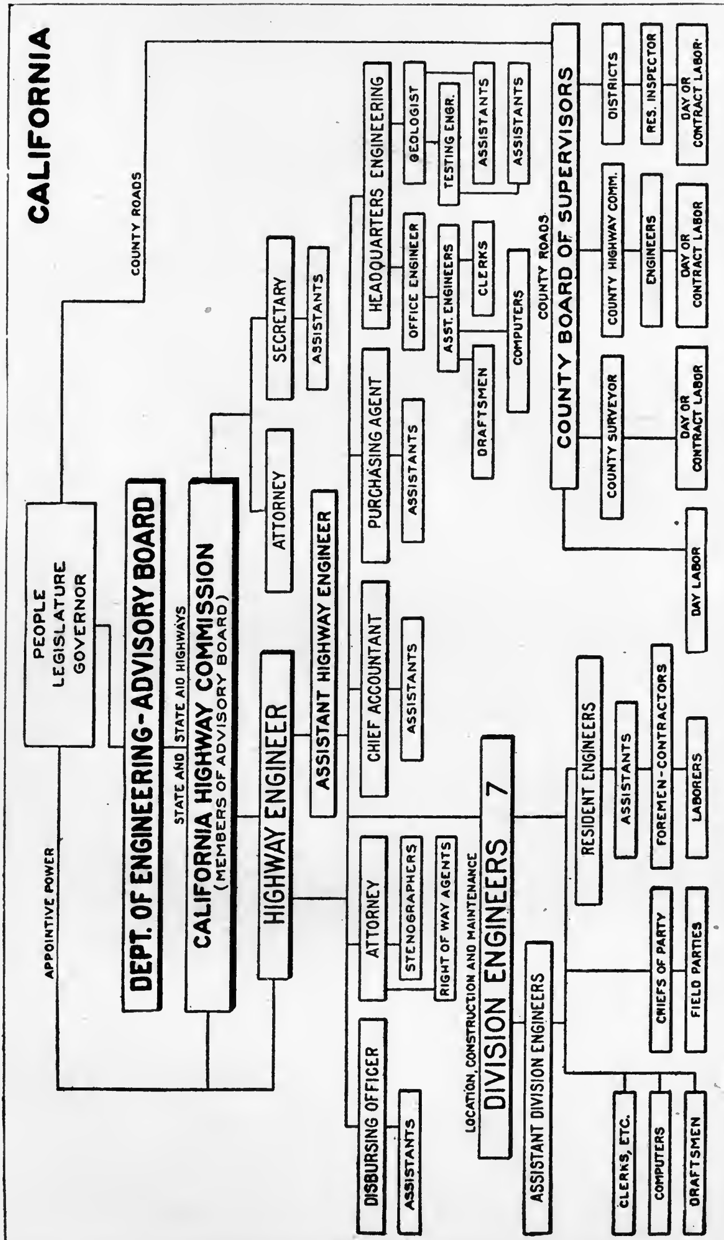


FIG. 172.—Organization Chart of the California Highway Commission

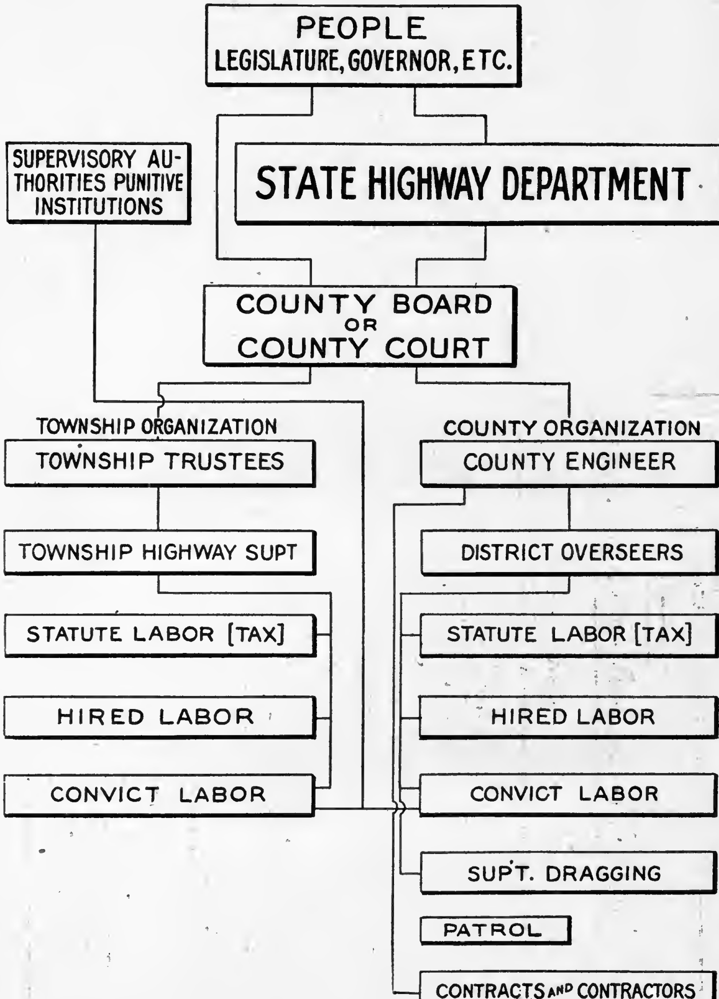


FIG. 173.—Typical Township and County Organization

sioners, or under the direction of the county court. In other States there is a smaller unit, the township, with township trustees. The county, or the township, is also sometimes divided into road districts and an overseer appointed or elected to look after the roads of the district. In extreme cases the road districts are independent units and have power to levy taxes on the property of the district. In other States a more comprehensive organization is effected in which practically all roads are under the supervision of the State highway department, or of the State and county officers jointly.

The tendency seems to be toward centralized organization, certain roads being designated "State highways" and their construction, and sometimes maintenance, given over to the State department. These roads share in the State aid money received from taxation, automobile licenses or Federal appropriations. Other roads are designated as county roads and left under the supervision of the county officers. Many States have laws requiring the selection of a county engineer (or a county surveyor who shall be county road superintendent) and to him is given the selection and charge, to a greater or less degree, of the minor road officers. The county engineer usually reports to the county board and to the State highway department. A typical organization chart for township and county organizations is given on page 354.

CHAPTER XVI

MISCELLANEOUS

Road Signs and Emblems.—Some States are systematically laying out, mapping and marking their main or trunk line roads, both as a convenience in filing records in the office and as an aid to travelers. Fig. 174 (*c*) shows the authentic mark adopted by Wisconsin. Smaller units, such as counties, are

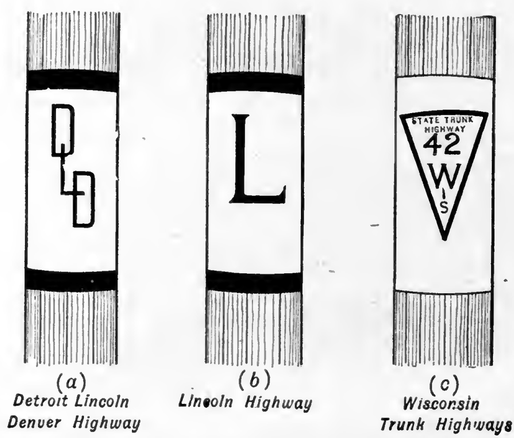


FIG. 174.—Typical Telephone Pole Road Markers.

likewise marking their roads. Fig. 175 shows a form of concrete sign adopted by Lancaster county, Nebraska, designed by county engineer A. H. Edgren. Fig. 176 gives the details of construction. Reversed letter patterns are attached to the inside of the form so that when the form is removed the letters are sunk into the concrete. The surface coating of the sign is made of white cement and white sand plastered on the inside of the form before the ordinary concrete of the interior is placed.

Fig. 175.—Edgren's Concrete Sign Post.

The letters are painted black with a waterproof paint. Other designs of markers are shown in Figs. 176 to 179.

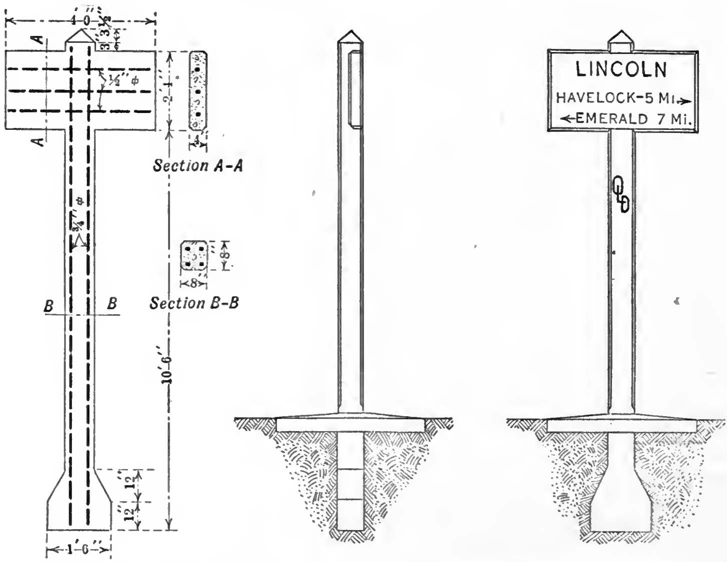


Fig. 176.—Standard Concrete Road Markers, Lancaster Co., Nebraska.

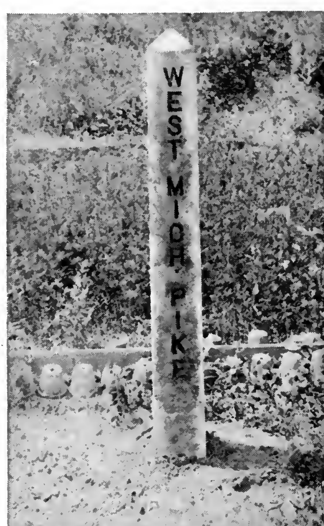
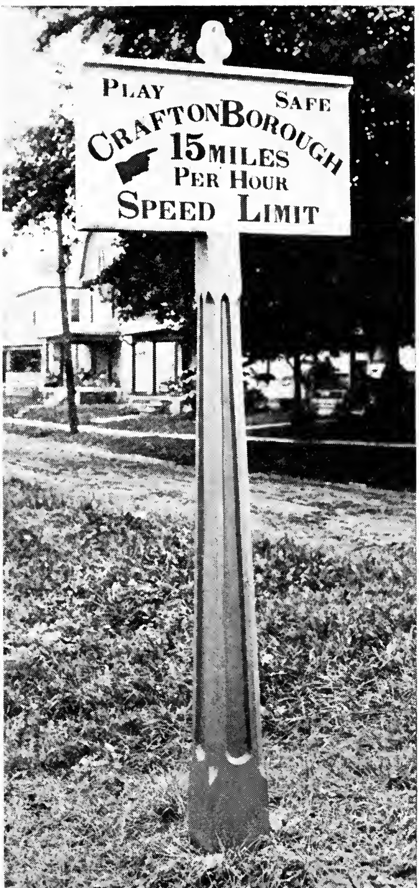


Fig. 177.—A Simple Concrete Road Marker.

Volunteer road organizations have marked long, even transcontinental routes across the country. Individual routes are



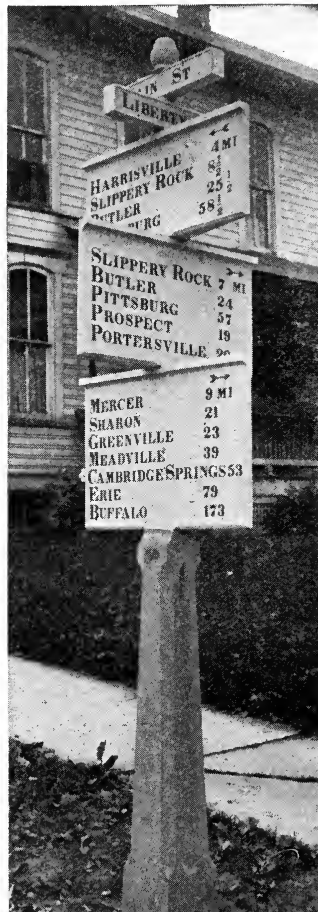


FIG. 178. FIG. 179.

Concrete Sign Posts

usually marked by an emblem or insignia. Many States now provide for the registering of these emblems and protect the route in the use of them. The route emblem or mark is conveniently placed upon the telephone poles along the road so that the tourist though a stranger can readily follow the way. Fig. 174 shows such emblems.

Sign posts are also placed at crossroads to direct to particular localities. Steel boards with the letters pressed into them or spot welded upon them, or made by drilling holes through them are now manufactured and placed upon the market. The steel board has the advantage over wood of being not only durable, but less liable to injury by the vandalic

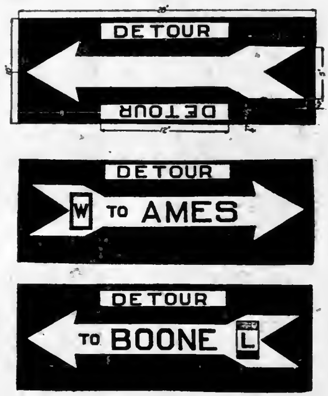


Fig. 180.—Iowa State Detour Signs.

sportsman's shotgun. Warning signs of dangerous crossings and bridges, nearness to schools and hospitals, of impassable roads ahead, and markers calling attention to points of historical or scenic interest along the route are also furnished and set up, both by public and private means.

Detour Signs.—Roads must frequently be closed to travel on account of construction, repairs, maintenance, washouts, and obstructions of various kinds. At such times the traveling public is entitled to notice and directions how to avoid the impediment with the least delay. The Iowa State Highway Commission has adopted standard directions for such signs stating distinctly upon whom the responsibility for their setting up and maintenance rests and the fund from which the expenses must be paid. Upon primary (State) roads the district engineer, and upon county roads the county engineer will be held accountable for the following:

First.—He shall determine whether or not a detour is needed.

Second.—He shall co-operate with the local officials in choosing a detour.

Third.—He shall provide for the proper marking of the detour.

Fourth.—He shall provide for the maintenance of the detour and report such provision to the central office.

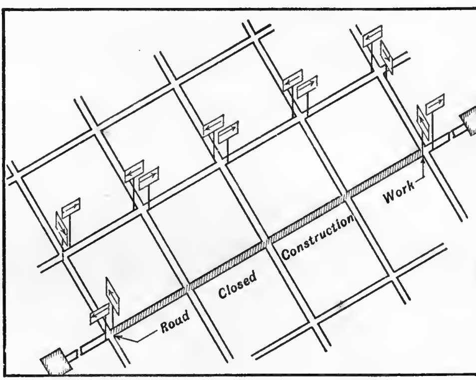


FIG. 181.—Typical Arrangement of Detour Signs

Since great care should be exercised in selecting the best possible detour engineers are always to consult with county boards.

Placing the Signs.—The signs are placed, Fig. 181, on the right-hand side of the road at the far side of the intersection; the arrow will point away from the intersection and give a positive direction. In order that the signs may be made up in quantities, the word "Detour" is printed in both directions, Fig. 180. The one which is upside down after the sign is placed is to be painted out. The names of the towns may be painted or stenciled in if desired. A substantial barricade with the word "Closed" is placed across the road, also a "slow down" sign some 300 feet away on the right-hand side of the roadway.

Road Maintenance Competition

Score Card for Road Maintenance Contests.—In some places a friendly rivalry has been established for the maintenance of rural roads. The score card below is one devised by Professor L. W. Chase for use in Fillmore County, Nebraska; it gives also the score and rank of several roads for the season of 1916.

SCORE CARD FOR FILLMORE COUNTY ROADS

Overseer's Name	Elements Given Consideration								
	Surface	Width	Crown	Gutters	Distribution of Traffic	Drainage	Parking	Total	Rank
Perfect score......	20	20	20	15	10	10	5	100	
Hansen, Henry....	16	10	20	14	8	9	4	81	1st
Klatt, John.......	15	20	15	13	5	8	4	80	2d
Kieser, C. H......	17	20	15	10	8	7	2	79	3d
	19	20	15	7	10	5	2	78	4th
	18	18	8	2	8	2	5	61	5th
	17	0	5	0	0	0	5	27	6th
Government Road.	20	18	20	12	10	9	1	90	

Fig. 182.—Score Card for Road Competition

Rating Local Road Superintendents.—A variation of the above as a means to promote competition among road superintendents is used by W. G. Tonkel, county highway superintendent of Allen county, Indiana. The blank form used by Mr. Tonkel, Fig. 183, is self explanatory.

Race Tracks

The shape of race tracks have been standardized by the various organizations using them. The county agricultural societies generally have a half-mile track, while State societies and other more ambitious organizations have mile tracks.

DISTRICTS	
1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24. 25. 26. 27. 28. 29. 30. 31. 32. 33.	**Grading of Road Superintendents of Allen County, Indiana** The four leading elements considered in maintaining County Highways are: No. 1. Grading, Dragging 25% No. 2. Crown and Bermes of Road - - 25% No. 3. Ditches, Drainage 25% No. 4. Management of District - - 25% 100%

1			
2			
3			
4			
TOTAL			

Date .... 19......

District No. ....

Supt. ....

Graded by ....

Remarks ....

FIG. 183.—Blank Used in Grading Work of District Road Superintendent.

Since the advent of the motor car still longer tracks are being constructed.

The surface of the ordinary track is earth. Horsemen

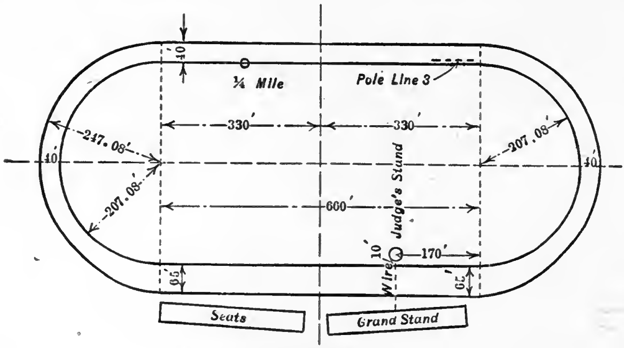


FIG. 184.

prefer a sandy loam containing considerable humus in the form of fine rootlets. This gives resiliency, thus making a "fast"

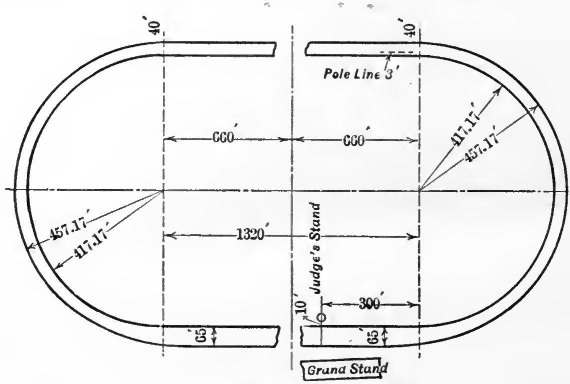


FIG. 185.—Standard Mile Track.

The width is not standardized. The length is measured on the pole line 3 ft. outside of the inner edge.

track. After a track has been used for many years and maintained by dragging, the surface becomes thoroughly puddled, hard and unyielding; it is then said to be "dead" and is cured by removing the surface and replacing it with fresh field loam. That immediately under the top sod in a clover field is recommended.

For automobile tracks the surface is best when hard and smooth. Such tracks are often surfaced with plank, concrete,

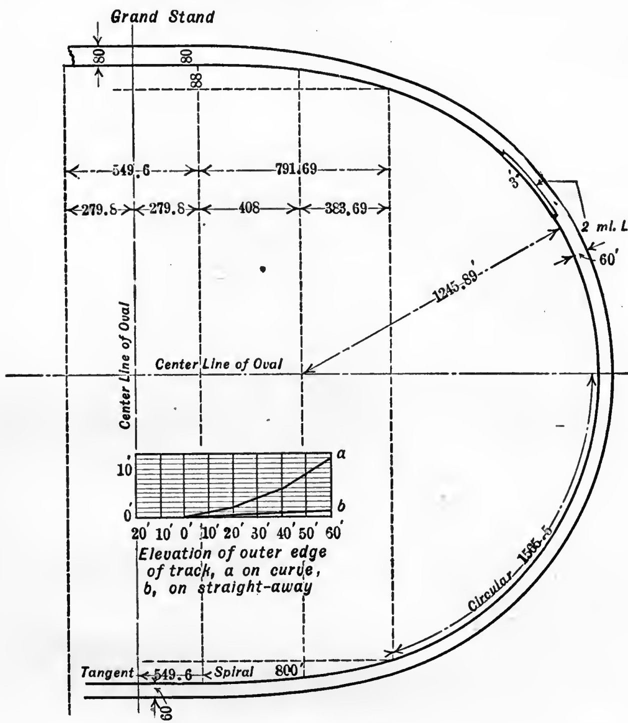


FIG. 186.—Two Mile Speed-way, Minneapolis–St. Paul, Minn.

or brick, and are banked or inclined toward the center of the curves much more than are horse tracks.

The design of standard tracks is such that one-half the distance is on the curve and one-half along the straight-away. The length of the track is measured along the pole line which is 3 feet from the inner fence. Plans of race tracks are shown in Figs. 184, 185, 186.

INDEX

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