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PORTLAND CEMENT CONCRETE ROADS.

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CONTENTS.

INTRODUCTION.

The purpose of this bulletin is to supply reliable information on the subject of concrete pavements for the use of highway engineers and others interested in the improvement of public roads. The methods of construction described are believed to represent the best practice at this time; but, as experience and research are continually suggesting improvements, those who have charge of concrete-road con-

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struction should be careful to keep themselves informed regarding results obtained by others engaged in similar work, and by laboratory experiments.

The earliest concrete pavement in the United States of which there is reliable record was constructed at Bellefontaine, Ohio, in 1893 and 1894. This pavement, which contains 4,400 square yards, was constructed in two courses and in squares similar to those employed in concrete-sidewalk construction. Prior to 1909 the total area of concrete pavements was comparatively small, and in most cases these pavements were frankly regarded as experiments. During 1909 the road officials of several communities concluded that the results already obtained were sufficiently encouraging to warrant them in undertaking the construction of concrete pavements on a larger scale, and since that time a large mileage has been completed. Wayne County, Mich., was one of the first communities to adopt this form of construction, and at present probably has a greater mileage of roads paved with concrete than any other county in the United States.

The majority of the concrete pavements which have been constructed have proved entirely satisfactory where traffic conditions were not unduly severe, and their use has increased rapidly. This is evidenced by the following tabulation, showing the approximate number of square yards of such pavements that have been placed under contract in the United States each year beginning with 1909, and the total constructed prior to 1909:

Concrete pavement constructed or under contract in the United States.

Year.	Roads.	Streets.	Alleys.	Totals.
	Sq. Yds.	*Sq. Yds.*	*Sq. Yds.*	*Sq. Yds.*
Prior to 1909	34, 061	444, 864	112, 491	591, 416
1909	32, 626	325, 158	86, 825	444, 609
1910	151, 148	682, 637	107, 874	941, 659
1911	291, 077	1, 011, 440	136, 674	1, 439, 191
1912	1, 869, 486	3, 326, 029	185, 703	5, 381, 218
1913	3, 339, 185	3, 946, 219	308. 365	7, 593, 769
1914	10, 608, 421	4, 830, 604	300, 138	15, 739, 163
1915	12, 050, 909	5, 933, 879	612, 921	18, 575, 709
1916	15, 906, 801	7, 395, 975	880, 179	24, 182, 955
1917	15, 333, 087	5, 238, 062	1, 200, 030	21, 771, 179
1918	12, 990, 519	3, 295, 817	585, 948	16, 872, 284
1919	41, 335, 342	11, 086, 419	1, 038, 173	53, 459, 934
1920	29, 326, 689	8, 814, 782	907, 164	39, 048, 635
Total to Jan. 1, 1921	143, 269, 351	56, 331, 885	6, 465, 485	206, 063, 721

The principal advantages which concrete pavements possess may be briefly stated and commented upon as follows:

1. As far as can be judged, they are durable under ordinary suburban and rural traffic conditions.

2. They present a smooth, even surface, which offers very little resistance to traffic.
3. They are practically dustless and may be easily cleaned.
4. They may be maintained at comparatively small cost.
5. They may be made to serve as a base for some other type of surface when resurfacing becomes necessary.

The principal disadvantages are:

1. They are somewhat noisy under steel-tired traffic.
2. They are subject to cracking, and wherever a crack develops it must be given frequent attention in order to prevent deterioration of the pavement.
3. On account of the sharp line of separation between the pavement and the shoulders and the marked difference in hardness, an abrupt and dangerous depression is sometimes formed at the edge of the pavement which reduces the effective width of the roadway.

A finished concrete road is shown in Figure 1, Plate X.

MATERIALS USED IN CONCRETE ROADS.

Concrete consists of a mixture of water, cement, sand, and gravel or stone or other similar materials. It is customary to refer to the sand as the fine aggregate, and to the gravel or stone as the coarse aggregate. Durable, clean, well-graded aggregates are absolutely essential to the success of a concrete pavement. Mixed aggregates, such as bank-run gravel or crusher-run stone, should not be used except under rigid laboratory control. For a successful concrete pavement, each of the different aggregates should be properly graded and kept clean and separate until proportioned to place in the mixer.

CEMENT.

Portland cement of a character satisfactory for use in pavement construction is at present manufactured in nearly every section of the country. The product of all cement plants is not always entirely uniform and of equal excellence, and even if it were uniform immediately after manufacture this condition might easily be changed by age or exposure. These facts make it imperative that cement for use in concrete pavements be subjected to very rigid tests. It should meet the requirements of the specification for Portland cement contained in Circular 33 of the United States Bureau of Standards and also issued by the American Society for Testing Materials, and accepted generally as the standard specification.

FINE AGGREGATE.

Sand is almost universally used as a fine aggregate for concrete pavements. In exceptional cases stone screenings have been used, but the use of screenings is not recommended, as the presence of dust in the screenings makes the proper mixing rather difficult and reduces the strength of the concrete, unless the time of mixing is considerably increased. Sand for use in concrete pavements should be selected with especial care. The strength of the mortar depends largely upon the quality of the sand and a strong mortar is imperative if the best results are to be obtained. Preference should be given to sand composed of a mixture of coarse and fine grains, with the coarse grains predominating, though sand consisting entirely of coarse grains is preferable to that in which the fine grains predominate. Sand which contains more than 3 per cent of foreign materials, such as clay or silt, or the grains of which are coated with clay or other objectionable material, should not be used. Sand which contains even a small percentage of organic impurities is unsuitable because the presence of such impurities seriously affects the strength of the concrete. The presence of these impurities can not be detected by the eye but may be readily detected by means of the recently developed colorimetric test,[1] which is suitable for use in the field. In order that the mortar may develop the necessary strength, it is usually specified that mortar made from the sand proposed for use in the concrete pavement shall develop a tensile or compressive strength equal to that developed by mortar made of the same cement and standard Ottawa sand when mixed in the same proportions and tested at the same age.

It is generally specified that fine aggregate for concrete pavements shall consist of particles smaller than one-quarter inch in size. A well graded fine aggregate should meet the following requirements:

	Per cent.
Passing a ¼-inch screen	100
Passing a ¼-inch screen and retained on a standard No. 10 sieve	5–25
Passing a standard No. 10 sieve and retained on a standard No. 50 sieve	50–90
Passing a standard No. 100 sieve, not more than	10
Weight removed by elutriation, not more than	3

COARSE AGGREGATE.

Coarse aggregate for concrete pavements usually consists of gravel or crushed stone, although occasionally blast-furnace slag is used. The choice between these materials depends largely upon local conditions. Satisfactory concrete pavements have been constructed with each, but so far as cracks are concerned limestone appears to have made a better record than gravel or any other variety of stone which has been used to any considerable extent.

[1] For a description of this test see U. S. Department of Agriculture Bulletin 949, Standard and Tentative Methods of Sampling and Testing Highway Materials.

The coarse aggregate, whether crushed stone, gravel, or slag, should possess at least as great resistance to wear as the mortar which fills the voids of the aggregate. Any sound stone or gravel, moderately hard and tough, will meet this requirement, but in general the harder and tougher the coarse aggregate, the greater will be the resistance to wear offered by the concrete. The best available stone should always be used.

The difficulties experienced in securing coarse aggregate of satisfactory quality are frequently caused by a lack of proper facilities for preparing the natural materials available. Very few gravel pits furnish a gravel suitable for use in concrete pavements without washing; and properly equipped washing plants are both difficult and expensive to construct. On the other hand, a great many stone quarries contain pockets of clay or inferior stone which should not be permitted in the aggregate, and it is sometimes very difficult to remove the objectionable materials while the stone is being crushed and screened. It is also frequently difficult to screen out the dust formed in crushing some varieties of stone. These difficulties can be largely overcome by obtaining the coarse aggregate from commercial sources that are properly equipped to supply clean, well-graded aggregates.

The coarse aggregate should be free from shale, slate, coal, ocher, or other materials which easily disintegrate and should meet the following requirements:

Stone: French coefficient of wear, not less than 7.

Gravel: When subjected to the abrasion test as described in Bulletin 555, United States Department of Agriculture, page 30, the loss by abrasion should not be more than 12 per cent.

Slag: The slag should be an approved blast-furnace product, weighing not less than 80 pounds per cubic foot.

A well-graded coarse aggregate is necessary in order that the percentage of voids may be as small as practicable. The grading of the coarse aggregate is usually accomplished by specifying the various percentages of material which will pass or be retained on screens with circular openings of different sizes. The maximum size of aggregate used varies according to the practice of various States and the character of materials available. The maximum size most commonly specified is 2½ inches. A well-graded coarse aggregate should meet the following requirements:

	Per cent.
Passing 2-inch screen	100
Passing a 2-inch screen and retained on a 1-inch screen	25–60
Passing ¼-inch screen, not more than	10

WATER.

Water used in mixing concrete should be practically free from oil, acid, alkali, or organic matter and reasonably clear. Brackish water and water carrying sewage or manufacturing wastes should not be used until tests have shown that it will not impair the strength of the concrete. For a description of a test to determine the quality of water, see United States Department of Agriculture Bulletin 949.

REINFORCEMENT.

Wire mesh, expanded metal, or steel rods may be used to reinforce the pavement. In any case the reinforcement should be reasonably free from rust, or other coatings, and should be so handled prior to use that it will not be coated with mud or clay when placed in the pavement.

PROPORTIONING.

The physical characteristics of the concrete are determined not only by the quality of the several materials which enter into it, but also, and perhaps to a greater degree, by the proportions in which the materials are mixed, especially by the amount of water used. A number of theories are offered concerning the proportions required to produce strong and economical concrete. All are based on experimental data, but at present no particular one is generally accepted, and a great deal of investigation is being carried on in the attempt to evolve a theory which will be generally acceptable.

The theory most generally accepted in the past is called the maximum density theory[2] and is based on the assumption that with a given amount of cement the strongest concrete is secured with aggregates graded and mixed so as to have the least amount of voids, without an excess of fine material. It has been found from a large number of tests that the average ratio of fine to coarse aggregate for maximum density is approximately 1 to 2, a fact which accounts for the rule-of-thumb mixes, as, for example, the 1:2:4 mix, which means 1 part of cement to 2 parts of sand and 4 parts of coarse aggregate. If greater strength is required a 1:1½:3 mix is used; if less strength is needed the proportions 1:2½:5 or 1:3:6 may be adopted, but the practice is to maintain the ratio of 1 to 2 between the volumes of the two aggregates. A large amount of concrete has been mixed according to these rules, but objection is made to them on the ground that the particular aggregates used may differ materially from the average. Good aggregate and cement mixed according to the maximum density theory with a proper amount of water will produce a good concrete, but the theory itself does not take into account the amount of water to be used. Lately the amount of water has been found to exert a most important influence on the strength of the concrete. Excess, it has been found, invariably brings about a decrease in strength.

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[2] "Concrete, Plain and Reinforced," by Taylor and Thompson.

The theory[3] has recently been advanced that the strength of the concrete depends entirely on the ratio of the amount of water to the amount of cement so long as the mix is workable. According to this theory variation in the grading of the aggregates affects the strength of the concrete made with a given amount of cement merely because it affects the amount of water that is required to produce a workable consistency. If the proportion of cement be varied to maintain a constant ratio of cement to water, any reasonable grading of aggregates can be made to yield a concrete of approximately any desired strength. An arbitrary quantity known as the "fineness modulus" is determined by sieve analysis of the aggregates and this quantity together with the maximum size of the aggregate determines the amount of cement to be used. The strength of the concrete made from the cement and aggregate in the determined proportions will depend upon the amount of water used. Tables and charts based upon experimental data supply the means for the practical application of the theory.

Another theory[4] is based on the assumption that to produce concrete of a given strength a certain amount of cement is required for each unit of surface area of the aggregate, taking into account the amount of water used in mixing. The particles are assumed to be spheres, and tables have been worked out from which the surface area of a given amount of the aggregate can be determined from the sieve analysis.

It is worthy of note that each of these theories tends to the use of well-graded aggregates and rich mixes where strong concrete is desired. They have all been evolved in the attempt to design concrete of high strength, which is needed in pavement concrete to enable the pavement to resist temperature and impact stresses without excessive cracking. That concrete high in compressive strength is also highly resistant to abrasion is the conclusion drawn from tests conducted by Prof. Duff A. Abrams, Lewis Institute, Chicago. It was observed in these tests that the resistance to abrasion fell off sharply when the compressive strength dropped below 3,000 pounds per square inch. The tests conducted by the Bureau of Public Roads do not support this conclusion, but indicate, rather, that the amount of wear of the concrete depends upon the character of the coarse aggregate. It should be noted that in the tests conducted by Professor Abrams only two kinds of coarse aggregate were used. For any given coarse aggregate, however, it is likely that increase in compressive strength will result in corresponding decrease in wear. From experience it has been found that pavement concrete should be proportioned to have a compressive strength of not less than 3,000

[3] Bulletin 1, Structural Materials Research Laboratory, Lewis Institute, Chicago.
[4] Proceedings of the A. S. T. M. for 1918, pt. 2, p. 236.

pounds per square inch. Pavements composed of concrete of less strength have generally proved unsatisfactory.

In practice it is generally not feasible to follow strictly any of the theories in the proportioning of the materials. The aggregates must usually be obtained from commercial sources and the specified grading of these aggregates must be such that they can be supplied without excessive expense or decreased output. The maximum size usually specified ranges from 1½ to 2½ inches. When the 2½-inch size is permitted it is usually provided that 90 to 95 per cent of the aggregate shall pass a 2-inch circular opening. For sand graded as described on page 4 and a coarse aggregate, well graded from ¼ inch to 1½ inches, the proper proportions for concrete pavements would be 1 part of cement to 2 parts of fine aggregate to 3 parts of coarse aggregate. For coarse aggregate from ¼ inch to 2½ inches in size, a proportion of 1:2:3½ or even 1:2:4 may be used provided there is sufficient mortar to finish the concrete properly. These proportions may have to be altered slightly, but for good commercial aggregate graded as described on page 5 the proportions given will prove satisfactory. Where it is not possible to obtain commercially graded aggregates of the sizes mentioned, different proportions of aggregate should be used. The following table,[5] which gives a large number of proportions designed to produce concrete of approximately 3,000 pounds compressive strength at 28 days when mixed with the water necessary to give a workable consistency, indicates the great variety of combinations that can be used.

Abrams's 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.]

Cement in barrels, aggregates in cubic yards.

Coarse aggregates.	Fine aggregates, screen openings per inch.														
	0–28			0–14			0–8			0–4			0–⅜ in.		
Size, inches.	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	2.0	3.0	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	1.68	.36	.85	1.55	.36	.85	1.52	.43	.81	1.53	.50	.70

[5] Table prepared by A. N. Johnson, based on results of investigations by Prof. D. A. Abrams, Structural Materials Research Laboratory, Lewis Institute, Chicago, Ill.

Abrams's table of proportions and quantities for one cubic yard of concrete—Continued.

Coarse aggregates.	Fine aggregates, screen openings per inch.														
	0–28			0–14			0–8			0–4			0–⅜ in.		
Size, inches.	Cement.	Fine.	Coarse.	Cement.	Fine.	Coarse.	Cement.	Fine.	Coarse.	Cement.	Fine.	Coarse.	Cement.	Fine.	Coarse.
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
½ to 1½:															
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
½ 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	1.5
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	1.5	3.2	1	1.9	3.5	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

QUANTITIES OF MATERIALS REQUIRED.

The quantities of materials theoretically required for concrete pavements of various proportions, thicknesses, and widths are given in the appendix, pages 61 and 62. The quantities of aggregates are given in cubic yards. To correct to an approximate tonnage basis, the fine aggregate quantities should be multiplied by one and one-half and the coarse aggregate quanties multiplied by one and one-third. In practice an allowance must also be made for waste or loss in handling these materials. This allowance should be approximately 2 per cent for cement, from 2 to 4 per cent for fine aggregate, and from 3 to 7 per cent for coarse aggregate, depending upon the method used in handling the material.

DESIGN OF CONCRETE ROADS.

There are two general types of concrete pavement, known, respectively, as one-course and two-course pavement. The former consists of one course of concrete, all of which is mixed in the same proportion and composed of the same kind of materials, while the latter consists of two courses, usually mixed in different proportions and containing different kinds of aggregate. The one-course pavement is much simpler to construct than the two-course type. For the one-course construction it is customary to employ a coarse aggregate of average wearing qualities, which can readily be obtained from commercial sources.

Where a very large volume of steel-tired traffic is anticipated, however, it is sometimes desirable to provide a surface of exceptionally good wearing quality to resist the abrasive action of this particular kind of traffic. Inasmuch as aggregates having high resistance to wear, such as granite and trap, frequently have to be imported from long distances at great cost, the cost of a road composed entirely of this aggregate would be almost prohibitive. This has led to the development of the two-course type of construction in which local coarse aggregate of average or low wearing qualities is used in the lower course and imported aggregate with high resistance to wear is used in the top course. For example, if the only materials locally available for use as aggregate are of inferior quality, it would usually be more economical to use them for aggregate in the lower course of a two-course pavement and import aggregate for the wearing course than to employ a one-course pavement and import all the aggregate. The coarse aggregate in the top course is somewhat smaller than in one-course construction and the thickness of the top course is usually about 2 inches.

In the two-course construction it has been somewhat general practice to permit leaner proportions for the lower course than would be required for one-course construction, but it is not believed that this practice is justifiable unless the thickness is correspondingly increased. With the development of modern traffic, the load-carrying capacity of the pavement is an important consideration, and the requirements of strength should govern the proportions of the lower course in two-course construction to the same extent as in one-course construction. The construction of a two-course pavement involves construction difficulties in mixing and handling two kinds of concrete and usually in securing two kinds of coarse aggregate, especially if one kind is shipped by rail, and therefore usually costs correspondingly more to build than the one-course pavement.

Under modern traffic conditions the amount of abrasive traffic on main roads is rapidly decreasing and observations of concrete pavements built with aggregates of average wearing qualities that have been in service from 6 to 8 years fail to show any serious wear from abrasion. Except under unusual conditions, therefore, it would not appear necessary to resort to two-course construction.

Besides the two general types of concrete pavement described above, there are several patented types, but so far as is known these do not possess any particular advantages and will not be discussed in detail. The one-course pavement is believed to be better adapted to most ordinary conditions than any other type of concrete pavement and will be principally considered in the following discussion.

WIDTH OF PAVEMENT.

The width of pavement necessary will depend upon the frequency with which vehicles are expected to pass each other, the character of the vehicles, and their speed. For single-track roadways a width of 10 feet is usually adopted. This width is ample for a single line of traffic, but passing vehicles will be forced to use the shoulders of the road which consequently will require considerable maintenance. The frequency with which vehicles pass each other has made it necessary in some instances to construct shoulders of broken stone or gravel.

It is believed that all trunk-line roads and roads of primary State systems should be constructed to accommodate two lines of traffic, whether the necessity for such a width exists at the time of construction or not. The history of highway improvement shows that there is always a tremendous increase in traffic upon the completion of the improvement. This potential increase usually justifies the double-track road. Where funds are the controlling factor in the construction of the primary system, it may be desirable to construct a single-track pavement in certain sections and make provision for widening the pavement at a later date when the volume of traffic justifies the expense. In doing this the road should be graded the necessary width for a double-track pavement and a 9-foot pavement built to one side of the center line of the grade. In widening a pavement of this type to 18 feet it would only be necessary to lay a slab 9 feet in width adjacent to the original slab. A typical cross-section for a pavement of this type is shown in Figure 7, page 28.

The character of vehicles, together with the clearance necessary for safety in passing, will largely determine the width of pavements for double-track roads. Motor-truck traffic has grown to such proportions that it has been necessary in many States to limit by statute the size of load and the total width of body. The maximum width of truck body generally permitted is 8 feet. If ample clearance is provided for the passing of trucks of maximum size a desirable factor of safety will be provided for smaller trucks and passenger motor vehicles. For slow-speed traffic, such as truck traffic, a clearance of 3 to 3½ feet is necessary for safety, while for high speed traffic, such as automobiles, a clearance of at least 5 feet should be provided. The amount of truck traffic is small, in comparison to automobile traffic, except in the neighborhood of large cities, so that the frequency with which one truck passes another is almost neglible in comparison with the frequency with which automobiles pass trucks. If, therefore, ample clearance is allowed for the passage of an automobile and a truck, the maximum of safety will be obtained at the minimum of cost.

The diagram, Figure 1, shows the width of pavement necessary for reasonable clearance for trucks passing each other and for an automobile passing a truck. At an average speed of 30 miles per hour it is unreasonable to expect the driver of an automobile to drive with the wheels closer than 1½ feet to the edge of the pavement. For trucks at an average speed of 15 miles per hour, this distance should not be less than 1¾ feet on account of the great width of the rear wheel. Inasmuch as a certain amount of truck traffic is to be expected on all main country roads, the minimum width of pavement for this class of road should be 18 feet. Where the frequency with which trucks pass each other becomes a big factor, as in the neighborhood of large cities, the minimum width of pavement should be 20 feet.

THICKNESS OF PAVEMENT.

The determination of the proper thickness of a concrete pavement for different kinds of traffic is a very complex problem in applied mechanics, and depends to a large extent on certain factors which at present are more or less indeterminate. In the first place, the loads acting on a pavement are not merely static loads, but are applied with considerable impact. This impact varies with the roughness of the pavement, the speed of the vehicle, the character of the tires, and the percentage of the total load which is carried above the springs of the vehicle. Under very unfavorable conditions it may be as high as five times the amount of the static load.

The pavement itself depends upon the subgrade for support, and this support is extremely nonuniform in character. The supporting power of a subgrade depends upon the type of soil, its capillarity, the

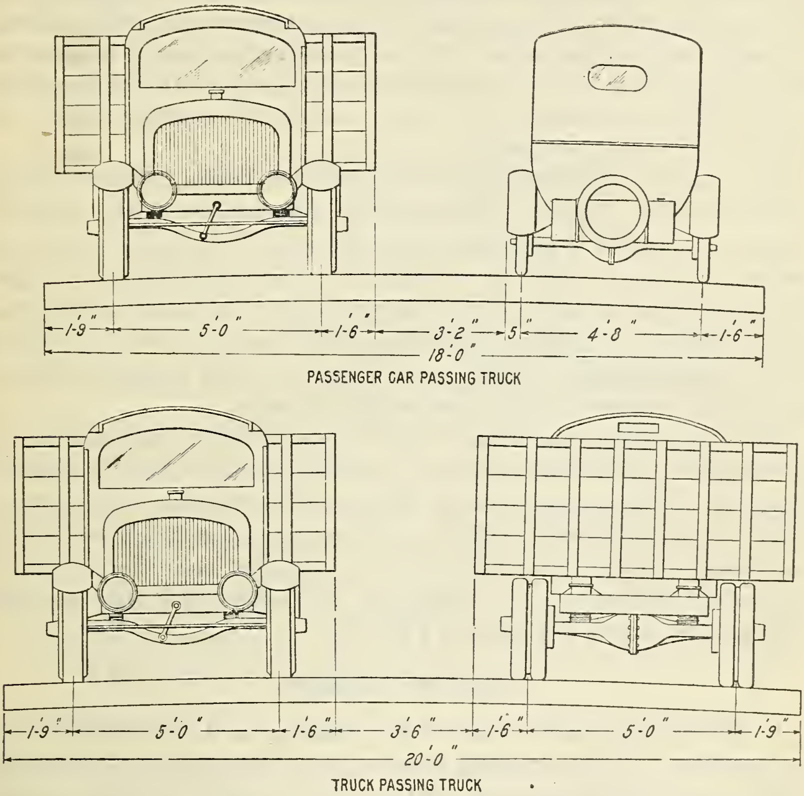


FIG. 1.—Width of road required for safe passage of vehicles.

proximity of ground water, the condition of surface drainage, the amount of sustained rainfall, and the extent of freezing and thawing.

All of these factors are extremely variable, and in combination are almost indeterminate, so that it is almost impossible to reduce the determination of pavement thickness to a simple mathematical computation. The behavior of concrete pavements of known thickness under known soil conditions and known conditions of traffic is the most satisfactory index of the thickness of pavement required.

It has been more or less customary in the past to use a flat subgrade for concrete pavements, and obtain the necessary crown in the pavement by making the concrete thicker at the center than at the sides. The flat subgrade was adopted originally, no doubt, for the reason that it was simpler to construct than any other form. For a double-track pavement, however, where two lines of traffic are accommodated, the use of a flat subgrade imposes the maximum wheel load on practically the thinnest part of the pavement. Under heavy traffic conditions this has often led to complete breakdowns of the edges of the pavement. This action is greatly accentuated where diagonal transverse cracks occur. For a double-track pavement where the volume of traffic confines the limits of travel in each direction, it is essential that the edges be of the same thickness as the remainder of the pavement. This can be secured by using a crowned subgrade and a uniform thickness of pavement.

On a sandy or sandy-loam soil, where the traffic consists mainly of horse-drawn vehicles and passenger automobiles, with comparatively few trucks, a thickness of pavement of 6 inches will often prove satisfactory. As the volume of truck traffic and the weight per truck load increase, the pavement should be made correspondingly thicker. A greater thickness should also be used on soils of poor bearing quality which are difficult to drain than on soils of good bearing quality which are easily drained.

For the average condition of soil under traffic conditions up to and including 150 trucks per day, a thickness of 8 inches is believed desirable. In the neighborhood of large cities where a large volume of heavily loaded truck traffic is to be expected, the thickness should preferably be 9 inches, and under very unusual conditions a thickness of 10 inches may be necessary. A failure of a thin concrete pavement is shown in Figure 2, Plate X.

CROWN OF PAVEMENT.

A concrete pavement lends itself readily to the construction of low crowns. A low-crowned road is very desirable for the traffic. Water does not damage the surface of a concrete road and under present traffic conditions the wear of the surface is comparatively small, so the necessity for a high crown does not exist in this type. The amount of crown need not be any more than is necessary to shed the water from the surface, taking into consideration the small imperfections and depressions which exist in it. A crown of one-eighth to one-fourth inch per foot is sufficient. In the operations of finishing a concrete pavement surface a slight amount of crown will be lost, so that if the tamper is cut to a true 2-inch crown, the resulting crown in the pavement will closely approximate $1\frac{3}{4}$ inches. This fact should be taken into consideration in specifying the amount of crown. The crown of a pavement may be either an arc of a circle or a parabolic curve. In road construction it is generally customary to make it an arc of a circle.

SUPERELEVATION OF CURVES.

For modern traffic it is becoming customary and desirable to superelevate pavements on all curves. Superelevation of pavements compensates centrifugal force, reduces the danger of skidding on curves, and induces traffic to keep to the right side of the road. The amount of superelevation necessary will depend upon the radius of the curve and the speed of the traffic, but under no circumstances

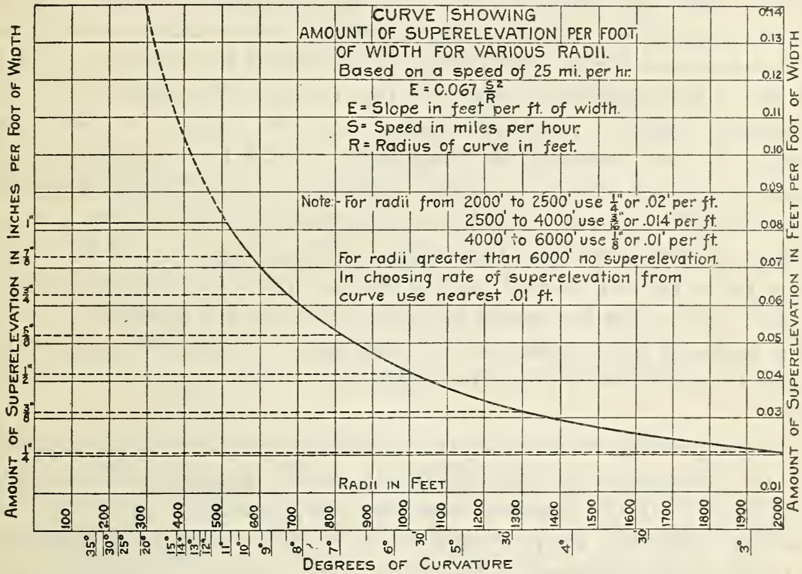


FIG. 2.—Curve showing superelevation per foot for curves of various radii.

should it be so great as to be objectionable or dangerous to horse-drawn traffic. The maximum superelevation for this latter class of traffic should not exceed 1 inch per foot of width. The speed of other vehicles on curves of short radius must therefore be reduced to conform to this superelevation. If this maximum be adopted, the amount of superelevation for the various radii of curvature may be easily computed. The curve, Figure 2, shows the amount of superelevation per foot of width for curves of various radii and a superelevated curve is shown in Figure 2, Plate IX.

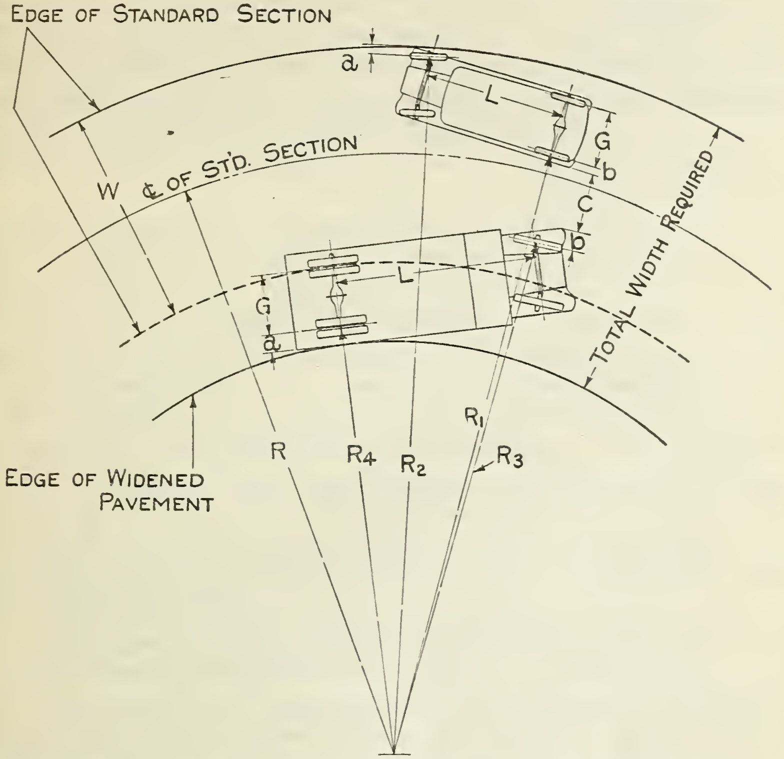
Superelevation may be accomplished by rotating the pavement about its central axis, i. e., lowering the inner edge of the pavement and raising the outer edge. If drainage conditions will not permit the lowering of the inner edge, the superelevation may be obtained by rotating the pavement about the inner edge, i. e., by raising the outside of the pavement. The maximum superelevation should be obtained at the point of curve and continued for the entire length of the curve. The pavement should begin to gain superelevation at a point on the tangent approximately 100 feet from the beginning of the curve, reach a maximum at the point of curve, and ease off to the regular pavement cross section the same distance beyond the point of tangency.

WIDENING ON CURVES.

In rounding a curve the rear wheels of a vehicle travel on a shorter radius than the front wheels. On this account a greater width of pavement is occupied by the vehicle on curves than on tangents. The additional width varies with the radius of the curve, the gauge of the wheels and the length of the vehicle. To allow the same clearance between passing vehicles on curves as on tangents the width of the pavement on the curves should be increased by an amount equal to the sum of the additional widths required by the two vehicles. If two vehicles of maximum size are assumed, i. e., trucks of 204-inch wheel base with a 5-foot gauge, it will be found that for curves of 30-foot radius the amount of widening required is 12.5 feet, while for curves of 150-foot radius the additional width is 2 feet and for a radius of 500 feet, only 0.5 foot. For curves of more than 500-feet radius the additional width required is negligible.

If the passing vehicles are two automobiles of averge size instead of two large trucks the additional width required will be less on account of the shorter wheelbase and narrower gauge of the smaller vehicles. If provision is to be made for the passage of a truck and an automobile the extra width required will be between the larger and the smaller amount. In widening curves the added width should be consistent with the provision that has been made on tangents. If the normal section on tangents is 16 feet wide the road will accommodate two automobiles in passing and the additional width on curves should be designed to provide for two such vehicles. The 18-foot normal section provides for the passage of an automobile and a truck, and the 20-foot section accommodates two large trucks. The additional width on curves, therefore, should provide for the passage of vehicles of the same type. The method of computing the amount of widening required is illustrated in Figure 3.

Theoretically the amount of widening determined in this manner is all that is required, but an additional allowance of a foot or two is generally made to allow greater clearance between the passing vehicles on curves for additional safety. As the clearance allowed



R= RADIUS OF CENTER OF STANDARD SECTION OF PAVEMENT.
W= WIDTH OF STANDARD SECTION OF PAVEMENT.
a= DISTANCE FROM EDGE OF PAVEMENT TO CENTER OF NEAREST WHEEL (TAKEN AS 1½ FT. FOR PASSENGER CARS AND 1¾ FT. FOR TRUCKS).
C= CLEARANCE BETWEEN VEHICLES.
L= LENGTH OF WHEEL BASE OF VEHICLES (TAKEN AS 12 FT. FOR PASSENGER CAR AND 17 FT. FOR TRUCK).
G= GAUGE OF VEHICLES (TAKEN AS 4⅔ FT. FOR PASSENGER CAR AND 5 FT. FOR TRUCK).
b= WIDTH OF VEHICLES OVERHANGING WHEELS (TAKEN AS ½ FT. FOR PASSENGER CAR AND 1½ FT. FOR TRUCK).

$R_2 = R + \frac{1}{2}W - a.$ $(R_1 + G)^2 = R_2^2 - L^2.$ $R_1 + G = \sqrt{R_2^2 - L^2}.$

$R_1 = \sqrt{R_2^2 - L^2} - G.$ $R_3 = R_1 - (C + 2b).$ $(R_4 + G)^2 = R_3^2 - L^2.$

$R_4 + G = \sqrt{R_3^2 - L^2}.$ $R_4 = \sqrt{R_3^2 - L^2} - G.$ TOTAL WIDTH REQUIRED = $R - R_4 + a + \frac{1}{2}W.$

FIG. 3.—Method of computing amount of widening on curves.

on the tangents is from 3 to 3½ feet, it is believed that a minimum of 5 feet should be provided on the curves.

101130°—22——2

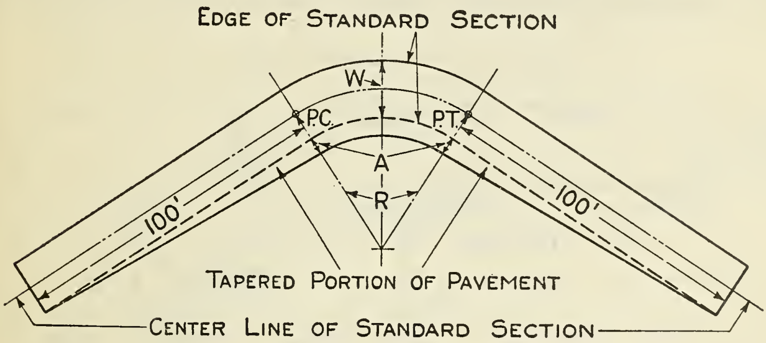
The table on page 19 gives the amount of widening for curves of 16, 18, and 20 foot pavements, computed on the basis of the above assumptions for curves up to 500-foot radius. For curves of greater radius than 500 feet the amount of widening would be practically constant and would be based upon the greater clearance required on curves for additional safety. At what point widening should be discontinued is somewhat problematical, but it is believed no additional clearance in passing is required for curves of 1,000 feet radius or greater.

It is now generally agreed that the increased width should be added to the inside rather than the outside of the curve; but there is considerable difference of opinion as to where the widening should begin. If the path of a vehicle around a circular curve is analyzed, it will be found that as the front wheels conform to the curve, the rear wheels effect a gradual transition to concentric curves of shorter radii and then follow these concentric curves around the circle. This transition of the rear wheels to curves of shorter radii begins on the tangent approximately one vehicle length from the point of curve and is generally completed in from one to one and one-half vehicle lengths on the curve. The necessity for curve widening, therefore, exists practically for the entire length of the circular curve; and for curves ordinarily used in highway practice, full widening should obtain both at the point of curve and the point of tangency.

The logical method of widening curves, therefore, is on the inside, full amount of widening for the entire length of circular curve. To gain this width at the two ends of the circular curve it is necessary that the widening of the pavement be begun at some distance from the points of curvature and tangency, thus providing a widening approach section to the curve. Theoretically, the length of this approach section should be varied with the degree of the curve, but in practice it is customary to employ a uniform length for all curves. A simple design which has proved satisfactory is shown in Figure 4, in which the approach section is in the form of a taper and the widening is begun at a distance of 100 feet from the ends of the circular curve. Instead of a straight-line taper, a transition curve may be used. In this case the offset from the tangent to the circular curve would be equal to the amount of widening and would determine the length of transition curve which would have to be used. A transition curve, however, cannot be used on widened curves of very short radii, because the amount of widening is so great and the length of circular curve so small that a true transition curve will not satisfy the conditions. For curves of 200-foot radius and over the transition curve will give satisfactory results.

If it is desired to use transition curves to connect the circular curve and the tangents, widening may be accomplished as shown in

Figure 5. As the offset from the tangent to the inner circular curve in this case will be increased by the amount of widening required, the length of the transition to the inner edge of the pavement will always be longer than the transition used on the outer edge of the pavement. The use of transition curves will materially increase the field operations of staking out the work, but it is believed their use is desirable on curves of from 200 to 1,000 foot radius.



R= RADIUS OF CENTER LINE OF STANDARD SECTION OF PAVEMENT.
P.C.= POINT OF CURVE.
P.T.= POINT OF TANGENT.
W= WIDTH OF STANDARD SECTION OF PAVEMENT.
A= ADDITIONAL WIDTH OF PAVEMENT ON ACCOUNT OF CURVE.
100 FEET = LENGTH OF TAPER.

NOTE:- THE TAPER WILL NOT STRICTLY BE TANGENT TO THE WIDENED PORTION OF THE CURVE AT THE P.C. THE POINT OF TANGENCY IS SO NEAR THE P.C., HOWEVER, THAT A SLIGHT SHIFTING OF THE FORMS AT THIS POINT DURING THE SETTING WILL CONNECT THE TAPER WITH THE CURVE WITHOUT ANY NOTICEABLE BREAK. IN NO CASE WILL THE FORMS AT THE P.C. HAVE TO BE MOVED MORE THAN .15 FOOT.

FIG. 4.—A simple method of widening curves.

Table of curve widening.

Radius of center line curve.	Additional width of pavement required for—			Radius of center line curve.	Additional width of pavement required for—		
	16-foot pavement.	18-foot pavement.	20-foot pavement.		16-foot pavement.	18-foot pavement.	20-foot pavement.
Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
30	8.0	11.0	14.0	125	3.5	4.0	4.0
40	6.0	8.0	9.5	150	3.5	3.5	3.5
50	5.5	6.5	7.5	175	3.0	3.0	3.0
60	5.0	5.5	6.5	200	3.0	3.0	3 0
70	4.5	5.0	5.5	250	3.0	3.0	2.5
80	4.0	4.5	5.0	300	3.0	2.5	2.5
90	4.0	4.5	4.5	400	3.0	2.5	2.0
100	4.0	4.0	4.5	500	2.5	2.5	2.0

JOINTS.

Concrete contracts or expands with changes in temperature and differences in moisture content. It also shrinks materially during the period of setting and initial drying out. In practically all early concrete pavements transverse expansion joints were constructed 25 to 30 feet apart, with the idea of relieving the pavement slabs of all stresses due to expansion and contraction, thereby preventing transverse cracking due to tensile stresses or failures due to compressive

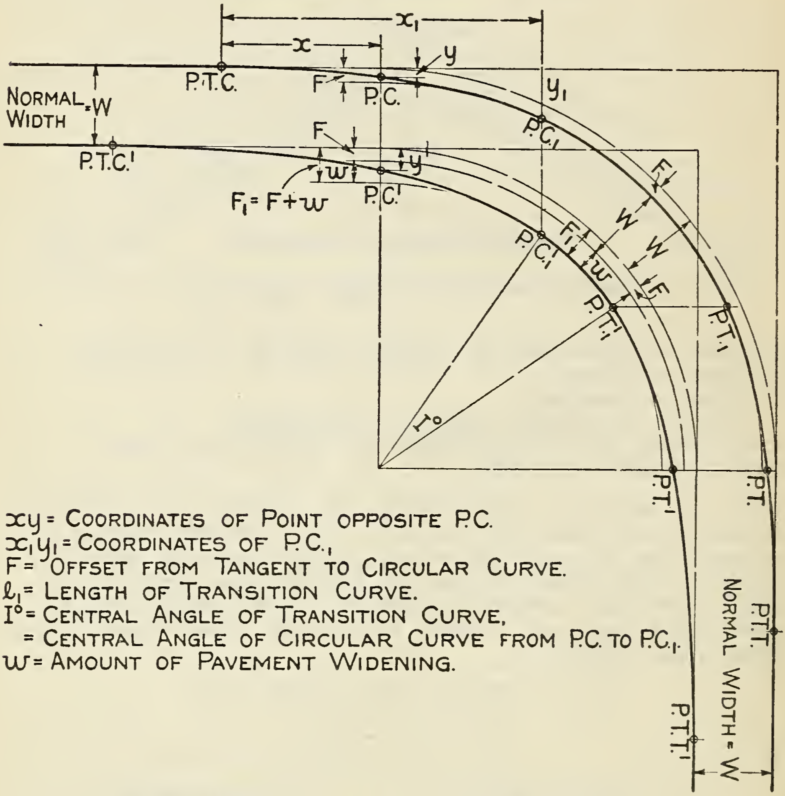


FIG. 5.—Method of widening curves using transition curves.

stresses. In these pavements it was found, however, that a majority of the slabs cracked transversely, that it was very difficult to secure a pavement with good riding qualities in the neighborhood of the joints, and that if the expansion joints were not constructed so as to be perpendicular to the surface of the pavement the end of one slab was very likely to rise above the end of the adjacent slab. Not infrequently this relative movement amounted to 2 or 3 inches and inconvenienced traffic very materially. If the joint varied from the vertical as little as 5°, this movement was likely to occur and it was found difficult in construction work to avoid even greater variations.

These findings led to the experiment of building pavements without expansion joints, and it was found in pavements so built that the transverse cracks did not occur more frequently than in those built with expansion joints and that the shrinkage due to the setting and initial drying out of the concrete provided sufficient room for such expansion as occurred later from changes in temperature and moisture content, except in pavements laid in cold weather. In pavements laid in cold weather it appeared that the shrinkage due to setting and initial drying out did not provide sufficient space for subsequent expansion caused by changes in temperature and moisture, and local failures of the pavement were not infrequent.[6] Experience, therefore, indicates that transverse joints are unnecessary in pavements laid when the air temperature is generally above 50° F., but are necessary in pavements laid in cold weather. The majority of plain concrete pavements are now constructed without joints. Transverse cracks will occur in pavements so constructed at more or less regular intervals, averaging 30 to 50 feet apart. These cracks in general are less objectionable than joints. They do not adversely affect the riding qualities of the pavement, slipping of the slabs rarely occurs, the cost of maintaining them is no greater, and, if properly maintained, they do not materially injure the pavement.

It is customary to construct transverse joints in reinforced pavements. They are generally spaced from 40 to 80 feet apart. The method most often used in constructing transverse joints is to separate the sections of the pavement by means of specially prepared bituminous felt boards. These are usually held in place by means of properly shaped steel templates until the concrete is deposited against them, after which the templates are removed and the concrete flows around the boards. The thickness of this joint has varied in common practice from one thickness of two-ply tar paper up to about one-half inch. A thickness of one-quarter inch seems to give very satisfactory results when the joints are spaced not more than 40 feet apart. Joints of this kind are sometimes provided with metal armor, which is intended to keep the adjacent edges of the concrete from spalling off. It is claimed that armored joints require less maintenance than other types, but they are more expensive to construct. As the amount of abrasive traffic on country pavements is steadily decreasing, there does not appear to be any necessity for this type of joint except under unusual conditions.

[6] A full discussion of the expansion and contraction of concrete roads may be found in U. S. Department of Agriculture Bulletin 532.

The use of longitudinal joints along the central axis of the road has generally been confined to pavements exceeding 20 feet in width. Where such joints have been used, it has been customary to construct one-half of the pavement width at one operation. After this portion of the pavement has been completed, the remaining half portion is constructed. The edges of the longitudinal joint are rounded with an edging tool, and after curing the joint is filled with bituminous material. The method of constructing a pavement in two half sections is particularly advantageous on some heavily traveled roads where it is not possible to divert the traffic. The construction of a pavement of this type can be carried on without diverting the traffic, although the operations of the contractor are hampered somewhat, resulting in slightly increased costs.

It has not been general practice to use a longitudinal joint in the construction of pavements 16 to 20 feet wide, when the full width of pavement has been constructed at one operation, but there are several arguments in favor of this form of construction. From observation of a large mileage of concrete pavements, it is found that longitudinal cracks rarely occur in pavements 9 or 10 feet wide, but frequently occur in pavements exceeding 16 feet in width. It is reasonable to assume, therefore, that a longitudinal joint along the central axis of the pavement would practically eliminate cracking.

Longitudinal cracks are more objectionable than transverse cracks because they have a tendency to gradually increase in width. When they occur along the line of wheel traffic the edges of the cracks deteriorate rapidly unless carefully maintained. Another important advantage of a longitudinal joint along the central axis of the road is that it serves to define sharply the limits of travel in each direction, thus providing a desirable factor of safety for road travel.

A longitudinal joint for full-width pavement construction should be of the submerged type. A joint of this type usually extends from the bottom of the pavement to within approximately three-fourth inch of the surface. The purpose of the submerged joint is to facilitate and simplify the operations of striking, tamping, and finishing the surface of the pavement, which would otherwise be rather difficult with the joint extending through the pavement. A strip of 18 or 20 gauge metal, held rigidly in place by pins driven into the subgrade, will usually prove satisfactory. The metal should preferably be corrugated or deformed sheets so as to key the two sections together. Reinforcing steel should be used to tie the two sections of the pavement together and prevent any lateral movement. The reinforcing steel should be placed halfway between the top and bottom of the slab. The practice of the Illinois highway department is to use five-eighths-inch deformed bars, 5 feet long, spaced

10 feet center to center, extending an equal distance into each section of the pavement. The metal joint may either be punched or slotted to provide for the reinforcing steel. When the surface of the pavement cracks above the submerged joint, the crack is filled with bituminous material.

STEEL REINFORCEMENT.

Steel reinforcement in the past has been used in concrete pavements, primarily to prevent excessive cracking. For this purpose it has been customary to use wire mesh or expanded metal weighing from 25 to 40 pounds per hundred square feet. Equally satisfactory results, however, can be obtained by the use of $\frac{1}{2}$-inch deformed bars spaced 24 inches center to center in both directions. This reinforcing should be placed not less than 2 inches from the finished surface of the pavement and should extend to within 2 inches of all joints, but not across them. Adjacent lengths of wire mesh or expanded metal should be lapped from 4 to 8 inches. For ease in handling, the wire mesh or expanded metal should be obtained in flat sheets. The use of this kind of reinforcement will add from 30 to 60 cents per square yard to the cost of the pavement and this additional cost is no doubt responsible for the fact that concrete pavements have not generally been reinforced in the past. Reinforcement of this type, moreover, does not entirely prevent cracks, but distributes them and keeps them small.

Under very severe traffic conditions and for pavements laid on exceptionally soft subgrades which cannot be materially improved, reinforcement may be necessary to give greater strength to the pavement by distributing the load over a larger area. Deformed bars should be used for this reinforcement and the percentage of reinforcement required will depend on the traffic loads, the condition of the subgrade, and the range of temperature and the variation in percentage of moisture. The reinforcement should preferably be placed both at the top and the bottom of the pavement and may vary from $\frac{1}{2}$ to $\frac{3}{4}$ inch bars spaced from 18 to 24 inches center to center in both directions. Reinforcement to give added strength to the pavement is rapidly gaining favor among engineers, and it is now being extensively used in localities where a large volume of heavy traffic is to be expected.

Another form of pavement reinforcement—circumferential reinforcement—consists of $\frac{3}{4}$-inch bars, placed half way between the top and bottom of the pavement, approximately 6 inches from the edges, and completely around the slab. This form of reinforcement gives added strength at the edges where cracks usually begin, and on a soft subgrade serves to hold the pavement together should cracking occur.

SHOULDERS AND DITCHES.

The width and kind of shoulders necessary for concrete pavements will depend upon the width of pavement and the volume of traffic. On single-track pavements the shoulders must be sufficiently wide to provide for safety of passing vehicles and must be composed of material which will support them satisfactorily. On double-track pavements the shoulders should be of sufficient width to allow for irregular and unexpected actions by inexperienced drivers or frightened animals, and, where the volume of traffic is large, to permit automobiles to turn out onto the shoulders for minor adjustments or tire repairs without blocking the traveled way. The width of each shoulder, then, should be not less than 5 feet; a width of 6 or 7 feet is preferable.

It has generally been customary to construct gravel or macadam shoulders to single-track roads on clay soils. This may be accomplished by constructing gravel or macadam strips 3 feet wide on each side of the pavement, or in the case of a single-track pavement built on one side of the center line by placing the gravel or macadam strip all on one side and making the width 6 feet. These gravel or macadam strips are usually 4 to 6 inches thick. On soils of a gravelly nature which have rather good supporting power when wet, metaled shoulders are not used. A double-track road should be wide enough to permit the passing of vehicles without turning out on the shoulders, so no shoulder should be necessary for this pavement other than the natural soil.

The slope of the shoulder should be such as will readily dispose of the water, and at the same time not be so steep that it will appear dangerous to drive on. Shoulders along a low-crowned pavement should have a slope as flat as possible so as not to accentuate the change in slope. A slope of ½ inch to 1 foot should prove satisfactory. Inasmuch as the shoulders of a concrete road are seldom rolled, some slight settlement takes place, and it is usually found that if a very flat shoulder is constructed it will have all the slope necessary after the road has been opened to traffic for a short time.

Surface ditches are usually constructed of two general shapes—the V shape, and the trapezoidal shape. In rolling country, where the surface water can be turned away from the road at frequent intervals, the V-shaped ditch has proved very satisfactory. Where it is necessary to carry water in the ditches for considerable distances the trapezoidal ditch should be used. The bottom of the ditch should be at least 18 inches lower than the center of the road; and when a large volume of water is to be carried the minimum depth should be 24 inches. The slopes to the ditches from the shoulder should not be steeper than 2 to 1.

CURBS AND GUTTERS.

To prevent erosion of the side ditches and the danger of washouts on relatively steep grades, some form of paved gutter, or combined curb and gutter, must be used. The amount of erosion depends upon the velocity of the water and the kind of soil. On soils of loose texture a small accumulation of water on grades as low as 3 per cent is sufficient to cause considerable erosion; while some soils of dense texture are not materially eroded on grades as high as 6 per cent. The grade, therefore, on which it will be necessary to use a paved gutter will depend upon the kind of soil. In general, it will be found desirable to provide paved gutters on all grades greater than 5 per cent.

A paved gutter, or the combined curb and gutter, may often be used to advantage in reducing the amount of grading in through and hillside cuts. For example, in deep cuts the amount of grading can often be reduced as much as 35 per cent by omitting the shoulders and side ditches and providing curbs along the edges of the pavement, so that the sides of the pavement serve as gutters. Similarly on heavy hillside work, by omitting the shoulder and ditch next to the hill and using a curb on one side, a considerable saving in grading can be effected. Inasmuch as the use of curbs confines traffic to the pavement, the width of the pavement should be slightly increased where curbs are employed. If curbs are used in connection with a standard 18-foot pavement with earth shoulders, the width between curbs should be at least 20 feet.

The paved gutter, or the combined curb and gutter, can be constructed as an integral part of the pavement, but this operation is a slow, tedious one which slows up the laying of the main body of the pavement and prevents the use of a mechanical finishing machine to the best advantage. Better results will be obtained if the regular width of pavement is constructed first and the gutter, or curb and gutter, constructed later. If this procedure is adopted, the gutter, or curb and gutter, should be tied to the main pavement by short pieces of reinforcing steel. This can be accomplished by drilling holes in the pavement forms midway between the top and bottom and inserting bars 3 feet long, spaced $2\frac{1}{2}$ to 3 feet apart, so they will project into the pavement about one-half their length. The bars should not be bent to conform to the gutter section until the forms have been removed. Joints should be placed in the gutter, or the curb and gutter, at points where joints exist in the pavement. Typical details of circular and V-shaped gutters and a combined curb and gutter are shown in Figure 6.

BITUMINOUS SURFACE TREATMENT.

A coating of bituminous material and sand, gravel, or stone chips applied to the surface of a concrete road is known as a bituminous surface treatment. The thickness of the coating is generally from one-fourth to three-eighths inch. Bituminous surface treatments have been used to some extent, principally because it was thought that they served to protect the concrete pavement by cushioning the

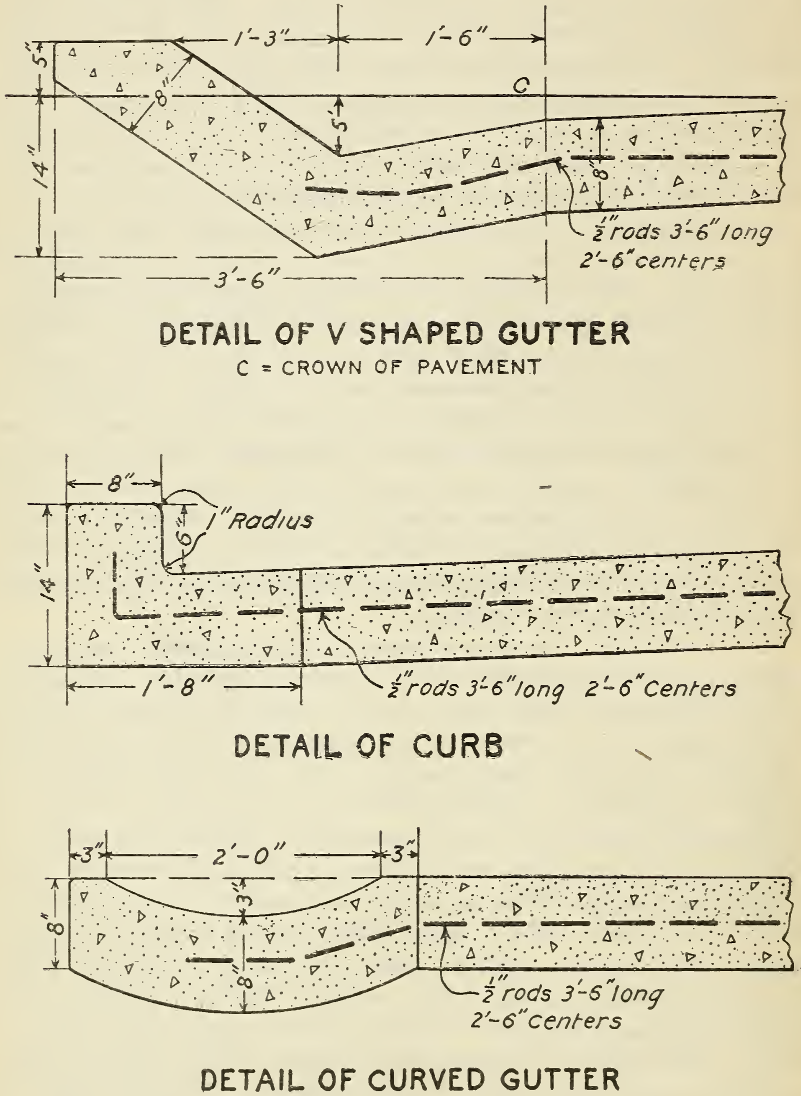


FIG. 6.—Typical details of gutter and curb.

impact of traffic and preventing the abrasion of the surface. Their use is now being generally discontinued. It is found that a bituminous surface approximately one-fourth inch thick has little, if any, cushioning value and consequently does not lessen the impact to any appreciable extent. The amount of abrasive traffic on country roads is steadily decreasing and a well-constructed concrete pavement no longer shows any marked deterioration through abrasive action. The chief advantage of a bituminous surface treatment lies in the fact that cracks are automatically bridged over as they appear and surface water is prevented from reaching the subgrade through these cracks. The difficulty of securing proper adhesion of the bituminous surface to the concrete, its cost, and the necessity for continuous maintenance of the surface constitute its greatest disadvantages. It is believed that these disadvantages greatly outweigh any possible advantages which might be obtained through its use.

THE CROSS-SECTION.

Typical cross sections of pavements based upon the foregoing discussion of design are shown in Figure 7.

CONSTRUCTION.

GRADING.

The grading requirements for concrete pavements are essentially the same as for other types of pavement. The shoulders may either be roughly built at the time the heavy grading is done or be constructed after the pavement has been placed. If the shoulders are roughly built before the pavement is placed, frequent drainage openings must be left in them to insure the rapid drainage of the subgrade during periods of rainfall. This is very essential if the pavement operations are not to be delayed by a poor subgrade.

DRAINAGE.

Surface drainage is secured by means of the pavement crown, the slope of the shoulders to the ditches, and frequent outlets for the water from the side ditches through culverts and bridges. In addition to surface drainage, soil conditions are sometimes such as to require subdrainage. Subdrainage is usually desirable over low, swampy ground and at points where ground water is encountered on hillsides or in deep cuts. Subdrainage may be effected by the use of drain tile, laid in trenches back filled with stone, gravel, or other porous material, or by the use of V-drain foundations in which large-sized stone is used and outlets are provided at all low points in the grade. The use of a V-drain foundation or any other form of prepared porous foundation under concrete pavements serves only to lower the point of support of the pavement. A somewhat wider distribution of pressure is secured by the use of these foundations; but on soils requiring this wider distribution of pressure it is believed it can be more cheaply obtained by reinforcement than by the use of the prepared foundation. The most effective subdrainage for concrete pavements is obtained by the use of tile laid under the outer edges of the concrete pavement, back filling the trench to the level of the bottom of the pavement with stone or gravel. Whether the tile should be used under both edges of the pavement will depend

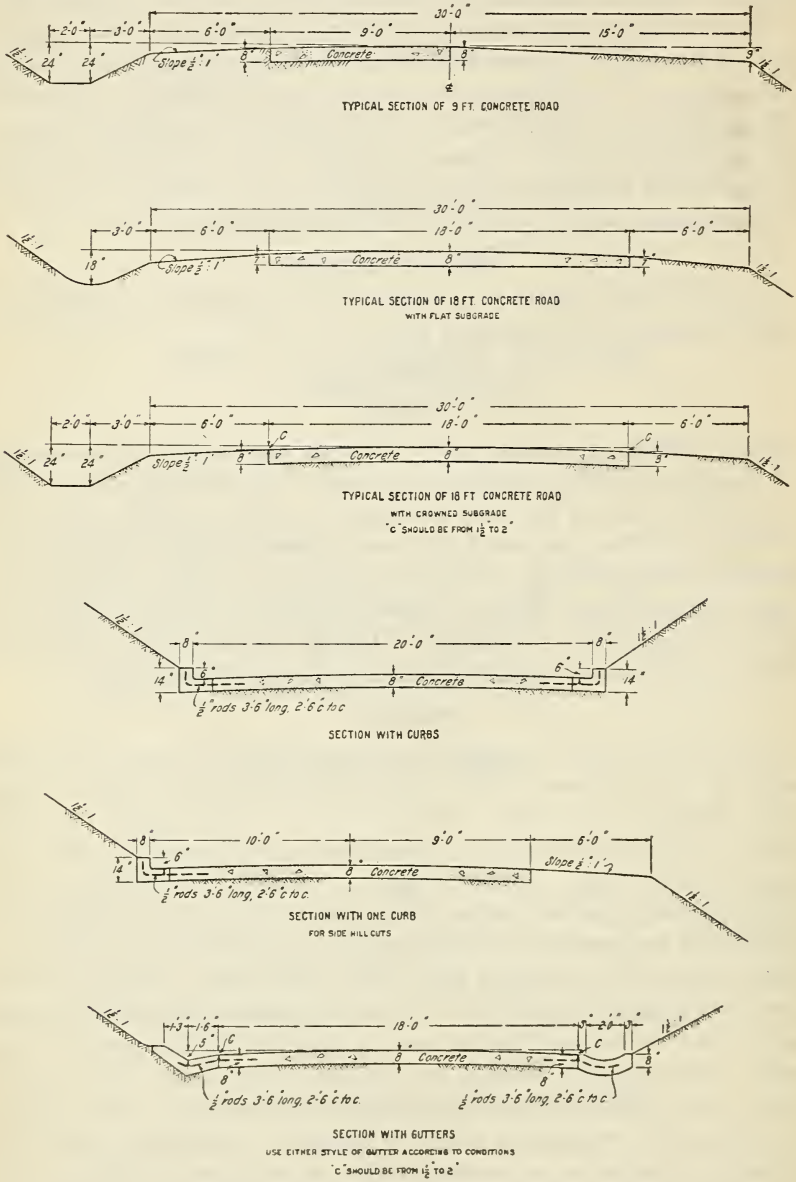


FIG. 7.—Typical pavement cross-sections.

upon the location of the pavement. On sidehill work one line of tile under the edge of the pavement nearest the hill will often suffice, but through cuts it will probably be necessary to use the tile on both sides. For a more detailed description of the use of tile drains see Bulletin 724, United States Department of Agriculture.

PREPARATION OF THE SUBGRADE.

The essential qualities of the subgrade are uniformity in grade, in cross-section, and in firmness.

The purpose of the rolling to which it is customary to subject the subgrade is to secure uniform firmness. Whether it accomplishes this result is a point upon which opinions differ considerably. Certainly no amount of rolling will result in uniform firmness if trucks or teams are driven over the subgrade to supply the mixer. Under certain conditions it is believed that no rolling is required. In particular it is not believed necessary to roll a newly graded road which has been closed to traffic and which has thoroughly settled before the pavement is placed, providing the concrete materials are hauled to the mixer by means of an industrial railway.

It is difficult to obtain uniform firmness by the use of the customary three-wheel type of macadam roller, because a small strip of the subgrade, wheel-gauge distance from the sides of the road is subjected to twice as much rolling as the edges. The tandem roller is not open to this objection, and it is believed that a condition of uniform firmness can be more nearly secured with a roller of this type than with any other kind.

Any soil with a clay content that is unduly compressed by rolling will swell considerably upon addition of moisture. Unless uniform firmness has been secured by the rolling, the subsequent absorption of moisture will result in uneven swelling which will outweigh any advantage which might have been obtained by rolling. For these reasons it is believed that, in general, light rolling is to be preferred to heavy rolling.

When an old macadam or gravel road is to be surfaced with concrete, the entire surface of the road should be scarified and plowed to the full depth of the existing surface before the subgrade is shaped to receive the concrete. If this is not done it will be almost impossible to secure a uniformly firm subgrade. In case the concrete surfacing is to be wider than the old road surface, the failure to loosen the old surfacing to its full depth will leave a hard, compact core in the subgrade. The uneven support afforded by subgrades with such hard cores is the cause of frequent longitudinal cracks in concrete pavements constructed over old macadam or gravel roads.

The uniform firmness of the subgrade should extend for a distance of at least 1 foot beyond the edges of the pavement, in order to provide a solid support for the side forms.

After the rolling the forms are set true to line and grade and they are then used as a guide for the finishing or trimming operations.

The finishing may be accomplished either by picks and shovels or by the use of a subgrade planer which rides upon the side forms. When materials are delivered to the mixer by hauling over the subgrade it is generally necessary to finish with picks and shovels. If materials are delivered by industrial railway, so that the subgrade is not used for hauling, it will usually be economical to use a subgrade planer. The planer, which is generally drawn by the roller, has its cutting edges so arranged that the slight excess of material trimmed from the subgrade is deposited in windrows at the quarter points, from which it is shoveled to the shoulders. For efficient use of the planer the rough grade should be slightly higher than the finished surface, a condition which is desirable in any case for the reason that it leads to the construction of subgrades of more nearly uniform firmness. Plate I, Figures 1 and 2, illustrate the construction and use of the subgrade planer and the finished subgrade.

The cross section may be either flat or shaped to conform to the finished surface of the pavement. In either case the allowable varia-

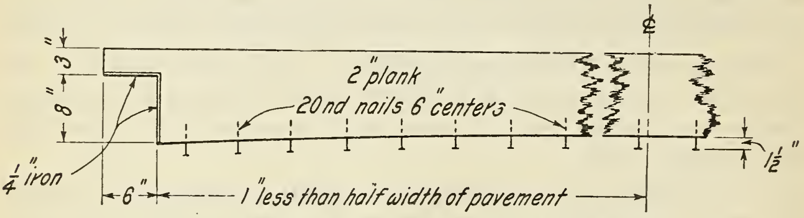


Fig. 8.—Details of nail template used to test the subgrade.

tion from the true grade and cross section is usually limited to one-eighth inch. This small variation is intended primarily to insure that the full thickness of pavement will be secured at all points. The subgrade is tested by means of a nail template (Fig. 8), which is moved back and forth over the forms. Should the test show that any portion is too low, the low area is generally filled with concrete as an integral part of the pavement, though sometimes the contractor is permitted to fill it with hand-tamped earth. While the engineer is charged with securing the full thickness of pavement required by the plans, the contractor aims to furnish that thickness and no more, because any additional concrete represents loss which rapidly runs into a large sum. The natural result is a subgrade as true to grade and cross-section as it is practicable to obtain.

FORMS.

The side forms for concrete pavements may be of steel or wood. Steel forms are preferable and should be used whenever the pavement to be laid exceeds one-half mile in length, and when machine finishing is to be used. A number of makes of steel forms can be purchased. If the pavement is to be machine-finished, heavy forms are desirable and usually are more economical than light ones, as they hold their shape much better under the vibrations set up by the finishing machine. The forms should always be set true to line and grade before the subgrade is finished, in order to serve as a guide for the finishing. It is very essential that the forms be firmly supported and bear uniformly upon the subgrade, as any sag produces an irregular surface in the pavement. The ends of the different sections of forms should be fastened together so that no relative displacement occurs. The joints between the sections on the two sides of the road should not be opposite each other, but should be staggered. The height of the forms should preferably be equal to the thickness of the pavement at the edge. Forms 1 inch less in height than the edge of the pavement can be used satisfactorily, however, by bolting under them a 1-inch strip of wood. These wood strips should be somewhat wider than the base of the forms, so that additional bearing can be secured. In States that use a variable thickness of pavement at the edge this arrangement reduces the amount of forms required for different classes of work.

Forms for concrete pavements should always be oiled before the concrete is placed against them. This oiling prevents the concrete from sticking to them, makes cleaning easy, and prolongs the life of the forms. Any crude oil can be used for this purpose and approximately 1 barrel per mile will be required.

The use of bent forms should be prohibited. It is usually specified that variations in the surface of the pavement of over one-fourth of an inch in 10 feet will not be permitted. These variations in the surface of the pavement are caused to a large extent by the forms, so it would appear that no greater variation should be permitted in the forms than is permitted in the pavement. Forms, therefore, should not be used if their top surfaces vary more than one-fourth inch when tested with a 10-foot straightedge. A sufficient number of forms should be provided so that it will not be necessary to remove them within 12 hours after the concrete is placed.

HANDLING AND HAULING MATERIALS.

For handling and hauling the materials used in concrete pavement construction a number of different methods may be used. The most economical method to employ will, of course, depend upon the particular problems of the work in question. The discussion of this subject will be confined to the general methods which may be employed and the advantages and disadvantages of each.

Nearly all of the materials used in concrete pavements are shipped by rail. The method of unloading the materials from railroad cars will depend to a large extent upon the method of handling the remainder of the work. The following methods may be employed: (1) Unloading by hand into wagons, trucks, or into light movable bodies which are hung against the side of the car and from which the material is dumped into wagons or trucks; (2) mechanical unloaders, using belt conveyors, discharging into wagons or trucks; (3) bucket elevators or skip hoists from pits below the track, discharging into bins; (4) a clam-shell bucket on a stiff-leg, or guy-line derrick; (5) a clam-shell bucket on an auto crane or locomotive crane. (See Fig. 1, Pl. VI.) The first three of these methods can be employed to advantage where a comparatively small amount of material is to be handled and this material can be obtained in bottom dump gondola or hopper cars. They can only be used, however, where the materials, are distributed on the subgrade or placed in stock piles on the shoulders of the road at short intervals. None of them affords any storage capacity at the unloading station.

Pavement construction is seasonal work. The peak demand for materials naturally occurs during the midst of the construction season, and it frequently happens that because of this increased demand regular deliveries and sufficient quantities of materials can not be obtained for the work at hand. With uncertain transportation facilities and a known shortage of railroad equipment for normal business conditions, the storing of materials is practically imperative if work is to proceed without interruption during the construction season. The storing of a considerable quantity of materials can best be done by means of a clam-shell bucket on either a derrick or a crane. On account of its ability to swing through a complete circle, a guy-line derrick can store more material than a stiff-leg. If a stiff-leg derrick is used, the maximum storing capacity will be reached by setting the derrick with one leg parallel to the railroad track. Cranes are considerably more flexible in operation than derricks, and it is possible to store a large amount of material if the storage piles parallel the track. In their principles of operation auto and locomotive cranes are the same, the only difference being that locomotive cranes are considerably heavier, have longer booms, and operate on railroad tracks. If the reloading bin is stationary, the amount of material that can be stored within reach of the bin without rehandling will depend upon the boom length of the derrick or crane. For large storing capacity a boom length of from 50 to 60 feet is desirable. With movable bins, however, good storing capacity without rehandling can be obtained with cranes having a boom length of 30 feet. The use of derricks and cranes combines the labor-saving feature with the storage feature, and where the materials are proportioned or mixed at the unloading yard, their use is practically indispensable.

FIG. 1.—SUBGRADE PLANER IN OPERATION.

FIG. 2.—THE FINISHED SUBGRADE.

FIG. 1.—HAULING WITH TRACTOR TRAIN.

FIG. 2.—FINE AND COARSE AGGREGATE PILED ON SUBGRADE READY FOR USE.

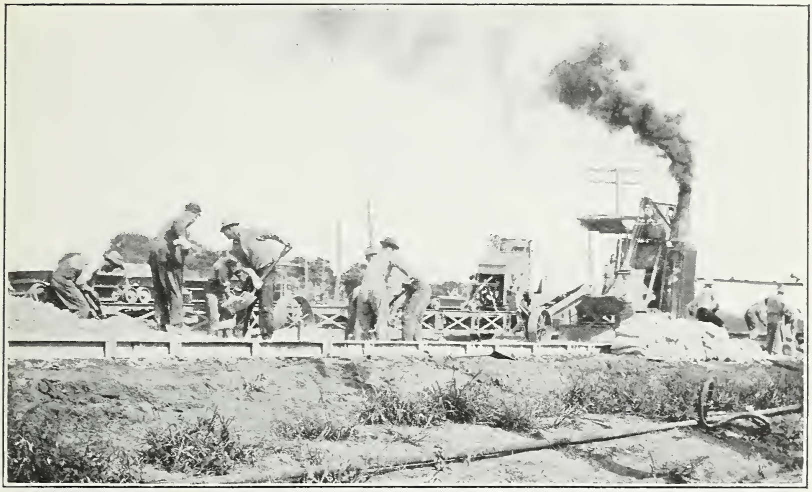


FIG. 1.—CHARGING THE MIXER WITH A BELT CONVEYOR LOADER.

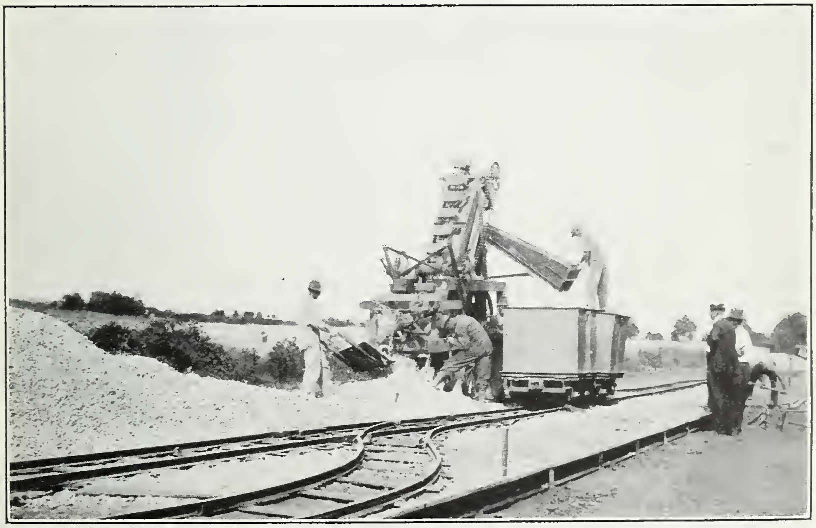


FIG. 2.—LOADING BATCH BOXES FROM SMALL STOCK PILES ON THE SIDE OF THE ROAD WITH A BUCKET ELEVATOR.

FIG. 1.—CHARGING MIXER WITH PROPORTIONED BATCHES HAULED IN TRUCKS.

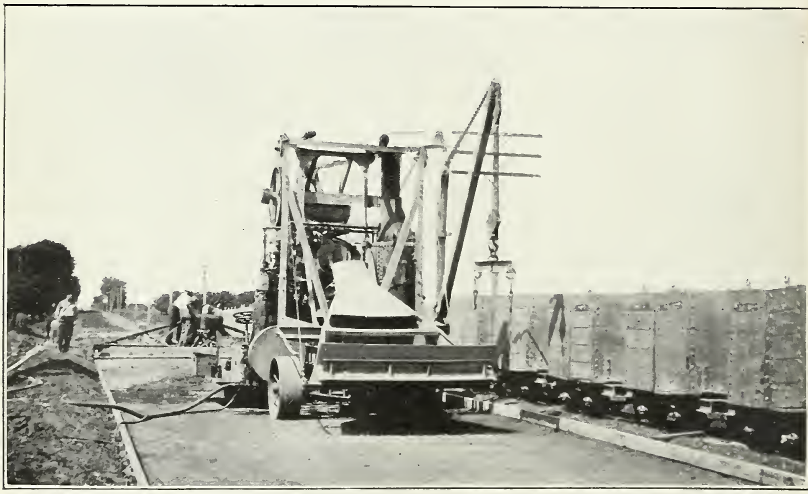


FIG. 2.—INDUSTRIAL RAILWAY HAULING PROPORTIONED BATCHES IN BOTTOM DUMP BOXES.

The equipment used for hauling must fit in with the general method of conducting the work. The proper hauling equipment will depend upon which of the three general methods of operation are employed. By the first method, the materials entering into the construction of the pavement are hauled separately to the work; by the second, they are proportioned at the unloading plant; and when the third method is used, the concrete is mixed at the unloading plant and hauled to the road. If the first method of operation is employed the materials must be distributed on the subgrade (see Fig. 2, Pl. II) or placed in stock piles on the road. Teams, trucks, tractors, or an industrial railway may be used for this hauling. Team haul is generally not economical where the maximum haul exceeds 3 miles. The economy of truck haul depends largely upon the condition of the road hauled over and the care exercised in the operation and maintenance of the trucks. It should not be attempted on a sandy or sandy-loam grade. No class of equipment used in pavement construction depreciates as rapidly as motor trucks if they are improperly operated. Constant changing of drivers and the overloading of the truck are two of the practices which contribute to this rapid depreciation. Trucks for this class of hauling should be equipped with power dump bodies. Tractors are usually used in conjunction with a train of 4 or 5 bottom-dump specially constructed wagons each with a capacity of about 5 cubic yards. The success of the tractor train is due to the large quantity which it is possible to haul at one time. (See Fig. 1, Pl. II.) On account of the great width of pile which the tractor train spreads, the proper distribution of the materials on the subgrade is rather difficult. On roads of average width some shoveling of the materials is necessary before the forms can be set. An industrial railway may be used for delivering the material to the subgrade, but when it is used, it would appear to be doubtful economy to dump the materials on the subgrade and rehandle them into the mixer when they can be handled directly into the mixer from the industrial railway by the use of batch boxes.

When the materials are proportioned at the unloading point, the only practicable method of hauling is with trucks or by industrial railway. Under this method of operation the properly proportioned materials for each mixer batch of concrete are dumped directly into the mixer skip. Each batch, therefore, constitutes a distinct unit and must be handled so that it is kept separate from other batches. Trucks of various sizes may be used for this work. The light trucks are usually equipped to haul only one 4-sack batch. Trucks of larger size, however, may be used by dividing the body of the truck into compartments separated by swinging transverse doors provided with a locking mechanism so that they can be released separately. (See Fig. 1, Pl. IV.) The number of compartments will depend upon the size of the batch and the capacity of the truck. For truck haul the proper proportions are obtained by the use of measuring hoppers attached to the bins in such a way that the materials will flow into them by gravity and discharge into the trucks by the same process. A measuring hopper should be provided for each kind of aggregate. Where the aggregates are handled from a single divided bin it is possible to arrange the measuring hoppers so that they can both be discharged into the truck at one operation. This arrangement is much preferable to the use of two separate and distinct bins for the aggregates, as the time of loading is practically cut in half. After the truck has received its load of proportioned aggregate it is driven past the cement house, where the proper amount of sacked cement is thrown into each compartment. As the truck is turning around on the road preparatory to backing to the mixer the sacked cement is emptied into the compartments. Where light trucks are used, the sacked cement is sometimes carried on the truck frame, just back of the driver's seat, and unloaded and emptied into the mixer skip by hand as the truck is discharging. The purpose of hauling the cement to the mixer in sacks is to avoid any loss occasioned by high winds. In dumping trucks containing more than one compartment, the dump body is raised and the end gate released, allowing the first batch to run into the loading skip. The truck is then run forward sufficiently to give clearance for the raising of the skip. After the skip is discharged and lowered the truck backs into position for unloading again and the first swinging compartment is released for the discharge of the next batch. With efficient truck operation and a good road to haul over this method of operation may be successfully employed.

The industrial railway is particularly well adapted for hauling proportioned batches. By this method the materials are hauled in removable car bodies or in batch boxes set directly upon the frame or platform of the industrial cars, from which they can be lifted by a suitable hoisting device. (See Fig. 2, Pl. IV.) Greater train capacity is obtained with batch boxes, and they are the more widely used than cars with removable bodies. Three general types of batch boxes are used, distinguished by their method of discharge, as follows: (1) Tip-over boxes; (2) side-discharge boxes; (3) bottom-dump boxes. These boxes are generally rectangular in shape and are constructed either of steel or wood. The wood box has one important advantage over the steel box; it can be easily repaired in case of a train wreck, while steel boxes, once they have become bent, are difficult to straighten. The tip-over box is provided with trunnions, placed below the center of gravity of the load, to which the lifting yoke attaches. During the lifting the box is prevented from turning over by a hook attached to the yoke. When the box is in position tc dump, the hook is released and the box turns over on the trunnions. If the trunnions are properly located very little "kick back" is noticeable and the load is rapidly discharged. The side-discharge box is provided with a false bottom, which slopes toward the front of the box, where discharge is effected by releasing a hinged door which usually makes up one-half of the front side of the box. The side-discharge box throws the material well to the front of the loading skip, but is somewhat slow of discharge and has a slight tendency to "kick back." The sloping bottom necessitates a larger box and also places the center of gravity of the load higher above the rail than otherwise. The bottom-dump box is discharged by releasing the 2 hinged doors which constitute the bottom of the box. This type of box discharges very rapidly and is practically free from any "kick back." Batch boxes may be loaded by means of measuring hoppers attached to the loading bins, but this arrangement is not necessary, as the box itself serves as a measuring device. The proper height to which the boxes are to be filled with each material may be marked by means of thin nailing strips or bolt heads. The loading plant should be designed so that 4 or more boxes can be loaded at the same time.

Batch boxes are usually loaded from open bins or a loading tunnel. In tunnel loading the industrial train is run under the stored material and loaded from overhead traps. (See Fig. 2, Pl. VI.)

The tunnel may be partly or wholly excavated into the ground or it may be constructed of wood on the surface of the ground. The material in either case is stored over the tunnel This method of loading permits practically the entire length of train to be loaded at one time, but it is open to the disadvantage that a considerable amount of material is required in storage which can not be used for loading purposes. The material is simply piled over the tunnel and all of it that lies to the side of the tunnel chutes is practically dead, so far as loading is concerned, unless it be rehandled. Tunnels are rather expensive to construct and this expense does not seem to be justified when the advantages of the tunnel method are compared with those of open bins holding two to three trainloads of material. Open bins with this capacity have successfully loaded trains where the maximum output with one mixer exceeded 1,200 square yards of pavement, 8 inches thick, per 10-hour day, and where the average output was well over 900 square yards per day for weeks at a time. If two mixers are to be operated on a long-and-short haul basis from one central porportioning plant, rapid loading is essential and a tunnel may be desirable, but for a single-mixer operation open bins are believed to be preferable. Industrial cars may be loaded from open bins either by chutes on the sides of the bins or by running the cars directly under the bins and loading from traps. (See Fig. 1, Pl. VI.) After the aggregates are loaded into the batch boxes the train is run past the cement house, where the required number of sacks of cement are dumped into the boxes. The cement house should be provided with a loading platform at approximately the same elevation as the top of the batch boxes.

A 24-inch gauge is commonly used on industrial railways for pavement construction and the track is generally laid along one shoulder of the road. Passing switches are provided where necessary. Both steam and gasoline locomotives are used to furnish tractive power. The limiting factor in industrial railway hauling is the rate of grade. On sustained grades exceeding 2½ per cent the speed and capacity of trains begins to be measurably reduced. On a 6 per cent grade the capacity is reduced to approximately one-fifth of the amount generally hauled on grades of less than 2½ per cent. The capacity on grades may be increased by the use of geared locomotives, but a locomotive of this type is much slower than a direct-acting locomotive. The great advantage of industrial railway hauling lies in the fact that the subgrade is not cut up by hauling over it, and that hauling is affected comparatively little by weather conditions. The delay on account of bad weather, therefore, is reduced to a minimum. Another important advantage is that the aggregates are kept clean and material is not wasted on the subgrade.

Attempts have been made to haul batch boxes on trucks and on wagon trains, but they have not generally been successful. A derrick independent of the mixer is necessary to discharge the boxes and it has been found that there is not sufficient room on the subgrade to maneuver these large machines or wagons without losing a considerable amount of time.

A combination of batch-box truck haul and industrial railway haul, however, has proved very satisfactory under certain conditions. Where the beginning of the pavement is a mile or more from the unloading plant and the road from the plant to the work contains grades as high as 5 or 6 per cent, an all-industrial-railway haul is not feasible. However, if the road from the plant to the work is in good hauling condition, trucks may be used to haul batch boxes to the beginning of the new pavement, where the boxes may be transferred by means of a portable overhead crane to an industrial railway train for the rest of the trip to the mixer. The transfer of 4 batch boxes from a truck to the industrial cars may be effected in from 5 to 7 minutes. (See Fig. 1, Pl. VII.) The pavement in this case is begun at the point nearest the unloading plant and as it becomes sufficiently strong to permit traffic the point of batch-box transfer is moved ahead on the new pavement.

The principal advantage of this method of hauling is that it permits the partial use of the industrial railway on work where it could not otherwise be used, thereby securing so far as possible the advantages of industrial railway haul. As the point of transfer is moved ahead an excellent road is made available for a part of the truck haul, and the wear and tear of the trucks is reduced to a minimum. The increased speed of the trucks on the new pavement over the industrial trains compensates for the time lost in effecting the transfer of the boxes from the trucks to the industrial cars. The amount of industrial railway equipment is reduced to a minimum. Usually not more than two locomotives and 1½ miles of track are required for the industrial railway feature of this operation.

If the concrete is mixed at the unloading plant and hauled to the road, trucks are about the only hauling equipment than can be used satisfactorily. Trucks for this purpose should preferably be equipped with turn-over dump bodies rather than hoisting dump bodies. (See Fig. 2, Pl. V.) In hauling, the concrete has a tendency to compact and stick to the truck body, making the discharge rather difficult. If hoisting dump bodies are used, a high angle of hoist is desirable. A comparatively dry concrete is more readily discharged from trucks than a wet, sloppy mix. It is generally accepted that concrete mixed at a central plant should be deposited in the pavement within 30 to 35 minutes after being mixed, though tests made by the Bureau of Public Roads show that the final placement may be delayed by as much as three hours without materially affecting the strength of the concrete. This limitation of time necessarily determines the limit of haul for mixed concrete. Under extremely favorable conditions mixed concrete may be hauled as far as 6 miles. The hauling of mixed concrete is particularly advantageous on work where the supply of water along the road is limited. Its principal disadvantages are that the subgrade must be used for hauling and that considerable delays are caused even by moderate rains.

HANDLING AND STORING MATERIALS.

Cement.—Cement for concrete-pavement construction may be purchased either in bulk or in sacks. Bulk cement is not used to any extent; in fact, its use is practically confined to operations where proportioned aggregate or mixed concrete is hauled to the road. Even for this use it is not recommended on account of the difficulty of measuring the proper quantity of cement for each batch. If it is used, the proper quantity for each batch should be weighed or measured by means of separate compartments placed in the batch boxes. Bulk cement is usually shipped in open-top cars, covered with tarpaulins for protection from the weather. It may be unloaded with a clamshell bucket. Storage for cement should always be provided at the unloading yard. The storage house should be leak-proof and should be lined with roofing paper to prevent the free circulation of air. The floor of the house should be elevated above the ground. The necessary storage capacity will depend upon the size of the job and the capacity of the equipment, but for the average small job of approximately 4 miles, storage capacity should be provided for about 2,000 barrels of cement. Storage capacity is especially desirable in case it should be necessary to hold the cement until tests can be obtained or until the cement has aged sufficiently to pass the soundness test. Where the materials are hauled to the road separately, the cement may be hauled by any of the methods previously described for hauling aggregates separately. With this method of operation, some storage of cement on the road is desirable. Cement stored on the road should be piled on boards, or racks, at convenient intervals and shelter should be provided for use in case of rain.

Aggregate.—A number of methods may be employed for handling the materials into the mixer. Where the aggregates are distributed on the subgrade they may be handled into the mixer skip by wheelbarrows or by a belt-conveyor loader as shown in Figure 1, Plate III. Wheelbarrows are most commonly used, and, where labor is plentiful and inexpensive, this method will prove economical. The materials should be distributed in such manner that no unnecessary labor and time will be consumed in wheeling the materials long distances to the mixer. The belt-conveyor loader consists essentially of a long, steel frame, on traction wheels, operated by independent power, on which low, bottom-dump measuring boxes are placed for measuring the materials and discharging them upon the belt conveyor. A wide continuous belt carries the materials forward to the loading skip. The principal advantage of the conveyor loader is that it does away with the wheelers. Its disadvantages are that the aggregates must be very accurately distributed on the subgrade for efficient operation, and on roads of average width it is very difficult to distribute the materials within the area of the subgrade so that no shoveling of material is necessary in setting the forms.

If the aggregates are stored in small stock piles on the subgrade or on the shoulders of the road, they are usually picked up by some form of bucket elevator and loaded in the proper proportions into batch boxes, light trucks, or carts in which they are hauled to the mixer and discharged directly into the skip. If batch boxes are used, they are hauled to the mixer by horse-drawn cars running on short sections of industrial track. (See Fig. 2, Pl. III.) The principal advantage of this system is that the materials can be placed on the shoulders of the road before the grading is begun, thereby allowing the teams or trucks to use the road before it is disturbed. Where materials are delivered to the mixer in batch boxes a derrick is necessary to hoist the boxes from the cars and swing them over the mixer skip. For this purpose the derrick may either be attached to the mixer or independent of it. A derrick attached to the mixer may be operated either by utilizing the power developed by lowering the skip or by independent power obtained from the mixer. That which utilizes the power developed by lowering the skip requires fewer working parts and less power expenditure than any other method. It is not as flexible, however, as a derrick operated by independent power and has the disadvantage that the same relative elevation must be maintained between the track and the subgrade in order that a constant height of lift may be secured to swing the boxes free of the cars. There is no particular advantage in using a derrick independent of the mixer when batch boxes are discharged into the mixer skip. The added expense of operation does not appear to be justified. However, for very large mixers, with overhead charge, a crane independent of the mixer must be used. These mixers are usually not equipped with traction and therefore depend upon an autocrane for movement.

Water.—The usual sources of water supply are city mains, running streams, lakes, ponds, or wells. A city main is the most satisfactory source of supply that can be obtained, as a uniform pressure is secured and no pump is required. It is seldom, however, that the work is located so that city water can be used. A frequent error on the part of engineers and contractors is that of overestimating the amount of water which can be obtained from any given stream or pond. Information should be obtained locally as to dry-season flow before placing dependence on small streams for water supply.

The most practicable method of delivering water is to pump it through a pipe line laid along the road. The diameter of the pipe line should be not less than 2 inches. If very large mixers are used, a pipe of larger diameter will be necessary in order to obtain sufficient water for curing. Tees for supplying water to the mixer and for sprinkling should be placed in the pipe line at intervals of from 200 to 300 feet. Gate valves should be spaced about 1,000 feet apart and unions about 500 feet apart. Rubber hose of 1½ inch diameter should be used for connecting the pipe line with the mixer, while 1-inch hose is usually used for sprinkling. Provision should be made for the expansion of the pipe either by providing expansion devices on the pipe line or by "snaking" the line. For cold-weather construction drain valves should be placed at all low points in order that the pipe may be drained to avoid damage by freezing.

Either steam or gasoline pumps may be used for supplying water. The horsepower required to deliver a stated quantity of water at any given point will depend upon the length and size of the pipe line and the height the water has to be raised from the source to the work. A method of computing the horsepower required for the delivery of different quantities of water is given in the appendix, page 63. To avoid overloading the pump, a relief valve should be placed in the pipe line near the pump. This valve should be set to open when the pump pressure exceeds that needed, and provision should be made to discharge the water back into the source of supply so that waste of water will be avoided.

The amount of water required for concrete-pavement construction is approximately 30 gallons per square yard of pavement. A 4-sack mixer laying an average of 800 square yards of pavement per 10-hour day will require 24,000 gallons of water, or 40 gallons per minute, for mixing and curing. The failure of the water supply is responsible for many of the delays in concrete construction. These delays may be overcome to a marked extent by using double-unit pumps. The added expense of this type of pumping plant is usually justified on work of any considerable magnitude.

MIXING AND PLACING.

The quantities of all materials entering into the concrete should be accurately measured before they are placed in the mixer. If wheelbarrows are used, their capacity should be checked by means of a 1-cubic-foot measuring box. No size of batch should be permitted which would require fractional sacks of cement. Concrete for pavements should invariably be mixed by means of mechanical mixers. If it is mixed at a central plant and hauled to the road, any satisfactory type of building mixer may be used. If it is mixed on the road, a paving mixer provided with traction and equipped with a device for distributing the concrete will be the most economical to use. Figure 1, Plate V, shows one type of mixer and a finishing machine.

The device to convey the concrete from the drum of the mixer to its place in the road may consist of a bucket and boom attachment or a chute. The bucket and boom device is believed to be preferable for pavement work, especially if a relatively dry mix is required. In chute distribution the tendency is to mix the concrete rather wet so that it will readily flow down the chute, and this is objectionable

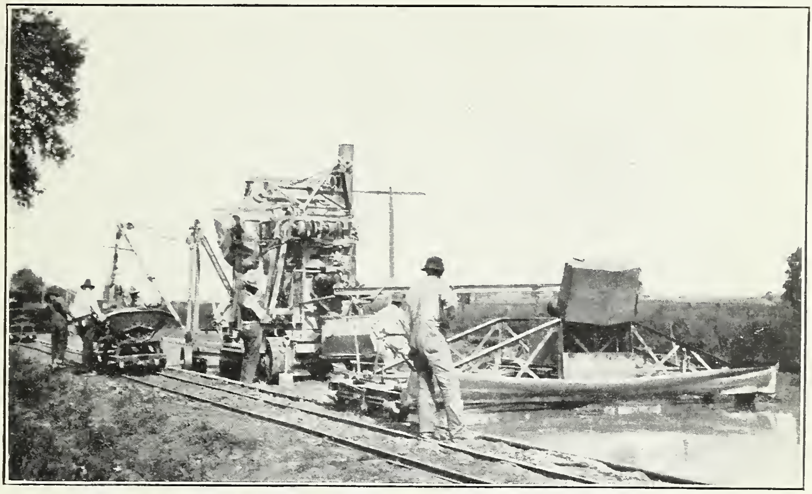


FIG. 1.—MIXING AND FINISHING THE CONCRETE.

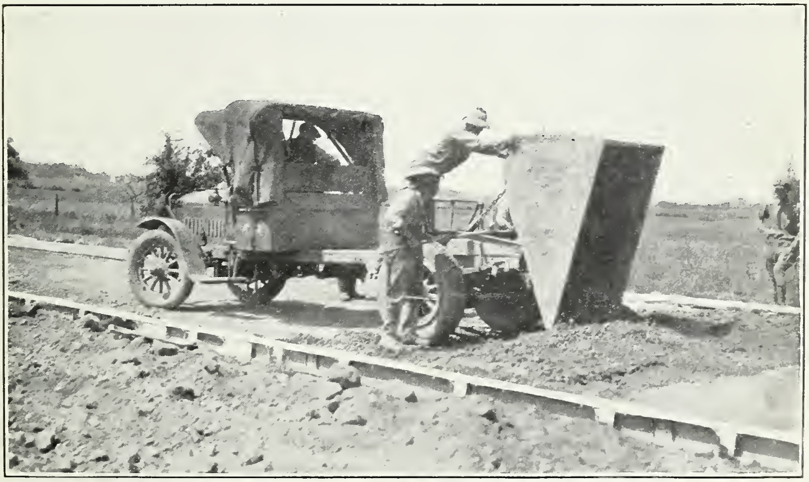


FIG. 2.—DUMPING MIXED CONCRETE ON THE ROAD.

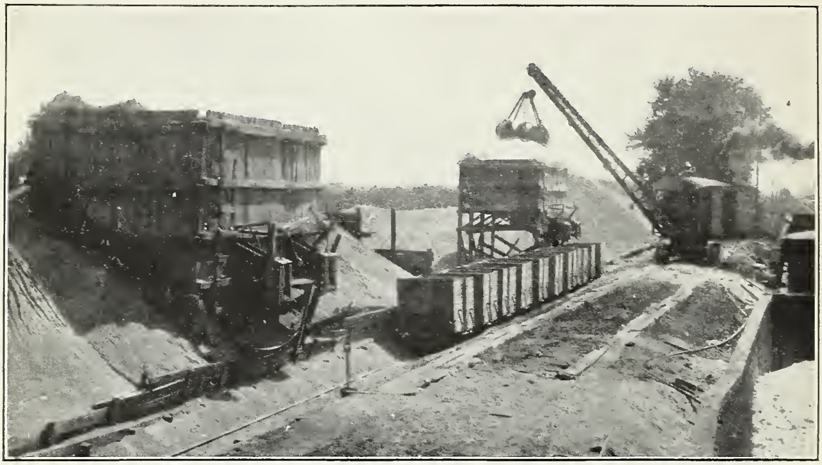


FIG. 1.—LOADING BATCH BOXES FROM OPEN BINS.

FIG. 2.—LOADING TUNNEL FOR BATCH BOXES.

because the excess of water reduces the strength of the concrete, and there is a tendency for the mortar to separate from the coarse aggregate.

The concrete should be mixed thoroughly to a uniform consistency. The time of mixing bears an important relation to the quality of the output. Generally speaking, the longer the time of mixing within practical limits, the greater will be the strength and the resistance to wear. On the other hand, longer-mixing means reduced production and more expensive concrete. The time of mixing should be long enough to secure the maximum of strength at a minimum of cost. One minute of mixing appears to meet this condition. Certainly, the time allowed should not be less, and it is questionable whether the increased strength obtained with a longer mix justifies the increased expense. To insure the mixing of every batch for the proper length of time the mixer should be equipped with an automatic timing device, or a combination timing and locking device that will prevent its discharge until all the materials have been mixed together for the minimum time required.

The consistency of the concrete also affects its strength and wearing qualities. For maximum strength and wear, only sufficient water should be used in mixing to secure a good workable consistency. The water-measuring tank on the mixer should be used as a means of obtaining the proper amount of water for each batch. A test known as the slump test is employed as a check on the consistency. The slump test is made by filling a metal form with the concrete to be tested, tamping it down until all the voids are filled and a slight film of mortar appears on the surface. The form is then removed and the vertical settlement or slump is noted as a measure of its consistency. The form may be either a cylinder or a frustum of a cone. If a cylinder is used, it is 6 inches in diameter and 12 inches in height. The settlement or slump in this case should not exceed 2 inches for proper consistency. If the frustum of a cone is used, the top diameter should be 4 inches, the base diameter 8 inches and the height 12 inches. The slump in this case should be not greater than 1 inch, nor less than ½ inch for proper consistency. (See Fig. 1, Pl. IX.)

After the concrete has been mixed the required length of time it should be placed between the side forms to the full thickness of the pavement and in successive batches for the entire width. If the subgrade is dusty, it should be sprinkled lightly before the concrete is placed. Each batch of concrete should be dumped as nearly in place as practicable and leveled off with shovels. If for any cause a wet batch or a batch in which portions of the aggregate are separated is deposited in the road, it should be thinly distributed over the subgrade so that there will be no segregated material in the surface of the pavement. Exceptionally wet batches should be shoveled from the subgrade and wasted on the shoulders.

FINISHING THE SURFACE.

After the concrete has been spread approximately to the required cross-section, the finishing operations are begun. These operations consist of striking-off and tamping the concrete, and finishing the surface. Two methods may be employed, viz, hand finishing and machine finishing. In hand finishing, each operation must be performed separately, while in machine finishing all operations can be performed simultaneously. Machine finishing is greatly to be preferred.

Hand finishing.—The concrete is first struck off with a strike board having from one-fourth to one-half inch more crown than the finished crown of the pavement. This allows for a slight amount of settlement when the concrete is compacted. The striking off is accomplished by advancing the strike board with a combined longitudinal and crosswise motion. A slight surplus of concrete should always be maintained ahead of the strike board. The tamping should be done by means of short, quick, up-and-down strokes of the tamper, which should have the same crown as the finished road. The best results are obtained by pivoting one end of the tamper on the side forms and advancing the other from 2 to 3 feet, at the same time tamping the area over which the tamper is advanced. This operation is then repeated by pivoting the tamper on the opposite form and advancing the end which was first pivoted. As soon as possible after the concrete has been tamped it should be rolled with a roller having a smooth, even surface and weighing approximately three-fourths of a pound per inch of length. The roller should preferably be 10 inches in diameter, and 6 feet in length and a long handle or ropes may be provided with which to operate it from the sides of the pavement. The purpose of rolling is to eliminate slight inequalities in the surface and remove the surplus water. After the pavement has been rolled the final finish is obtained by means of a belt. A 10 or 12 inch canvass or rubber belt is generally used for this purpose. The belt should be at least 2 feet longer than the width of the pavement and should be provided with wooden handles at each end. The first application of the belt should consist of long strokes with only a slight longitudinal advance at each stroke. A greater longitudinal advance and somewhat shorter stroke should be used for the second belting. The final belting should not be done until after the water glaze or sheen on the surface disappears. It should consist of a rapid longitudinal advance with as short a stroke as possible. After the final belting the pavement should present a smooth, uniform surface. Suitable designs for the tools used in the hand finishing of pavements are shown in Figures 9 and 10. The small, long-handle float can be used to great advantage in touching

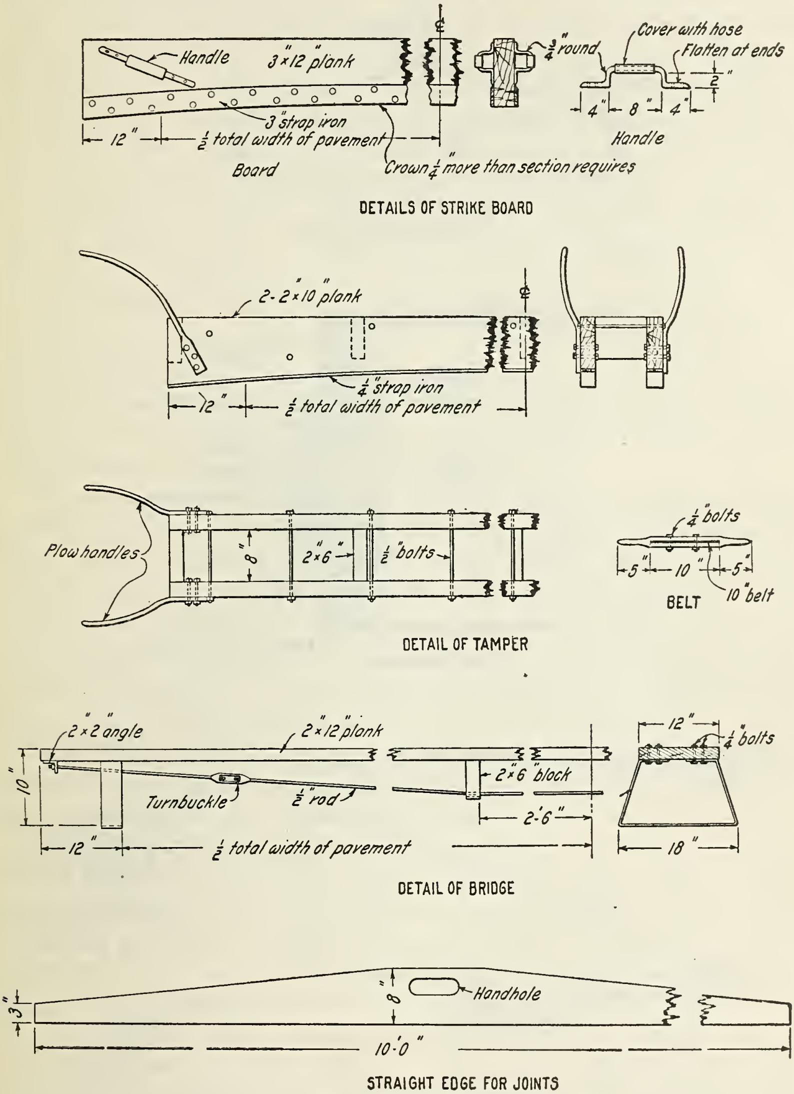


Fig. 9.—Details of tools used in hand finishing.

up rough spots in the pavement when a particle of coarse aggregate has been dislodged by the belt.

Machine finishing.—Machine finishing is accomplished by means of a power-driven mechanical finishing machine. (See Fig. 2, Pl.

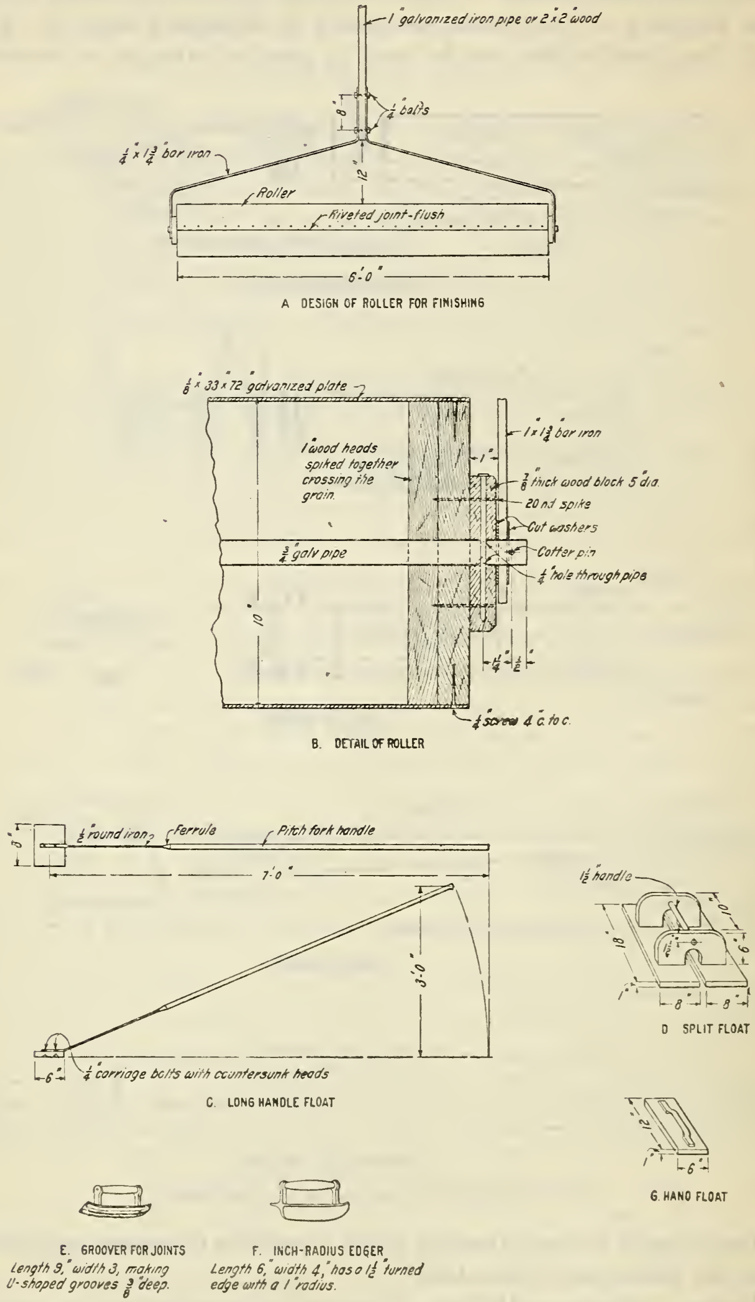


FIG. 10.—Details of tools used in hand finishing.

VII.) The machine is supplied with flanged wheels, which travel on the side forms used for the pavement. Power for traction and operation is generally furnished by an air-cooled gasoline engine. The machine is provided with a striking template, a tamper, and a finishing belt so arranged that each may be operated separately, or any two, or all operated simultaneously. In practice, the striking template and tamper, and the tamper and belt are usually operated at the same time. After the concrete has been roughly spread it is struck off by means of the striking template. On the second passage of the machine, the strike board is still in place and the tamper is placed in operation. The third time over usually only the tamper is permitted to operate. For the fourth passage both the tamper and the belt are used. For the final finishing operation either the belt alone is employed, or the tamper and belt. A common fault where machine finishing is used is the tendency to let the machine do a large part of the spreading. The machine was never intended for this purpose and will not operate satisfactorily if a large amount of concrete must be pushed ahead of the striking template. For best results not more than 2 inches of excess thickness should be ahead of the striking template at any one time.

The principal advantages of a finishing machine from the standpoint of cost are derived from the striking template and the tamper. These devices replace the usual heavy timber strike board and tamper, which require from two to four men to operate them. From an engineering standpoint the machine serves a useful purpose by making it possible to use a drier and hence a stronger concrete than it would be possible to use if hand finishing methods were employed. Its principal disadvantage is that it is not adjustable to various widths of pavement without providing new trusses, striking template, and tamper. The objection is not serious, however, in States that have their road widths well standardized.

From the standpoint of the traveling public the finish of the surface is the most important quality of the pavement. Regardless of its strength and wear, the traveler invariably judges a pavement by its riding qualities. A smooth surface should, therefore, be the constant aim. The surface should be frequently tested by means of a straightedge laid parallel to the center line of the pavement. Variations in the surface of over one-fourth inch in 10 feet should be corrected before the final belting. The joints are the chief source of trouble in securing a good surface. High joints can practically be eliminated by the use of the straight-edge, and its use is particularly recommended at joints between sections of concrete laid on different days. The edges of the pavement and of all joints should be rounded to about 1-inch radius with an edging tool.

PROTECTING AND CURING THE CONCRETE.

The quality of the concrete depends to a great extent upon the conditions under which it is cured. A concrete cured with the proper amount of moisture has strength and wearing qualities almost twice as great as the same concrete cured in the open air. Either of the following general methods may be used for curing: Covering the pavement with earth or straw, and keeping this material moist; or covering the pavement with water. Until the pavement has set sufficiently hard so that it will not be damaged by walking upon it, it should be protected with a canvas covering. The canvas covering may be supported by wooden frames or laid directly on the concrete if care is taken to avoid marring the surface. (See Fig. 1, Pl. VIII.) Under ordinary weather conditions about 24 hours will be required for the concrete to set sufficiently hard not to be damaged by walking upon it.

If an earth covering is used it should be at least 2 inches thick and should cover the edges of the pavement. It should be thoroughly watered twice each day for a period of 14 days and remain upon the road for at least 20 days from the time of its application. The earth for covering is usually obtained from the shoulders or the sides of the road. Where earth for covering is difficult to obtain, as for example, where the shoulders are composed of hard compacted material, straw may be used, in which case the covering should be not less than 4 inches thick after wetting. The principal advantage in the use of straw is that it can be easily loaded and hauled forward for use again. In localities where straw can be obtained at small cost it is believed to be more economical than earth.

The method of curing by covering the pavement with water is commonly called "ponding." (See Fig. 2, Pl. VIII.) The water is retained on the pavement by earth dams placed across and along the edges of the pavement. The pavement is then covered with water to a depth of 2 inches. The water should be maintained on the surface for a period of not less than 14 days. Flooding is generally done in the evening when the water is not needed for the mixer. The ponding method is more positive than any other, and should be used wherever possible. It can not be used satisfactorily, however, on grades in excess of 3 per cent or where the earth available for the dams will not retain the water.

During the period of curing the roadway should be kept entirely closed to traffic. If the weather conditions are favorable for rapid curing, as for example during midsummer, the pavement should be sufficiently strong to be opened to traffic at the end of 21 days. In cold weather a longer time should elapse before traffic is permitted on the pavement.

When the average temperature is below 50° F. it is better to omit covering and ponding, and sprinkle the pavement only when the concrete shows signs of drying out too rapidly. Sprinkling night and morning will usually be sufficient; it should be omitted altogether when there is danger of freezing.

PLACING CONCRETE IN FREEZING WEATHER.

Concrete pavement construction should not be attempted during freezing weather. Satisfactory results can not be obtained, and the expense of attempting to heat the water, the aggregates, and the finished work is not justified unless only a very short length of pavement is necessary in order to complete an important piece of work. If danger of freezing develops after the concrete is laid and before it has developed a hard set, the pavement should be protected by means of a heavy layer of straw, covered with canvas. Concrete should not be placed upon a frozen subgrade, and should not be mixed and placed when the air temperature is below 35° F.

ORGANIZATION AND EQUIPMENT.

When it is considered that from 50 to 60 per cent of the total cost of constructing a concrete pavement is chargeable to the equipment and labor employed in doing the work after the materials are delivered at the unloading plant, the importance of proper organization, proper equipment, and economical methods becomes clearly apparent. Failure to give these features proper consideration may easily result in adding from 10 to 25 per cent to the cost of a concrete pavement, and has no doubt frequently caused contractors to sustain a net loss on projects where profits might have been made.

It is not the province of this bulletin to furnish detailed rules for the guidance of contractors in planning and executing their work, but it seems desirable to discuss briefly a few important points which contractors and engineers in charge of force account work should consider in concrete pavement construction. The points which are of most importance and to which the discussion will be confined are concerned first with the proper order and progress of the work; second, the selection of equipment; and, third, the amount of capital necessary to carry on the work economically.

ORDER AND PROGRESS OF THE WORK.

In constructing a concrete pavement it is especially desirable that the work of mixing and placing the concrete shall proceed without unnecessary interruption after it is begun. When the mixer is permitted to stand idle for even a few days, the force of laborers employed in operating it will usually become more or less disorganized and a certain amount of loss and unsatisfactory work will generally result when the mixing is resumed. On this account the order and progress of the work should ordinarily be planned with the primary view to keeping the mixer going full time every working day that the weather will permit. This means that ample provision should be made for completing the drainage structures, the grading, and the preparation of the subgrade well ahead of the mixer. Provision should also be made for supplying the mixer with all necessary materials. Where the materials are obtained by rail shipment, and it is expected that these shipments will be rather irregular, sufficient material for at least ½ to 1 mile of road should be stored on the subgrade or at the unloading yard before the mixing is started. This material can be stored with a comparatively small working force, so that an interruption of their work will not be as costly as a delay to the full hauling and mixing force.

The small drainage structures should preferably be completed in advance of the grading in order to obviate the necessity of moving embankment material the second time. They should always be completed in advance of the pavement. It is not economical to leave out a section of the pavement over a small culvert, and this practice should not be permitted. The extra expense involved in going back and putting in a section of this kind after the pavement has progressed a considerable distance ahead is usually considerable and is often underestimated. This method of doing the work also involves a delay in opening the road, adds two extra joints, and usually results in securing an improperly cured pavement over the culvert.

Organizing a force of laborers to operate a paving mixer efficiently requires considerable skill in handling men. The best results are generally obtained when a mixer is fully manned and each laborer is assigned a definite work to perform.

Diagrams showing organization and plant layout for a number of typical methods employed in concrete pavement construction are given in Figures 11 to 15, inclusive. These organizations and layouts have been used in actual construction work and have proved to be very satisfactory.

EQUIPMENT.

Any discussion of equipment must necessarily be more or less general, because the same equipment is not always best suited for each particular piece of work. Each project possesses certain characteristics which determine the kind of equipment best adapted for handling it. A contractor may either wait until he has secured a contract before he decides on the type of equipment to purchase or he may purchase the equipment which he feels will give him the best satisfaction and only bid on work for which this equipment is suited.

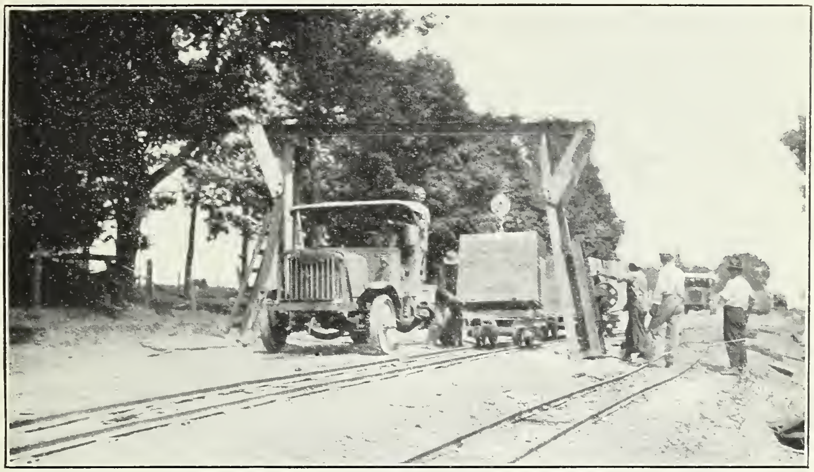


FIG. 1.—TRANSFERRING BATCH BOXES FROM TRUCK TO INDUSTRIAL RAILWAY.

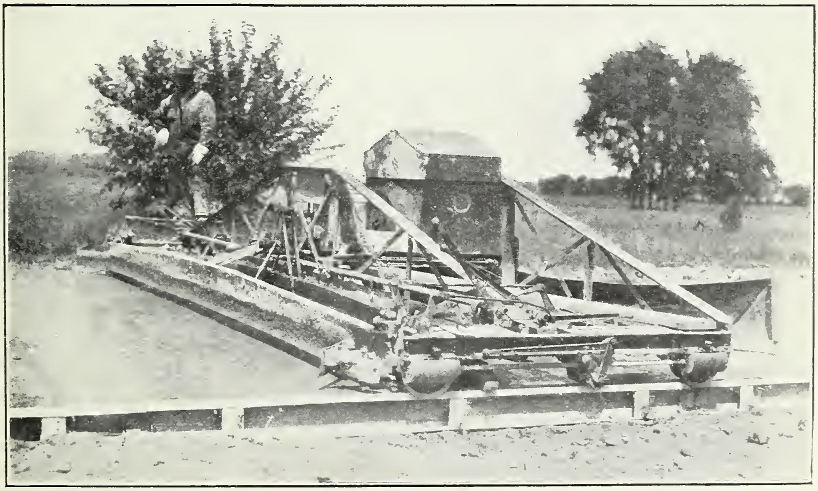


FIG. 2.—MECHANICAL FINISHING MACHINE FOR CONCRETE PAVEMENTS.

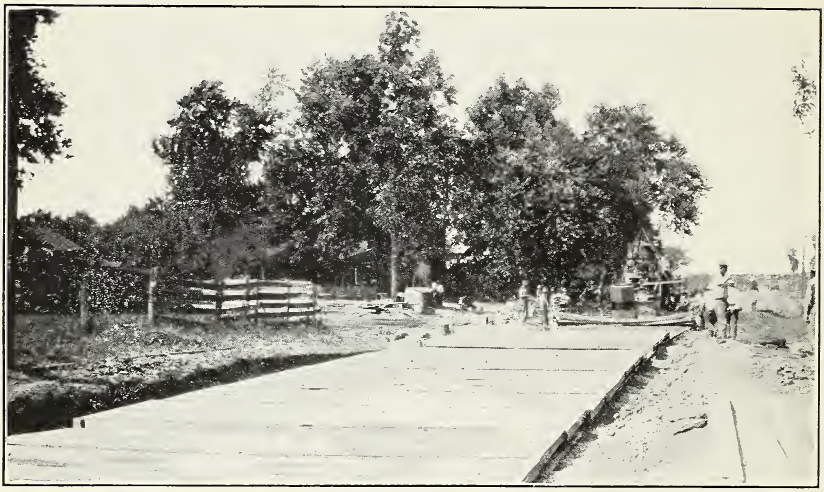


FIG. 1.—PROTECTING NEWLY LAID CONCRETE WITH CANVAS STRETCHED ON WOODEN FRAMES.

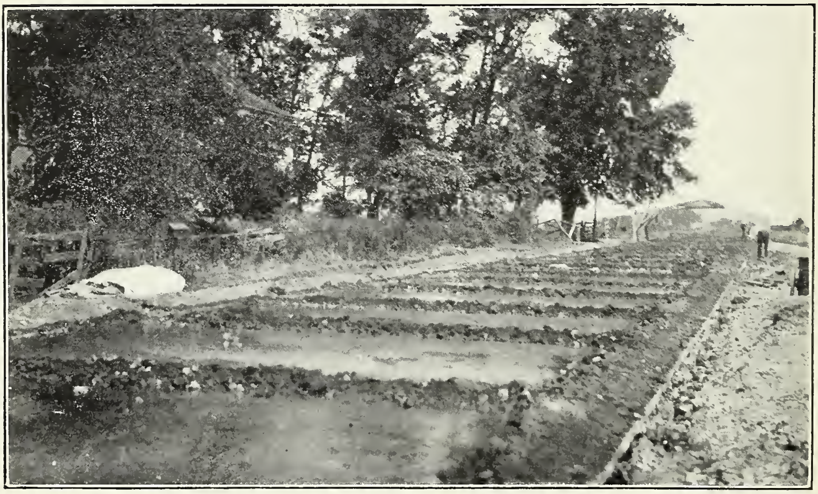
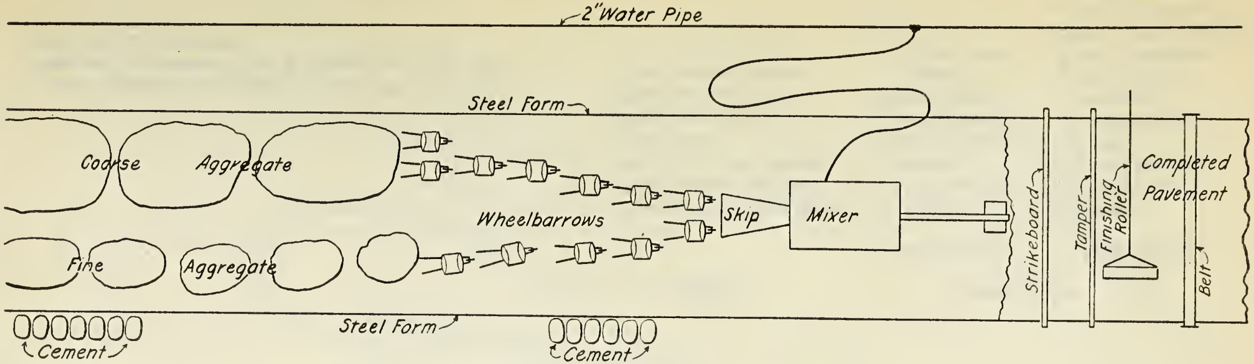


FIG. 2.—THE PONDING METHOD OF CURING.



ORGANIZATION AND EQUIPMENT

DISTRIBUTION OF FORCE

1 Foreman
7 Men wheeling coarse aggregate
3 Men loading coarse aggregate
4 Men wheeling fine aggregate
2 Men loading fine aggregate
2 Men handling cement
1 Mixer Engineer
1 Fireman
1 Formsetter
3 Men spreading concrete
2 Men striking off
2 Men tamping
1 Concrete finisher

NOTE

Men for preparing the subgrade, setting the forms, and covering the concrete with earth should be provided in addition to the above.

This organization is capable of laying from 350 to 400 linear feet of pavement 8 inches thick 16 feet wide per 10 hour day under favorable conditions.

MAJOR EQUIPMENT

1 Four-sack Concrete mixer
1 Road Roller
12 Wheel barrows
1 Strike board
1 Tamper
1 Concrete finishing roller
1 Finishing belt
Pump and water pipe
Steel forms
Shovels-Forks and miscellaneous

FIG. 11.—Typical organization and plant layout, wheelbarrow equipment.

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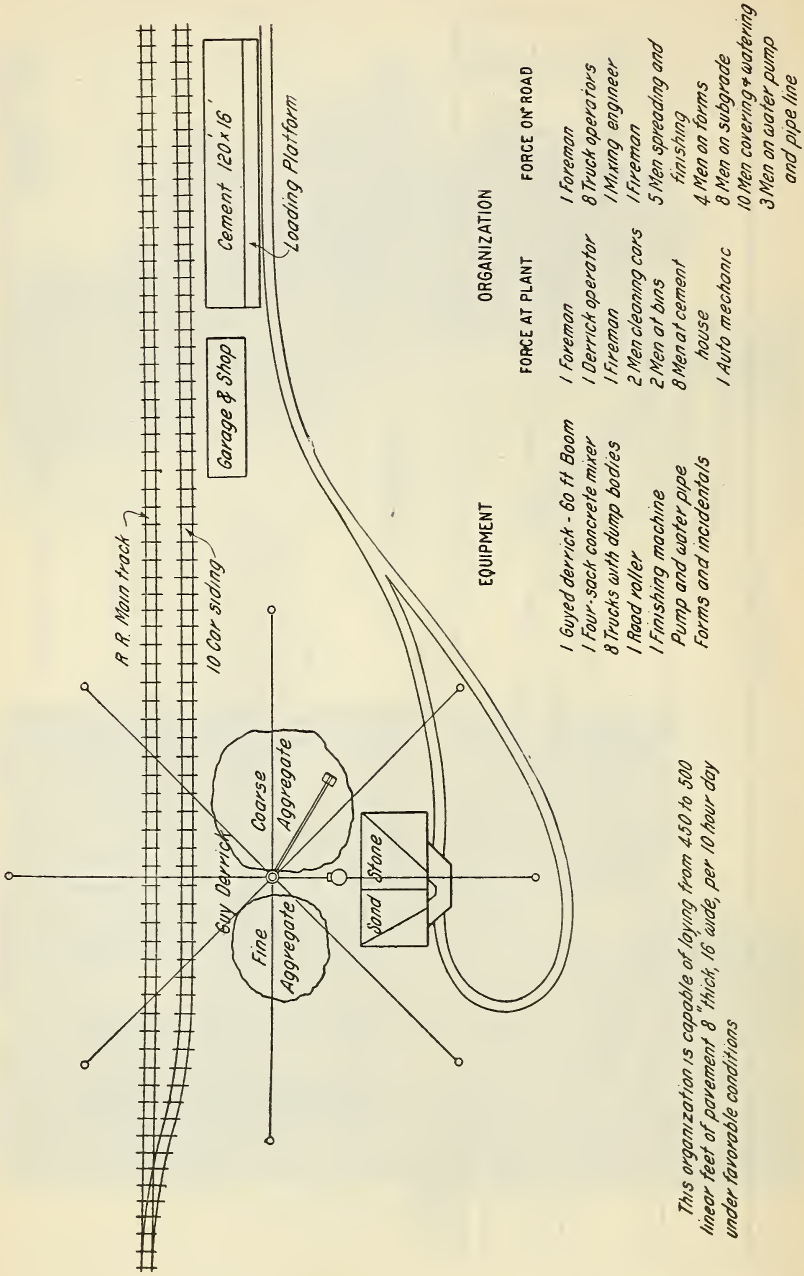

FIG. 12.—Typical organization and plant layout, truck haul.

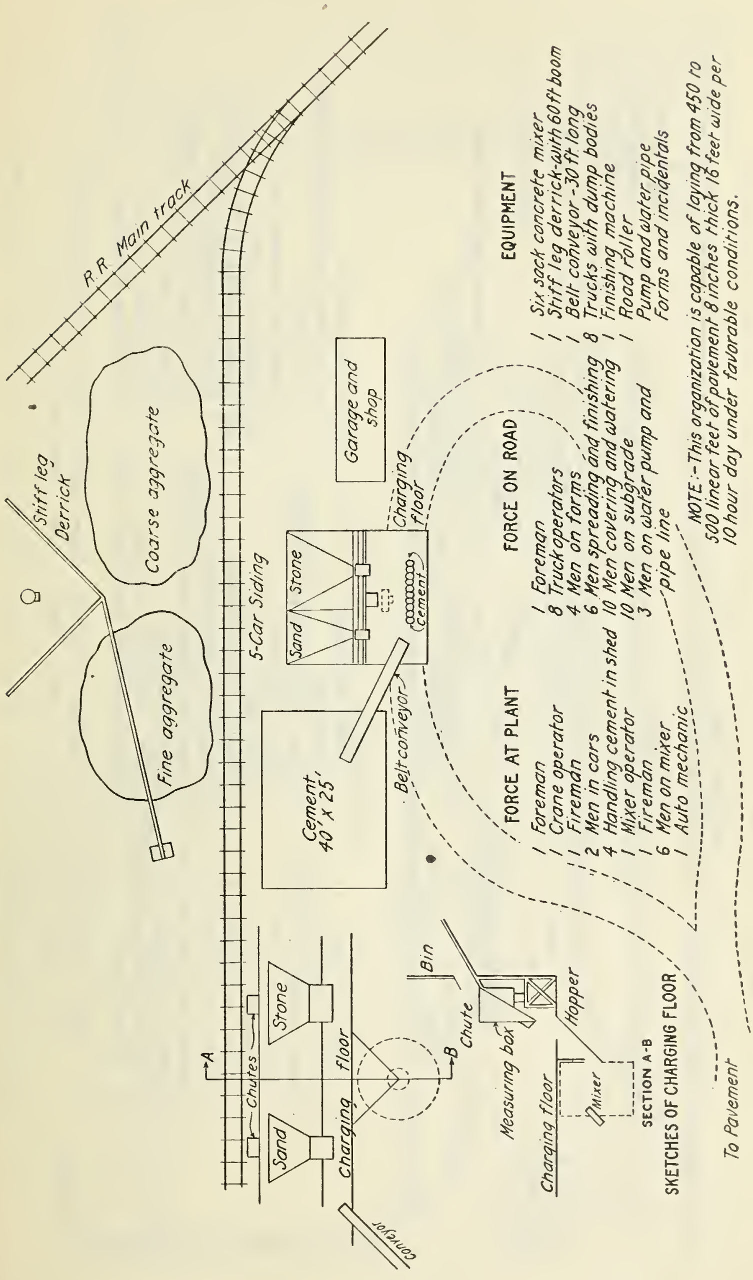

FIG. 13.—Typical organization and plant layout, central mixing, truck haul.

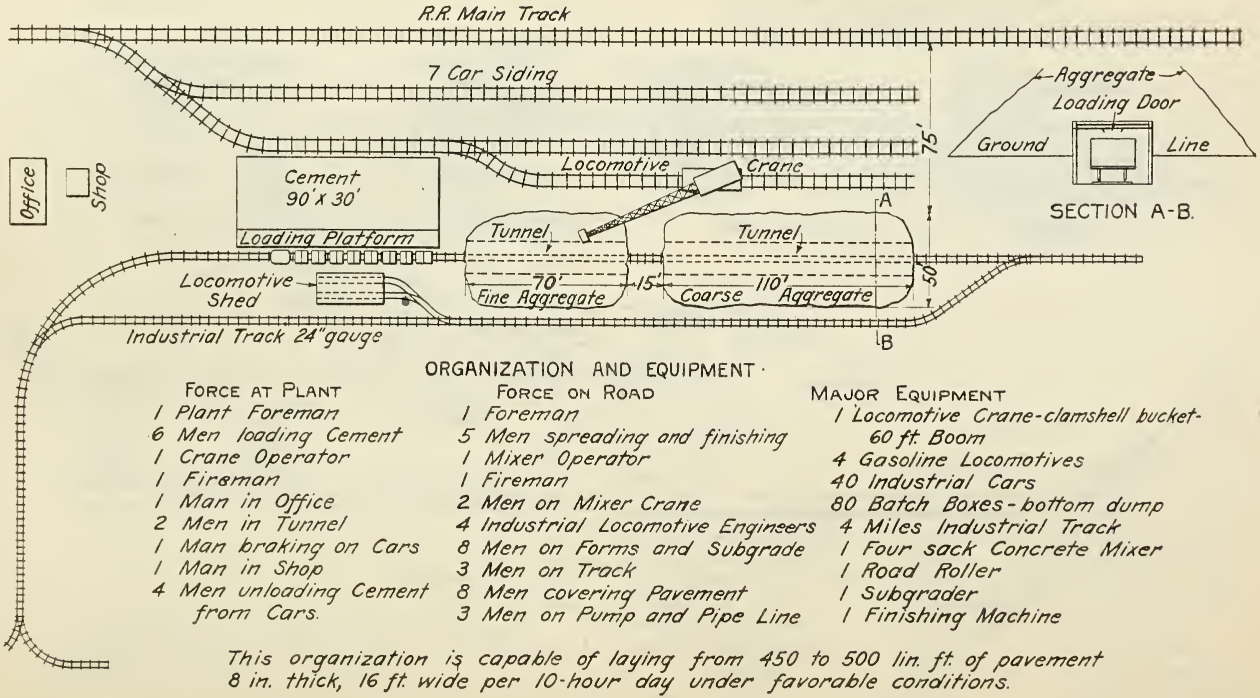

FIG. 14.—Typical organization and plant layout, central proportioning, tunnel loading, industrial haul.

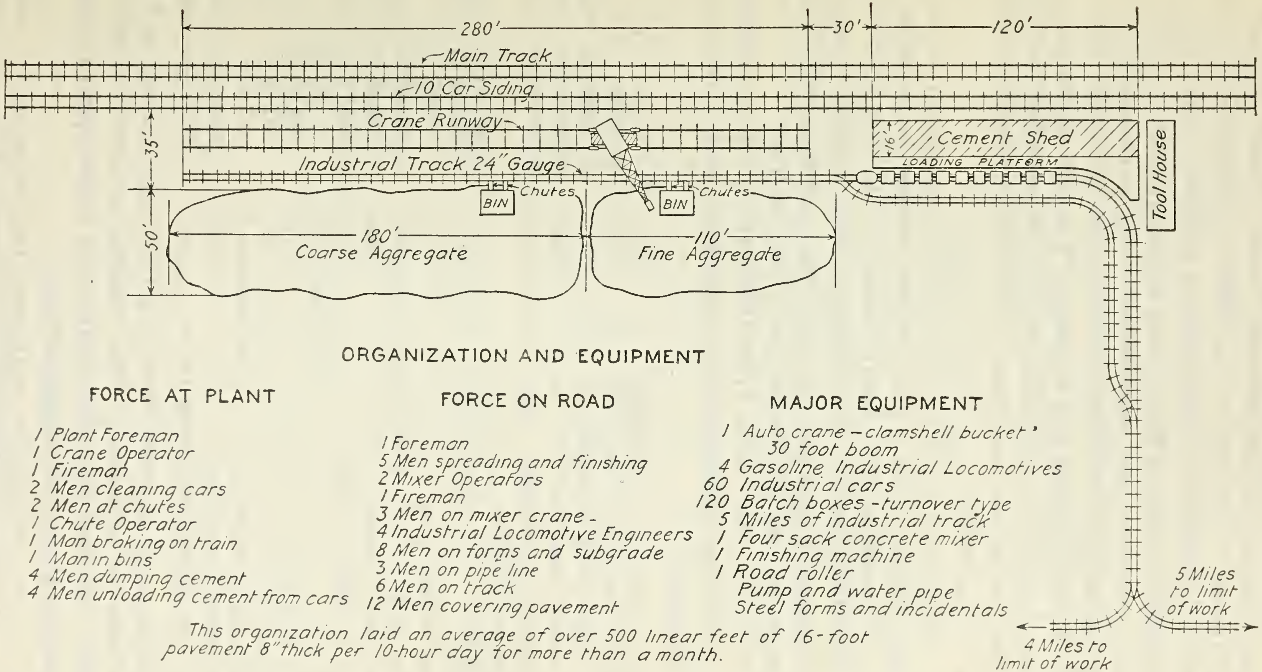

Fig. 15.—Typical organization and plant layout, central proportioning, open bin loading, industrial haul.

The magnitude of the work should be a guide in purchasing equipment. One 2-sack mixer would be as much out of place on a 10-mile contract as an 8-sack mixer would be on a 1-mile contract. Considering the two extremes of too little equipment and too much equipment, the tendency of contractors, especially those just entering this class of work, is toward too much equipment. The success of a contractor upon the completion of any work should be measured by the amount of money the work has produced, not by the amount of equipment he has on hand. The aim of the contractor, therefore, should be to finish the work in the specified time and use the smallest amount of equipment with which operations can be carried on economically.

The capacity of each piece of equipment purchased should bear its proper relation to the capacity of the combined equipment in order that all parts may be nicely balanced. A large mixer with a small unloading plant or poor transportation facilities would be a poorly balanced equipment on which the contractor would not receive proper returns in efficiency for his expenditure.

The following list, based upon 1920 prices, will give some idea of the cost of the various kinds of equipment used in building concrete pavements:

Locomotive cranes with clamshells	each	$15,000.00	to	$20,000.00
Automotive cranes with clamshells	do	6,500.00	to	12,000.00
Derrick cranes with clamshells	do	4,500.00	to	6,500.00
Mixers—4-sack capacity	do	6,500.00	to	9,000.00
Road rollers—macadam type	do	3,500.00	to	4,800.00
Industrial locomotives:				
Gasoline	do	2,500.00	to	4,500.00
Steam	do	5,000.00	to	8,000.00
Industrial railway cars	do	75.00	to	90.00
Industrial railway track, 24-inch gauge	per mile	4,500.00	to	5,800.00
Industrial batch boxes	each	35.00	to	70.00
Concrete finishing machines	do	1,600.00	to	2,000.00
Steel forms	per lineal foot	.50	to	.60
Subgrade planer	each	400.00	to	500.00
Water pump	do	600.00	to	1,000.00
2-inch wrought-iron pipe	per lineal foot	.22	to	.25
Tractors, caterpillar, 5-ton	each	5,500.00	to	6,500.00
Trucks, 3-ton capacity, with dump bodies	do	3,000.00	to	5,000.00

The equipment necessary for doing the rough grading and building culverts in connection with concrete pavement work is not essentially different from that required for other types of pavements and needs no particular discussion here.

The total expenditure for equipment for preparing the subgrade mixing and placing and finishing the concrete depends on the rate at which it is proposed to carry on the work. Based on 1920 prices for equipment, a wheelbarrow outfit, consisting of a four-sack mixer, finishing machine, road roller, water pump, pipe, forms, and all other miscellaneous equipment, will cost approximately $18,000, exclusive of the grading, unloading, and hauling equipment. An industrial railway outfit, consisting of a four-sack mixer, unloading crane and clamshell bucket, 4 miles of industrial track, 60 industrial cars, 120 batch boxes, 4 gasoline locomotives, road rollers, subgrade planer, water pump, pipe, forms, and all other miscellaneous equipment, will cost approximately $75,000, exclusive of the grading equipment. The magnitude of this expenditure makes it imperative that considerable thought should be given to the selection of equipment and that a well-balanced outfit be secured.

CAPITAL REQUIRED.

The amount of capital required to carry on concrete-pavement construction depends almost wholly on the size of the project. As a general rule, the amount of working capital required after the equipment has been secured will vary from 5 to 10 per cent of the total amount of the contract. A small project will require a larger percentage of working capital than a large one; so that while a working capital of 10 per cent or over might be required on a comparatively small project, a relatively large project can often be handled with a working capital as low as 5 per cent of the contract total. The usual method of paying for the work provides for semimonthly or monthly estimates to the contractor based upon the amount of work done, from which a nominal percentage is withheld until the completion of the work. Ordinarily this method should enable the contractor to meet most of his bills for labor and materials after the first two or three estimates are paid. The amount of working capital required also depends to a considerable extent upon the quantities of materials maintained in storage. Some storage of materials is nearly always necessary and it is especially desirable that these materials be stored during the off season. The storage of a large quantity of materials usually requires an outlay of capital greater than the average pavement contractor can afford to make. The buyers of the pavement, however, whether State or local subdivision, can relieve the contractor of the burden of carrying stored materials by paying for materials delivered and placed in storage. This policy enables the contractor to secure storage of materials at the cost of unloading, and by encouraging such storage the time of completion of the work is generally hastened, benefiting both the State and the contractor. This policy is recommended.

COST OF CONCRETE PAVEMENTS.

The cost of concrete pavements depends upon the amount of grading necessary, the number and size of culverts required, the cost of cement and the aggregates, the price and efficiency of labor, and the nearness of the work to the unloading stations. These factors are entirely dependent upon the location of the work and are seldom exactly the same even for two projects in the same locality.

The most satisfactory method of arriving at the probable cost of a proposed pavement is first to ascertain by survey the amount of the various kinds of work to be done and the quantities of the materials required. An itemized estimate based on these quantities and the unit costs which prevail in the community for such work and materials may then be made. An intelligent estimate of cost requires considerable experience and knowledge of construction work. An estimate prepared without this knowledge represents nothing more than a blind guess. No attempt will be made to outline the procedure followed in making estimates of cost, because the subject can not be handled briefly. Following is the list of items included in a cost estimate form for one-course concrete pavement construction suggested by the Wisconsin Highway Commission. A number of these items frequently are overlooked in preparing estimates.

Item.	Operation.
Cost of sidings and moving equipment to job.	(*a*) Hauling and loading mixer, clamshell, pipe, pump, tools, camp equipment, industrial equipment, teams, trucks, etc.
	(*b*) Freight on above.
	(*c*) Unloading and hauling to job.
	(*d*) Moving overhead (other than rail shipment).
	(*e*) Cost of erection of camp, including water supply, storage bins, derrick, etc.
	(*f*) Return of above equipment to storage. (Note.—Item (*f*) is applicable only to job requiring whole season for completion or on last job of season.)
Lost time in moving equipment	Number days ......, at ...... per day. (Lost time to include time lost in transit to job, between jobs, or between different set-ups on same job.)
Cement	Number barrels in pavement.
	Cost per barrel f. o. b. destination.
	Cost of ...... barrels, at ...... per barrel.
	Cost of unloading, hauling, and covering.
	Cost of storing and rehandling ...... barrels.
	Insurance on stored cement and empty sacks.
	Sack loss.
	Freight return on empty sacks.
	Demurrage.
	Total cost of cement.
Clamshell and derrick supplies	Fuel, oil, etc., only. (Do not include repairs.)
Fine aggregate	Number of cubic yards including waste.
	Cost per ton at pit or quarry.
	Cost per cubic yard at pit or quarry.
	Freight per ton.
	Freight per cubic yard.
	Hauling cost per cubic yard.
	Estimated demurrage $.........., divided by total yardage gives cost per cubic yard.
	Cost rehandling from stock pile ......, divided by total yardage gives cost per cubic yard.
	Total cost per cubic yard on job.

FIG. 1.—MEASURING THE CONSISTENCY OF CONCRETE BY THE SLUMP TEST. TOO MUCH WATER USED IN MIXING THE SPECIMEN AT THE RIGHT.

FIG. 2.—SUPER ELEVATED CURVE BEFORE THE CONSTRUCTION OF THE SHOULDERS.

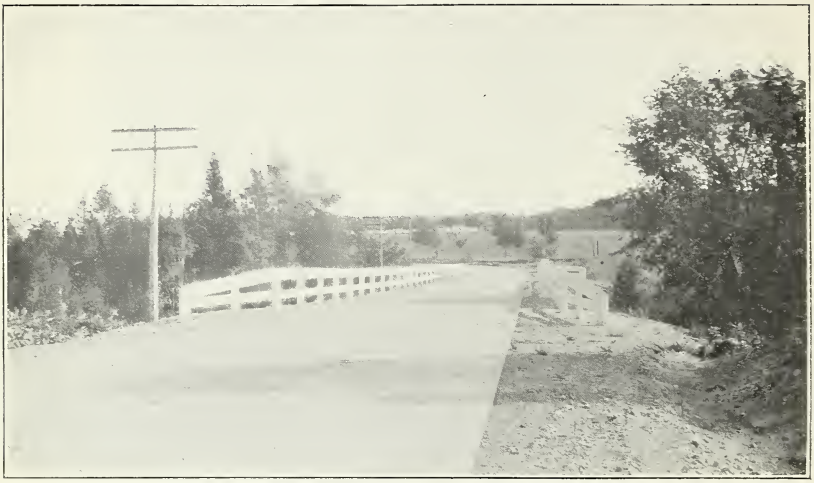

FIG. 1.—A FINISHED CONCRETE PAVEMENT.

FIG. 2.—FAILURE OF A THIN CONCRETE PAVEMENT UNDER HEAVY TRAFFIC.

Item	Operation.
Coarse aggregate	Number of cubic yards including waste. Cost per ton at pit or quarry. Cost per cubic yard at pit or quarry. Freight per ton. Freight per cubic yard. Hauling cost per cubic yard. Estimated demurrage $.........., divided by total yardage gives cos per cubic yard. Rehandling from stock pile per cubic yard. Total cost per cubic yard on job.
Surfacing	Preparation of subgrade. Cost of joint material on job. Cost of reinforcing metal on job. Labor, mixing, and placing concrete, including engineer, fireman, form setters, fine graders, wheelers, shovelers, cement men, puddlers, baling and sorting sacks, curing, covering, uncovering, finishers, water boy, watchmen, pump man, barricades, and lights. Cost of hauling mixed concrete, including fuel, and depreciation on hauling equipment. Water supply and pumping, including labor, connecting pipe, setting pump, fuel for pump, disconnecting pipe and drilling well. Mixer supplies, fuel and oil only. Miscellaneous supplies, such as boots, hardware, etc.
Camp loss	Including loss on board of men on operating days as well as on idle days, loss on full-time men not included in overhead, etc. (Do not include depreciation on camp equipment.)
Miscellaneous costs	(*a*) Cost of hiring and shipping in men. (*b*) Water rent. (*c*) Rent of grounds and buildings. (*d*) Cost of building cross-overs.
Contingencies	Delays due to railway embargoes, strikes at pits, quarry, or jobt material plant breakdown, machinery breakdown, failure of water supply, unusually bad weather, freezing of pipe line, etc.
Compensation and public liability insurance	
Bond cost	Personal or surety bonds.
Overhead	Per cent manager's yearly salary. Per cent yearly salary of stenographer and clerk. Per cent yearly salary material man and timekeeper. Per cent yearly expense of manager, including railway fare, hotel bills, bidding cost, auto, etc. Per cent yearly office rent. Per cent yearly office telephone and telegrams Per cent office supplies, miscellaneous. Corporation insurance. Interest on working capital not otherwise included Association dues.
Profit	
Charges for machinery and equipment	

For the benefit of those who may desire to have some idea of the cost of concrete pavements, a table has been prepared showing the weighted average cost per square yard and per mile of all Federal-aid concrete pavements contracted for or constructed in each of the States during the years 1919 and 1920. The costs per mile are based on a uniform width of 18 feet. The figures given are for the concrete pavement only and do not include the cost of grading, culverts, or bridges. This tabulation is given in the appendix, pages 64 to 66. In considering the costs given in these tables it should be borne in mind that the 1920 prices probably represent the peak of war prices.

MAINTENANCE.

The shoulders, slopes, and drainage structures of concrete roads require the same kind of maintenance as those of other types of improved roads. The maintenance of the pavement consists, for the most part, in repairing cup holes, cracks, joints, and perhaps the renewal of an occasional defective area. Cup holes are spots in the surface of the pavement which break down under traffic and which may result from a number of causes. The most frequent cause of such defects is the presence of sticks, lumps of clay, particles of unsound stone, or other soft material in the aggregates. When cup holes first appear they are usually from 1 to 2 inches in diameter and from ½ to 1 inch in depth, but they are gradually enlarged by the action of traffic, which loosens the concrete around their edges, and unless promptly repaired they may soon have an area of several square feet and a considerable depth. The action of traffic also gradually breaks away the concrete at the edges of cracks and joints, and if proper maintenance is not provided a considerable area of the surface of the pavement will be destroyed. The maintenance of cup holes, cracks, and joints usually consists of filling them with tar or asphalt and covering the bituminous material with coarse sand, pea gravel, or stone chips. Satisfactory results can be secured by this method only when a crew with proper equipment and materials goes over the road, making the necessary repairs at least once and preferably twice a year.

Where defects of any considerable size are to be repaired the edges should be chiseled down until they are approximately vertical and not less than 1 inch deep. The hole should be thoroughly cleaned and painted with tar or asphalt, after which it should be filled with clean, coarse stone chips, thoroughly grouted with tar or asphalt. The surface of the patch should then be covered with coarse sand, pea gravel, or fine stone chips. A cold mix of small stone and bituminous material has sometimes been successfully used for this type of repair work.

Either tar or asphalt may be used for making such repairs. Satisfactory results have been obtained with each. There is some difference of opinion among engineers as to just what consistency the tar should possess in order to give the best results, but the most general requirement in this particular seems to be that the tar when subjected to the float test in water at 50° C. will permit the float to sink n, about 100 seconds. In order to apply a tar of this kind satisfactorily, it is necessary that it be heated to about 225° F.

The repair equipment may consist of a small portable tar kettle, a light truck, pouring pots, wire brooms, hammers, and stone chisels. The tar kettle is usually hauled by attaching it to the rear of the truck.

When it becomes necessary to renew any portion of the pavement with concrete, that portion should be entirely closed to traffic, and the concrete should be mixed, placed, and cured in the same way as a new pavement. The edges of the old concrete should be thoroughly cleaned and coated with neat cement mortar before the new concrete is placed.

A properly constructed concrete pavement ought to wear down uniformly and develop few defects. Poorly constructed and poorly maintained joints are probably responsible for more defects of the kind described than can be attributed to any other one cause. For this reason the joints should receive very careful attention at the time of construction.

RESURFACING OLD CONCRETE PAVEMENTS.

Under certain traffic conditions it may be necessary at tmes to resurface old concrete pavements so as to provide an additional thickness of pavement for the increased traffic. The thickness of the resurfacing layer should be not less than 3 or 4 inches at any point, and the concrete should be mixed in the proportions of 1 : 1½ : 3, using a coarse aggregate graded from ¼ inch to 1½ inches in size. Steel reinforcement weighing at least 25 pounds per 100 square feet, placed in the middle of the resurfacing layer, should preferably be used where the resurfacing is to be 3 inches thick. If the resurfacing layer is to be 4 inches thick, it is not believed that any reinforcement is necessary. Where an old concrete pavement is to be resurfaced, it should be thoroughly cleaned and all the bituminous filling used to cover cracks and small holes removed. The new concrete is placed and finished in the manner previously described for concrete pavements. Joints should be provided in the resurfacing layer directly over those in pavement below. The service records of a number of resurfaced concrete pavements indicate that it is immaterial whether or not a bond is secured between the two layers of the concrete.

APPENDIX.

A. QUANTITIES OF MATERIALS REQUIRED FOR CONCRETE PAVEMENTS.

1 : 1½ : 3 mix.

Per cubic yard { Cement............ 1.91 bbls. / Fine aggregate.... .40 cu. yd. / Coarse aggregate.. .81 cu. yd.

Fine aggregate.... 0″ to ¼″
Coarse aggregate.. ¼″ to 1½″

Width.	Thickness.		Area.		Quantities per lineal foot.[1]				Quantities per mile.[1]			
	Edge.	Center.	Per linear foot.	Per mile.	Concrete.	Cement.	Fine aggregate.	Coarse aggregate.	Concrete.	Cement.	Fine aggregate.	Coarse aggregate.
Feet.	*In.*	*In.*	*Sq. yds.*	*Sq. yds.*	*Cu. yds.*	*Bbls.*	*Cu. yds.*	*Cu. yds.*	*Cu. yds.*	*Bbls.*	*Cu. yds.*	*Cu. yds.*
9......	6	[2] 8	1.000	5,280	0.204	0.389	0.081	0.165	1,077	2,057	431	872
9......	7	[2] 8	1.000	5,280	.213	.407	.085	.172	1,124	2,147	450	910
9......	6	6	1.000	5,280	.167	.319	.067	.135	881	1,683	352	713
9......	7	7	1.000	5,280	.194	.371	.078	.157	1,024	1,956	410	829
9......	8	8	1.000	5,280	.222	.424	.089	.180	1,172	2,238	469	949
10......	7	8	1.111	5,866	.237	.453	.095	.192	1,251	2,389	500	1,013
10......	6	6	1.111	5,866	.185	.353	.074	.150	977	1,867	391	792
10......	7	7	1.111	5,866	.216	.413	.086	.175	1,141	2,179	456	924
10......	8	8	1.111	5,866	.247	.472	.099	.200	1,304	2,490	521	1,056
16......	6	8	1.777	9,383	.361	.690	.144	.292	1,906	3,640	762	1,544
16......	7	8	1.777	9,383	.378	.722	.151	.306	1,997	3,814	799	1,617
16......	6	6	1.777	9,383	.296	.565	.118	.240	1,563	2,985	625	1,267
16......	7	7	1.777	9,383	.346	.661	.138	.280	1,827	3,489	730	1,480
16......	8	8	1.777	9,383	.395	.754	.158	.320	2,086	3,984	834	1,689
18......	6	8	2.000	10,560	.407	.778	.163	.330	2,149	4,105	860	1,741
18......	7	8	2.000	10,560	.426	.814	.170	.345	2,249	4,295	900	1,822
18......	6	6	2.000	10,560	.333	.637	.133	.270	1,758	3,358	703	1,424
18......	7	7	2.000	10,560	.389	.743	.156	.315	2,053	3,921	821	1,663
18......	8	8	2.000	10,560	.444	.849	.178	.360	2,344	4,477	938	1,898
20......	6	8	2.222	11,732	.453	.865	.181	.367	2,392	4,569	957	1,938
20......	7	8	2.222	11,732	.473	.904	.189	.383	2,498	4,771	999	2,023
20......	7	7	2.222	11,732	.432	.825	.173	.350	2,281	4,357	912	1,848
20......	8	8	2.222	11,732	.494	.943	.198	.400	2,608	4,981	1,043	2,112
20......	9	9	2.222	11,732	.555	1.061	.222	.450	2,930	5,596	1,172	2,373

1 : 2 : 3 mix.

Per cubic yard { Cement............ 1.74 bbls / Fine aggregate.... .49 cu. yd. / Coarse aggregate.. .74 cu. yd.

Fine aggregate.... 0″ to ¼″
Coarse aggregate.. ¼″ to 2″

9......	6	[2] 8	1.000	5,280	0.204	0.355	0.100	0.151	1,077	1,874	528	797
9......	7	[2] 8	1.000	5,280	.213	.370	.104	.158	1,124	1,956	551	832
9......	6	6	1.000	5,280	.167	.290	.082	.123	881	1,533	431	652
9......	7	7	1.000	5,280	.194	.338	.095	.144	1,024	1,782	502	758
9......	8	8	1.000	5,280	.222	.387	.109	.164	1,172	2,039	574	867
10......	7	8	1.111	5,866	.237	.412	.116	.175	1,251	2,177	613	926
10......	6	6	1.111	5,866	.185	.322	.091	.137	977	1,700	479	723
10......	7	7	1.111	5,866	.216	.376	.106	.160	1,141	1,985	559	844
10......	8	8	1.111	5,866	.247	.430	.121	.183	1,304	2,269	639	965
16......	6	8	1.777	9,383	.361	.628	.177	.267	1,906	3,316	934	1,410
16......	7	8	1.777	9,383	.378	.658	.185	.280	1,997	3,475	979	1,478
16......	6	6	1.777	9,383	.296	.516	.145	.219	1,563	2,720	766	1,157
16......	7	7	1.777	9,383	.346	.602	.169	.256	1,827	3,179	895	1,352
16......	8	8	1.777	9,383	.395	.687	.194	.292	2,086	3,629	1,022	1,544
18......	6	8	2.000	10,560	.407	.709	.200	.301	2,149	3,739	1,053	1,590
18......	7	8	2.000	10,560	.426	.741	.209	.315	2,249	3,913	1,102	1,664
18......	6	6	2.000	10,560	.333	.580	.163	.247	1,758	3,059	861	1,301
18......	7	7	2.000	10,560	.389	.677	.191	.288	2,053	3,572	1,006	1,519
18......	8	8	2.000	10,560	.444	.773	.218	.329	2,344	4,078	1,148	1,735
20......	6	8	2.222	11,732	.453	.788	.222	.335	2,392	4,162	1,172	1,770
20......	7	8	2.222	11,732	.473	.823	.232	.350	2,498	4,346	1,224	1,849
20......	7	7	2.222	11,732	.432	.752	.212	.320	2,281	3,969	1,118	1,688
20......	8	8	2.222	11,732	.494	.859	.242	.365	2,608	4,537	1,278	1,930
20......	9	9	2.222	11,732	.555	.967	.272	.411	2,930	5,098	1,436	2,168

[1] Quantities given are the theoretical quantities required. In actual practice an allowance must be made for loss in handling.
[2] For pavement on one side of center line, one-way crown.

A. QUANTITIES OF MATERIALS REQUIRED FOR CONCRETE PAVEMENTS—Continued.

1 : 2 : 3½ Mix.

Per cubic yard { Cement............ 1.61 bbls. / Fine aggregate.... .45 cu. yd. / Coarse aggregate.. .79 cu. yd. }

Fine aggregate....0″ to ¼″
Coarse aggregate..¼″ to 2½″

Width.	Thickness.		Area.		Quantities per lineal foot.[1]				Quantities per mile.[1]			
	Edge.	Center.	Per linear foot.	Per mile.	Concrete.	Cement.	Fine aggregate.	Coarse aggregate.	Concrete.	Cement.	Fine aggregate.	Coarse aggregate.
Feet.	*In.*	*In.*	*Sq. yds.*	*Sq. yds.*	*Cu. yds.*	*Bbls.*	*Cu. yds.*	*Cu. yds.*	*Cu. yds.*	*Bbls.*	*Cu. yds.*	*Cu. yds.*
9......	6	[2] 8	1.000	5,280	0.204	0.328	0.092	0.161	1,077	1,734	484	850
9......	7	[2] 8	1.000	5,280	.213	.343	.096	.168	1,124	1,809	506	888
9......	6	6	1.000	5,280	.167	.268	.075	.132	881	1,418	396	696
9......	7	7	1.000	5,280	.194	.312	.087	.153	1,024	1,648	461	809
9......	8	8	1.000	5,280	.222	.357	.100	.175	1,172	1,887	527	926
10......	7	8	1.111	5,866	.237	.381	.107	.187	1,251	2,014	563	988
10......	6	6	1.111	5,866	.185	.298	.083	.146	977	1,573	440	772
10......	7	7	1.111	5,866	.216	.348	.097	.171	1,141	1,837	513	901
10......	8	8	1.111	5,866	.247	.398	.111	.195	1,304	2,099	587	1,030
16......	6	8	1.777	9,383	.361	.581	.162	.285	1,906	3,069	858	1,506
16......	7	8	1.777	9,383	.378	.609	.170	.299	1,997	3,215	899	1,577
16......	6	6	1.777	9,383	.296	.477	.133	.234	1,563	2,516	704	1,235
16......	7	7	1.777	9,383	.346	.557	.156	.273	1,827	2,941	822	1,443
16......	8	8	1.777	9,383	.395	.636	.178	.312	2,086	3,358	938	1,647
18......	6	8	2.000	10,560	.407	.655	.183	.322	2,149	3,460	967	1,698
18......	7	8	2.000	10,560	.426	.686	.192	.336	2,249	3,620	1,012	1,776
18......	6	6	2.000	10,560	.333	.536	.150	.263	1,758	2,830	791	1,389
18......	7	7	2.000	10,560	.389	.626	.175	.307	2,053	3,305	923	1,621
18......	8	8	2.000	10,560	.444	.715	.200	.351	2,344	3,773	1,055	1,852
20......	6	8	2.222	11,732	.453	.729	.204	.358	2,392	3,851	1,076	1,889
20......	7	8	2.222	11,732	.473	.762	.213	.374	2,498	4,022	1,124	1,974
20......	7	7	2.222	11,732	.432	.696	.194	.341	2,281	3,673	1,026	1,802
20......	8	8	2.222	11,732	.494	.795	.222	.390	2,608	4,199	1,173	2,060
20......	9	9	2.222	11,732	.555	.894	.250	.438	2,930	4,717	1,318	2,314

1 : 2 : 4 Mix.

Per cubic yard { Cement............ 1.50 bbls. / Fine aggregate.... .42 cu. yd. / Coarse aggregate.. .84 cu. yd. }

Fine aggregate....0″ to ¼″
Coarse aggregate..¼″ to 2½″

9......	6	[2] 8	1.000	5,280	0.204	0.306	0.086	0.172	1,077	1,615	452	904
9......	7	[2] 8	1.000	5,280	.213	.319	.089	.178	1,124	1,686	472	944
9......	6	6	1.000	5.280	.167	.250	.070	.140	881	1,321	370	740
9......	7	7	1.000	5,280	.194	.291	.082	.164	1,024	1,536	430	860
9......	8	8	1.000	5,280	.222	.333	.093	.186	1,172	1,758	492	984
10......	7	8	1.111	5,866	.237	.355	.099	.198	1,251	1,876	525	1,050
10......	6	6	1.111	5,866	.185	.278	.078	.156	977	1,466	410	820
10......	7	7	1.111	5,866	.216	.324	.091	.182	1,141	1,711	479	958
10......	8	8	1.111	5,866	.247	.370	.104	.208	1,304	1,956	548	1,096
16......	6	8	1.777	9,383	.361	.541	.152	.304	1,906	2,859	801	1,602
16......	7	8	1.777	9,383	.378	.567	.159	.318	1,997	2,995	839	1,678
16......	6	6	1.777	9,383	.296	.444	.124	.248	1,563	2,345	657	1,314
16......	7	7	1.777	9,383	.346	.519	.145	.290	1,827	2,741	767	1,534
16......	8	8	1.777	9,383	.395	.593	.166	.332	2,086	3,129	876	1,752
18......	6	8	2.000	10,560	.407	.611	.171	.342	2,149	3,224	903	1,806
18......	7	8	2.000	10,560	.426	.639	.179	.358	2,249	3,373	945	1,890
18......	6	6	2.000	10,560	.333	.500	.140	.280	1,758	2,637	738	1,476
18......	7	7	2.000	10,560	.389	.583	.163	.326	2,053	3,079	862	1,724
18......	8	8	2.000	10,560	.444	.667	.187	.374	2,344	3,516	984	1,968
20......	6	8	2.222	11,732	.453	.679	.190	.380	2,392	3,588	1,004	2,008
20......	7	8	2.222	11,732	.473	.710	.198	.396	2,498	3,747	1,049	2,098
20......	7	7	2.222	11,732	.432	.648	.181	.362	2,281	3,421	958	1,916
20......	8	8	2.222	11,732	.494	.741	.207	.414	2,608	3,912	1,095	2,190
20......	9	9	2.222	11,732	.555	.833	.233	.466	2,930	4,395	1,231	2,462

[1] Quantities given are the theoretical quantities required. In actual practice an allowance must be made for loss in handling.
[2] For pavement on one side of center line, one-way crown.

B. TABLES FOR DETERMINING THE SIZE OF PUMP REQUIRED FOR DELIVERING WATER.[1]

Loss in Friction Head.

Water required per minute.	Friction head in 2-inch pipe—			
	1 mile.	2 miles.	3 miles.	4 miles.
	Feet.	*Feet.*	*Feet.*	*Feet.*
20 gallons	51	102	153	204
30 gallons	110	220	330	440
40 gallons	194	388	582	776
50 gallons	296	592	888	1,184
60 gallons	468	936	1,404	1,872

[1] From an article by Clyde E. Learned, Highway Engineer, Bureau of Public Roads, published in Public Roads, June, 1919.

To the loss in head in the above table it will be necessary to add the vertical height that the water is to be pumped and to make allowance for angles and valves.

The theoretical horsepower required to furnish water under different heads is given in the following table:

Theoretical Horsepower Required.

Water required per minute.	Total head.[1]					
	100 feet.	200 feet.	300 feet.	400 feet.	500 feet.	600 feet.
	Horsepower.	*Horsepower.*	*Horsepower.*	*Horsepower.*	*Horsepower.*	*Horsepower.*
20 gallons	0.50	1.00	1.50	2.00	2.50	3.00
30 gallons	0.75	1.50	2.25	3.00	3.75	4.50
40 gallons	1.00	2.00	3.00	4.00	5.00	6.00
50 gallons	1.25	2.50	3.75	5.00	6.25	7.50
60 gallons	1.50	3.00	4.50	6.00	7.50	9.00

[1] Total head required equals friction head, plus height to be raised, plus loss of head in valves, elbows, etc.

Multiply the theoretical horsepower by 4 for deliveries of 30 gallons per minute or less and by 3 for deliveries of from 30 to 125 gallons per minute.

Example.—Required, 40 gallons per minute; maximum distance to be pumped, 2 miles up a hill 100 feet in height.

From first table:	Feet.
Loss in head in pipe line	388
Vertical height up hill	100
Estimated loss of head in valves, elbows, etc	20
Total head	508
From second table:	Horsepower.
Theoretical horsepower required	5
Actual horsepower required for engine and pump, three times theoretical horsepower	15

C. COST OF FEDERAL-AID CONCRETE PAVEMENTS.

Plain Concrete Pavements.

State.	1919				1920				Cost per mile for 18-foot pavement only, based on these prices.	
	Total area awarded or built.	Average price per square yard.	Mix.	Cross-section.	Total area awarded or built.	Average price per square yard.	Mix.	Cross-section.	1919	1920
	Sq. yds.				*Sq. yds.*					
Arizona	41,416	$1.65	1:2 :3½	5-″ uniform thickness	187,174	$2.43	1:2 :3½	6″ uniform thickness	$17,424	$25,661
Arkansas	81,198	3.00	1:2 :3	8″ center, 7″ edges					31,680	
California	414,010	1.69	1:2 :4	4″ uniform thickness	119,834	1.91	1:2 :4	4½″ uniform thickness	17,846	20,170
Do	173,760	2.48	1:2 :4	6″ uniform thickness					26,189	
Colorado	114,338	2.51	1:2 :3	7½″ center, 6″ edges	337,379	2.89	1:2 :3	7½″ center, 6″ edges	26,506	30,518
Connecticut					360,460	2.74	1:2 :4	8¼″ inch center, 6″ edges		28,934
Delaware	63,622	5.21	1:2 :4	8″ center, 6″ edges					55,018	
Georgia					46,189	3.20	1:2 :4	6″ center, 5″ edges		33,792
Do					154,307	3.17	1:2 :4	6″ uniform thickness		33,475
Do					34,914	2.81	1:2 :3	do		29,674
Do					106,930	2.58	1:2 :3	6½″ uniform thickness		27,245
Do					69,844	2.48	1:2 :4	6½″ center, 6″ edges		26,189
Do					26,078	2.50	1:2 :4	7″ center, 5″ edges		26,400
Do					27,950	2.38	1:2½:5	do		25,133
Do					95,275	2.45	1:2 :3	7″ center, 6″ edges		25,872
Do					26,036	2.78	1:2 :4	8″ center, 6″ edges		29,357
Do					140,739	3.00	1:2 :3	do		31,680
Idaho					73,920	3.095	1:2 :3	6½″ center, 5½″ edges		32,683
Illinois	4,902,991	2.53	1:2 :3½	8″ center, 7″ edges	362,607	3.11	1:2 :3½	8″ uniform thickness	26,717	32,842
Indiana	1,296,391	2.69	1:1½:3	8″ center, 6″ edges					28,406	
Kansas	169,632	2.88	1:2 :3½	do	235,878	3.60	1:2 :3½	8″ center, 6″ edges	30,413	38,016
Kentucky	67,324	2.54	1:2 :3	do					26,822	
Maine					48,218	1.89	1:2 :3½	8″ center, 6″ edges		19,958
Do					76,286	1.73	1:2 :3½	9″ center, 7″ edges		18,269
Maryland	662,860	2.36	1:2 :4	8″ center, 6″ edges	38,270	2.81	1:2 :4	8″ center, 6″ edges	24,922	29,674
Massachusetts	175,032	2.15	1:2 :4	7½″ center, 5″ edges	66,320	2.55	1:2 :4	7½″ center, 5″ edges	22,704	26,928
Do	56,313	2.17	1:2 :4	6″ unifrom thickness	9,246	3.29	1:2 :4	8″ center, 6″ edges	22,915	34,742
Do	79,744	2.44	1:2 :4	8¼′ center, 6 ′ edges					25,766	
Michigan	290,892	2.36	1:1½:3	8″ center, 6″ edges	147,287	3.05	1:1½:3	8″ center, 6″ edges	24,922	32,208
Minnesota	740,713	2.32	1:2 :4	7½″ center, 6½″ edges	294,244	3.23	1:2 :4	7½″ center, 6½″ edges	24,499	34,109
Mississippi					27,920	2.99	1:2 :3	8¼″ center, 6″ edges		31,574
Missouri	63,976	1.75	1:2 :3	8″ center, 6″ edges	626,825	3.08	1:2 :3	8″ center, 6″ edges	18,480	32,525
Do					95,677	3.50	1:2 :3	8″ uniform thickness		36,960
Montana					289,661	2.52	1:2 :3	8″ center, 6″ edges		26,611
Nebraska	62,606	2.72	[1] 1:3	8″ center, 6″ edges	18,705	3.85	[1] 1:3	do	28,723	40,656
Nevada	70,960	2.33	1:2 :4	6″ uniforn thickness	144,315	3.33	1:2 :4	6″ uniform thickness	24,605	35,165

New Jersey	41,453	2.31	1:1½:3	8½" center, 6" edges	48,866	3.10	1:1½:3	8½" center, 6" edges	24,394	32,736
Do	62,107	2.53	1:2 :3	8" center, 6" edges	97,119	3.68	1:1½:3	8¾" center, 6" edges	26,717	38,861
Do	95,867	2.93	1:2 :3	8½" center, 6" edges	28,737	3.99	1:1½:3	10½" center, 8" edges	30,941	42,134
Do	263,035	2.66	1:2 :3	8¾" center, 6" edges	18,627	3.90	1:2 :3	do	28,090	41,184
Do	128,031	3.14	1:2 :3	10½" center, 8" edges					33,158	
New Mexico					210,450	2.30	1:2 :3	7" center, 5" edges		24,288
New York	226,887	2.24	1:1½:3	7" center, 5" edges					23,654	
North Carolina	87,770	2.76	1:1½:3	8" center, 6" edges	165,609	3.11	1:1½:3	8" center, 6" edges	29,146	32,842
Ohio	134,052	2.64	1:1½:3	do					27,878	
Do	106,189	2.91	1:1½:3	8½" center, 6½" edges					30,730	
Do	551,165	2.79	1:1½:3	9" center, 7" edges					29,462	
Do	67,014	3.08	1:1½:3	10" center, 8" edges					32,525	
Oklahoma	480,108	2.41	1:2 :3	8½" center, 6¼" edges	18,076	3.45	1:2 :3	7" uniform thickness	25,450	36,432
Oregon					83,048	2.74	1:2 :3	6½" center, 5½" edges		28,934
Rhode Island					25,523	2.77	1:2 :3	8½" center, 6" edges		29,251
South Carolina	53,159	1.19	1:2 :4	7" center, 5" edges	125,480	3.29	1:2 :4	8" center, 6" edges	12,566	34,742
Do	12,222	1.45	1:2 :4	8" center, 5½" edges					15,312	
Tennessee	22,000	1.23	1:2 :3	7½" center, 6 edges	95,012	2.90	1:2 :3	7½ center, 6" edges	12,989	30,624
Texas	15,721	2.87	1:2 :3	7" center, 5" edges	5,483	3.30	1:2 :3	7" center 5" edges	30,307	34,848
Do	107,260	2.65	1:2 :3½	8" center, 6" edges	88,479	3.25	1:2 :3½	do	27,984	34,320
Do	3,396	2.85	1:2 :3	8" center, 7" edges	46,498	3.50	1:2 :3	7½" center, 6" edges	30,096	36,960
Utah					131,790	2.79	1:2 :3	8" center, 6" edges		29,462
Vermont	14,636	2.73	1:2 :3	8" center, 6" edges					28,829	
Virginia	161,332	2.36	1:2 :4	7" center, 5" edges	251,600	3.07	1:2 :4	7" center, 5" edges	24,922	32,419
Do					65,160	3.15	1:2 :4	8" center, 6" edges		33,264
Washington	803,929	2.29	1:2 :3	7½" center, 6" edges	413,721	2.50	1:2 :3	7½" center, 6" edges	24,182	26,400
West Virginia	94,714	2.30	1:2 :4	8" center, 6" edges	42,399	3.23	1:1½:3	8" center, 6" edges	24,288	31,109
Do	101,445	2.83	1:1½:3	do					29,885	
Wisconsin	651,957	2.03	1:2 :3½	8" center, 7" edges	597,957	2.75	1:2 :3½	8" center, 7" edges	21,437	29,040
Wyoming					14,900	2.90	1:2 :3	7" center, 5½" edges		30,624
	13,813,257	2.477	All mixes.	All sections	6,665,572	2.913	All mixes	All sections	26,157	30,761

[1] Combined sand-gravel aggregate.

D. COST OF FEDERAL-AID CONCRETE PAVEMENTS—Continued.

Two-Course Concrete Pavements.[1]

State.	1919					1920					Cost per mile for 18-foot pavement only—Based on these prices.	
	Total area awarded or built.	Average price per square yard.	Mix.		Cross-section.	Total area awarded or built.	Average price per square yard.	Mix.		Cross-section.	1919	1920
			Top.	Base.				Top.	Base.			
	Sq. yds.					*Sq. yds.*						
Florida	16,104	$2.51	1:2 :3	1:3 :6	6″ uniform thickness	13,200	$2.53	1:2 :3	1:3 :6	7″ center, 6″ edges	$26,506	$26,717
Do	20,750	2.505	1:2 :3	1:3 :6	7″ center, 6″ edges						26,453	
Kansas	490,994	2.74	1:1½:2½	1:2½:4	8 center, 6″ edges	355,040	3.53	1:1½:2½	1:2½:4	8″ center, 6″ edges	28,934	37,277
Do						47,974	3.70	1:1½:2½	1:2½:4	8½″ center, 7″ edges		39,072
Missouri	142,666	2.75	1:2 :3	1:3 :5	8″ centers, 6″ edges	20,713	3.60	1:2 :3	1:3 :5	9″ center, 7½″ edges	29,040	38,016
Texas	31,766	2.73	1:3⅓	1:7½	7⅔″ center, 6″ edges	155,872	2.65	1:2 :3	1:3 :6	7½″ center, 6½″ edges	28,829	27,984
Do	46,800	2.82	1:3½	1:7½	8⅔″ center, 7″ edges						29,779	
	749,080	2.735	All mixes		All sections	592,799	3.292	All mixes		All sections	28,882	34,764

[1] No work of this type awarded in States not listed in tabulation.

D. COST OF FEDERAL-AID CONCRETE PAVEMENTS—Continued.

Reinforced Concrete Pavements.[1]

State.	1919					1920					Cost per mile for 18-foot pavement only—Based on these prices.	
	Total area awarded or built.	Average price per square yard, including reinforcement.	Mix.	Reinforcement per square yard.	Cross-section.	Total area awarded or built.	Average price per square yard, including reinforcement.	Mix.	Reinforcement per square yard.	Cross-section.	1919	1920
	Sq. yds.			*Pounds.*		*Sq. yds.*			*Pounds.*			
California	47,843	$2.58	1:2:4	3.47	4″ uniform thickness	315,652	$2.26	1:2:4	3.47	4″ uniform thickness	$27,245	$23,866
Do	209,949	2.57	1:2:4	3.47	5″ uniform thickness	94,248	2.25	1:2:4	3.47	5″ uniform thickness	27,139	23,760
Iowa	79,184	3.59	1:2:3½	1.88	8″ center, 7″ edges	1,366,231	3.99	1:2:3½	1.88	8″ center, 7″ edges	37,910	42,134
Do						94,837	3.76	1:2:3½	2.50	8″ uniform thickness		39,706
Kentucky						78,290	2.94	1:2:3	3.60	8″ center, 6″ edges		31,046
Montana						20,173	2.80	1:2:3	2.50	6″ uniform thickness		29,568
New York	125,343	2.52	1:1½:3	1.95	7″ center, 5″ edges						26,611	
North Carolina	11,350	3.20	1:1½:3	7.65	9¼″ center, 7″ edges						33,792	
Ohio	163,957	2.78	1:1½:3	2.60	8″ center, 6″ edges						29,357	
Do	194,188	3.75	1:1½:3	2.60	10″ center, 8″ edges						39,600	
Oregon						60,845	3.19	1:2:3	2.90	7″ uniform thickness		33,686
Pennsylvania	2,721,627	2.83	1:2:3	2.25	8″ center, 6″ edges	1,435,122	4.08	1:2:3	2.25	8″ center, 6″ edges	29,885	43,085
Texas	24,404	3.60	1:2:3	2.70	7″ center, 5″ edges	11,017	4.22	1:2:3	2.25	7″ center, 5″ edges	38,016	44,563
Do	28,000	2.93	{1:3½ top. 1:7½ base.}	1.98	7⅔″ center, 6″ edges	28,913	3.54	1:2:3	2.25	8″ center, 6″ edges	30,941	37,382
Do	30,605	2.85	1:2:3½	2.25	8″ center, 6″ edges	64,425	4.03	1:2:3	2.25	9″ center, 7″ edges	30,096	42,557
Washington	88,579	2.67	1:2:3	2.98	7½″ center, 6″ edges	26,436	2.88	1:2:3	3.93	7½″ center, 6″ edges	28,195	30,413
West Virginia						19,911	3.48	1:1½:3	2.25	do		36,749
Wisconsin	9,542	1.95	1:2:3½	3.60	7″ uniform thickness	15,895	2.83	1:2:3½	3.60	7″ uniform thickness	20,592	29,885
	3,734,571	2.864	All mixes		All sections.	3,632,000	3.763	All mixes.		All sections.	30,244	39,737

[1] No work of this type awarded in States not listed in tabulation.

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