PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

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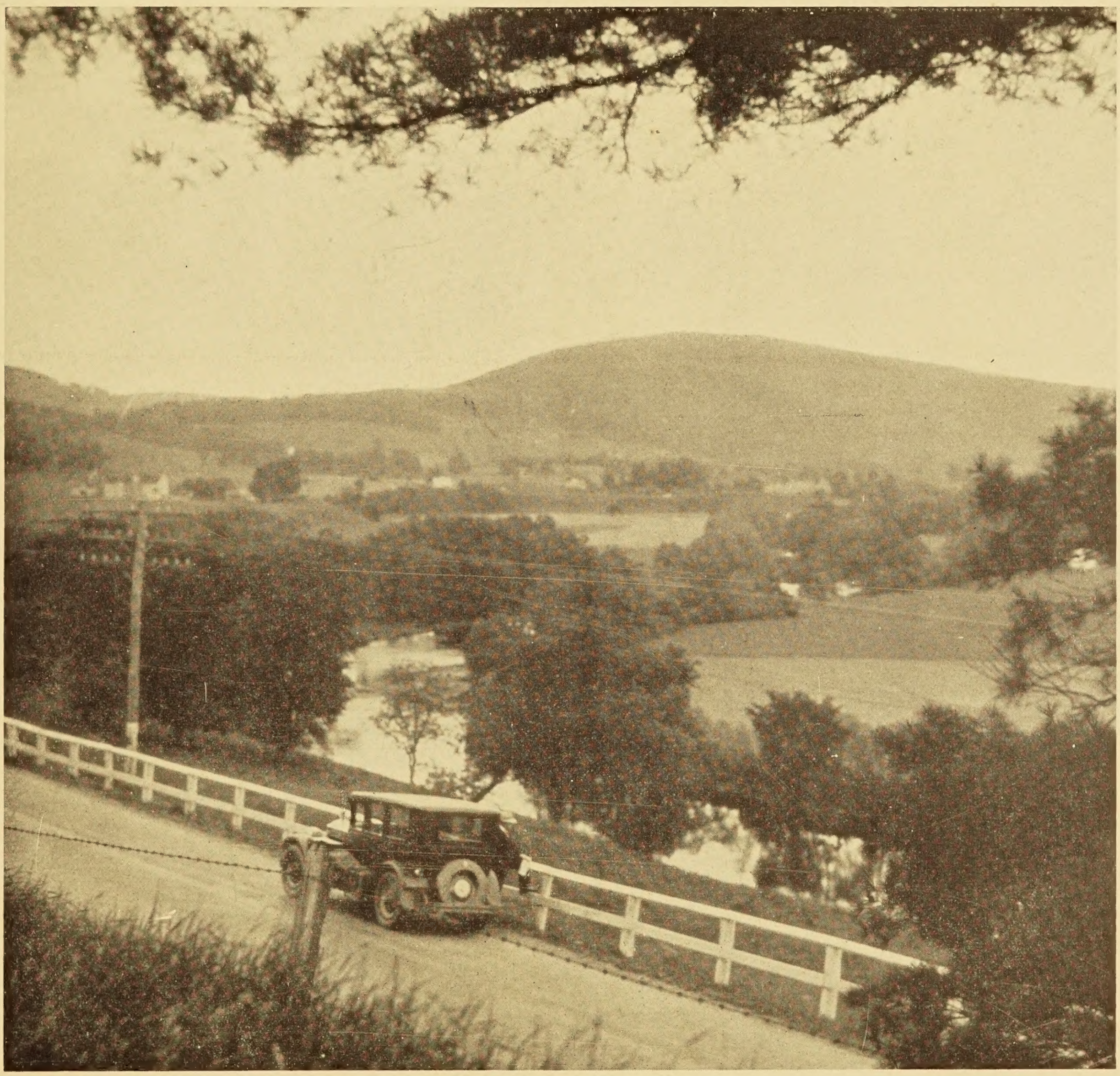

ATTRACTIVE SCENE ON NEW YORK STATE HIGHWAY SYSTEM

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COOPERATIVE SURVEY OF CORRUGATED METAL CULVERTS ON THE AUSTIN-SAN ANTONIO POST ROAD

Reported by E. F. KELLEY, Chief, Division of Tests, U. S. Bureau of Public Roads

THE corrugated metal pipe culverts included in this inspection were installed in the spring and summer of 1915 on the Austin-San Antonio Post Road (now U. S. Route 81) in Comal and Hays Counties, Tex. The installations were made as an experiment for the purpose of comparing, under the conditions prevailing in this locality, the behavior of different base metals used in the construction of corrugated sheet metal culverts.

From time to time during the ensuing years inspections have been made by representatives of the Bureau of Public Roads, the last one prior to this survey having been made in 1926. A number of inspections have also been made by representatives of other interested organizations.

From the beginning a very considerable interest has been manifested in this experimental culvert installation. This has been due to the desire for information regarding the relative merits of the base metals used in corrugated culverts, coupled with the fact that this project is unique in having a fairly complete history, and includes a number of base metals of known composition and age.

The only previous published report on this project was issued in 1918.[1] This report gives a general description of the installation, analyses of the base metals, and the results of a condition survey made in March, 1917. Since this survey was made when the culverts had been in place less than two years, deterioration had not progressed sufficiently to be significant. Although no other official report has ever been released, conflicting reports regarding the relative merits of the different base metals, as evidenced by these culverts, have been current.

NEED FOR CAREFUL SURVEY REALIZED

This situation led to the decision in 1929, when the culverts had been in service for 14 years, to make a careful examination which would definitely determine the facts regarding their condition. The need for such a survey was further emphasized by the fact that in the reports of all previous inspections made by the bureau and, so far as is known, in those of other organizations, the condition of the metal was described in general terms and did not make it possible to make direct and adequate comparisons of the behavior of the different culverts. It was realized that the application, in the proposed survey, of a rating schedule of condition, similar in principle to those developed by the Highway Research Board and several State highway departments, would obviate this difficulty and make possible a direct comparison of culvert behavior.

The rating of the condition of the metal in culverts fabricated from corrugated sheets has been developed to the point where, with the use of a suitable rating schedule, fairly accurate and comparable results may be expected. However, ratings depend on visual inspection and on the identification of certain rather definite stages in the life of the metal. The results, therefore, are subject to personal errors of observation and to a certain extent are influenced by personal opinion.

COMMITTEE OF 10 ORGANIZED TO CONDUCT INSPECTION AND SURVEY

This situation made it apparent that the accuracy of any report or conclusions based on the observations of an individual might be questioned. On the other hand, a report based on the findings of a number of observers, provided their ratings showed a reasonable degree of uniformity, would not be open to the suspicion of personal error or personal bias. It was decided to organize a group of representative engineers who would cooperate in the inspection and rating of the culverts and whose observations would be the basis of a report on the present condition of the various metals involved, with the exception of Mr. P. H. Everett, who died on May 24, 1930.

A group of 10 observers[2] was organized and the inspection on which this report is based was made in November, 1929.[3] The report has been reviewed and approved by each of these observers.

PROJECT DESCRIBED

The metal culverts in this project were installed during the spring and summer of 1915 on the Post Road between Austin and San Antonio. They were distributed over a distance of approximately 34 miles from a point about 4 miles north of San Marcos (1 mile south of the Blanco River) to a point about 12 miles south of New Braunfels. The general direction of the road is from northeast to southwest with numerous sections which do not follow this general direction. For the purpose of this report the road is considered to run from north to south, the directions to the right and left, when facing toward Austin, being considered as east and west, respectively.

Originally the installation included 3 galvanized pipes and 3 black (ungalvanized) pipes of each of 5 different metals making a total of 30 pipes. All pipes were 24 inches in diameter and of 14-gage (U. S. Standard) metal. These pipes were installed in 19 culvert structures, each having from one to four lines

[1] U. S. Department of Agriculture Bulletin No. 586, pp. 27-30.

[2] The engineers who cooperated in making this survey and who, with the exception of Mr. Everett, have reviewed and approved this report, are as follows: R. W. Crum, director, Highway Research Board; J. B. Early, maintenance engineer, State Highway Department of Texas; G. G. Edwards, construction engineer, State Highway Department of Texas; J. D. Waldrop, State highway engineer, North Carolina State Highway Commission; S. B. Slack, bridge engineer, State Highway Board of Georgia; D. D. McGuire, engineer of tests, Tennessee Department of Highways and Public Works (since Apr. 1, 1930, division engineer, National Sand and Gravel Association, St. Louis); H. S. Gillette, materials engineer, district 6, Bureau of Public Roads; C. T. Nitteberg, highway bridge engineer, district 6, Bureau of Public Roads; the late P. H. Everett, senior highway engineer, district 6, Bureau of Public Roads; E. F. Kelley, chief, division of tests, Bureau of Public Roads.

[3] Acknowledgment is made to the State Highway Department of Texas for its cooperation, through Mr. Gibb Gilchrist, State highway engineer, and his associates in placing the culverts in a condition suitable for inspection. Many of them were partially buried and a large amount of excavation was necessary to expose the ends sufficiently for inspection. Heavy rains just prior to the inspection also made a considerable amount of pumping necessary in order to expose the inverts of low culverts. This work was largely done prior to the arrival of the inspection party and permitted the observations to be made with a minimum expenditure of time and energy. Without this cooperation it would have been impossible to make the inspection in the time available.

TABLE 1.—*General information regarding culvert installation*

Culvert number or landmark	Station number [1]	Approximate total distance (odometer)	Number lines pipe in culvert structure	Designation of culvert pipe	Type of metal	Location of pipe in culvert	Direction of flow
HAYS COUNTY		*Miles*					
Blanco River, South Bank	1357	0					
No. 62	1419	1.2	1	62	Black Bessemer steel		East.
No. 65	1457+50	1.9	1	65	Galvanized Bessemer steel		Do.
No. 68	1515	3.0	1	68	do		West.
North city limits San Marcos (San Marcos River)	1584	4.3					
No. 74	1748+70	7.5	1	74	Galvanized open-hearth steel		East.
No. 75	1765+35	8.0	1	75	Black Bessemer steel		Do.
Hays-Comal County line:							
Hays County survey	1986	12.4					
Comal County survey	539+16	12.4					
COMAL COUNTY							
No. 94—I. & G. N. R. R. crossing	508	12.9	1	94	Galvanized copper-bearing steel		Do.
No. 97	476+10	13.5	1	97	Black copper-bearing iron		West.
No. 98	466+60	13.7	1	98	Black copper-bearing steel		Do.
No. 101	393+85	15.2	1	101	Galvanized copper-bearing steel		Do.
No. 103	355	15.9	1	103	Black ingot iron		East.
No. 110	112+50	20.6	2	110-N	Galvanized open-hearth steel	North pipe	Do.
				110-S	Black open-hearth steel	South pipe	Do.
North city limits, New Braunfels—Guadalupe River	0+00	23.0					
South city limits, New Braunfels	539+16						
No. 127	716	29.1	2	127-N	Galvanized ingot iron	North pipe	West.
				127-S	Galvanized copper-bearing iron	South pipe	Do.
No. 128	726	29.3	2	128-N	Black copper-bearing iron	North pipe	Do.
				128-S	Galvanized copper-bearing iron	South pipe	Do.
No. 131	777	30.3	2	131-N	Black open-hearth steel	North pipe	Do.
				131-S	Black copper-bearing steel	South pipe	Do.
No. 134	815	31.0	1	134	Galvanized ingot iron		Do.
No. 143	937	33.4	4	143-N	Galvanized copper-bearing steel	North pipe	Do.
				143-NC	Galvanized copper-bearing iron	North center pipe.	Do.
				143-SC	Black copper-bearing iron	South center pipe.	Do.
				143-S	Black copper-bearing steel	South pipe	Do.
No. 148	1012	34.9	1	148	Black ingot iron		East.
No. 149	1018	35.0	2	149-N	Galvanized ingot iron	North pipe	Do.
				149-S	Black ingot iron	South pipe	Do.
Comal-Guadalupe County line	1045+27						

[1] In Hays County the station numbers increase southward from station 1357 at the Blanco River to station 1986 at the Hays-Comal county line. In Comal County the station numbers decrease southward from station 539+16 (539+16=station 1986, Hays County survey), at the Hays-Comal county line to station 0+00 at the north city limits of New Braunfels, and increase southward from station 539+16 at the south city limits of New Braunfels to station 1045+27 at the Comal-Guadalupe county line.

of pipe. One culvert structure (No. 109) consisting of four lines of pipe, two galvanized and two black of each of two metals, was removed from the road prior to 1920. This reduced the number of pipes available for inspection to 26, and in the case of two metals reduced the number of both black and galvanized pipes from 3 to 2. The previous report states that all structures were provided with concrete head walls. At the present time several, toward the south end of the project, are provided with head walls of rubble masonry. The number, location, and general description of the existing culverts are given in Table 1.

DRAINAGE AND RAINFALL DISCUSSED

The general topography of this section of Texas is rolling. The drainage areas of the individual culverts range from flat to rolling, and, in the case of one or two culverts, to rather hilly. In several cases the drainage areas are so nearly level that, in the absence of flowing water, it is difficult to determine the direction of flow.

As regards rainfall, the official records of the stations of the United States Weather Bureau at San Marcos and New Braunfels may be considered representative since these towns, which are about 18 miles apart are both located within the project. The total annual rainfall and the average monthly rainfall at both of these stations for the period from 1915 to 1928, inclusive, are shown graphically in Figure 1. During this period the mean annual precipitation at New Braunfels was 30.3 inches and at San Marcos 32.4 inches. The minimum average monthly rainfall for the period was in excess of 1.5 inches at both stations. However, as would be expected, the records for individual years show a wide variation from the average.

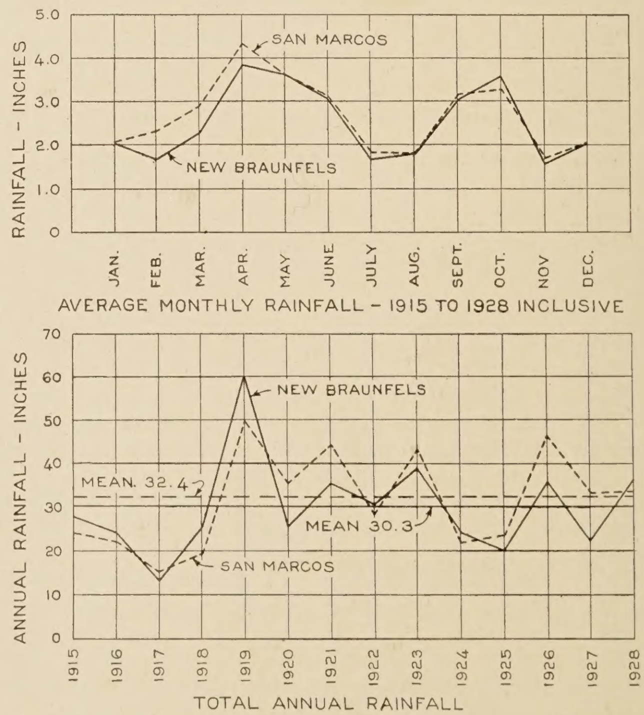


FIGURE 1.—GRAPHS SHOWING AVERAGE MONTHLY RAINFALL AND TOTAL ANNUAL RAINFALL FOR SAN MARCOS AND NEW BRAUNFELS, TEXAS

TABLE 2.—*Chemical characteristics of soils*

Sample No.	Sample taken at culvert number	Color of dry sample	Analysis of H_2O solution [1] (parts per million)				[2] Ph value	Description of sample
			CO_2	$CaCO_3$	Organic matter	Total soluble		
20	62	Gray white	1.1	120	40	161.1	8.8	Natural soil at west (inlet) end. Contained 93 per cent $CaCO_3$ and 6 per cent clay.
19	65	Brown gray	7.9	261	363	631.9	7.8	Filled material from inside of pipe. Contained much vegetable matter.
18	68	Dark gray	3.4	127	73	203.4	8.6	Natural soil at west (outlet) end.
17	74	Light gray	5.6	190	122	317.6	8.2	Natural soil at east (outlet) end.
16	94	Gray brown	4.5	125	155	284.5	8.4	Washed material from west (inlet) end.
15	94	Chocolate brown	4.5	175	145	324.5	8.2	Natural soil at west (inlet) end; rich in humus.
14	97	Yellowish brown	3.4	184	96	283.4	8.4	Natural soil at east (inlet) end; contained 70 per cent sand and gravel and 30 per cent clay.
13	101	Dark gray	3.4	123	125	251.4	8.6	Natural soil at west (outlet) end.
10	101	Light gray	2.3	146	118	266.3	8.8	Material washed through culvert.
8	103	Dark gray	2.3	123	122	247.3	8.6	Natural soil from west (inlet) end. taken from top 1 foot of natural ground.
9	103	do	3.4	125	73	201.4	8.6	Natural soil from elevation of culvert invert about 2½ feet below ground surface.
7	110	do	2.3	136	62	200.3	8.6	Natural soil at west (inlet) end.
12	131	Light gray	3.4	190	170	363.4	8.6	Natural soil at east (inlet) end.
11	131	Gray black	4.5	154	126	284.5	8.6	Filled material from inside of pipe 131-N.
5	134	Gray brown	3.4	166	98	267.4	8.6	Natural soil at west (outlet) end.
6	134	Dark gray	4.5	146	118	268.5	8.6	Filled material from inside of pipe.
3	148	Light gray	4.5	202	158	364.5	8.2	Natural soil at east (outlet) end.
4	148	do	3.4	177	167	347.4	8.4	Filled material from inside of pipe.
2	149	do	5.6	175	143	323.6	8.6	Natural soil at east (outlet) end.
1	149	do	3.4	80	144	227.4	8.8	Filled material from inside of pipe 149-N.

[1] Analysis of liquid extraction obtained by thoroughly dispersing 10 grams of material in 200 cubic centimeters distilled water, and, after all suspended matter had settled out, filtering off clear liquid.

[2] Ph determinations made on 1 gram of material in 10 cubic centimeters distilled water by colorimetric method using cresol red indicator having Ph values from 7.2 to 8.8. Ph values indicate the degree of concentration of hydrogen ions in solution, the neutral point being 7. For Ph values above 7 the reaction is basic; for values below 7 it is acid.

SOME CULVERTS FILLING, OTHERS SELF-CLEANING

At the present time 13 of the culvert pipes are in various stages of filling. This filling, in several instances, has progressed to the point where the pipe is almost or wholly inoperative as a drainage structure. The condition, in general, is due to the location of the culvert invert below the general level of the existing flow line of the drainage area. In certain cases it seems apparent that this defect existed at the time of construction; in others it is possible that changing conditions since the time of installation are responsible for it. The remaining 13 culvert pipes are generally free from deposits of silt and may be classed as self-cleaning rather than scouring since there is little or no evidence of abrasive action. From the conditions existing at the time of the inspection, which was made immediately after rather heavy rains, it is evident that flow occurs in none of the culverts except following rains and therefore may be classed as intermittent.

An examination of the rainfall records shows that normally there is an appreciable precipitation in all months of the year. This fact, together with the observed conditions surrounding the individual culvert installations, leads to the conclusion that the earth within all the culverts which have filled is generally in a wet or damp condition. On the other hand, because of the intermittent character of the flow, it is probable that, except following rains, the earth surrounding all the culverts is generally in a fairly dry condition. Subsequently, in this report, the soil condition is considered as damp in the case of filling culverts and dry in the case of self-cleaning culverts.

SOIL SAMPLES ANALYZED

Visual inspection indicates that the soil within the project is generally of the type known locally as "black-waxy," a soil which, when wet, is black and highly plastic. The mother rock with which it is underlain is reported to be a white, chalky limestone, and, toward the north end of the project, considerable amounts of this limestone are present in the soil in the form of gravel of varying size.

In connection with the survey, soil samples were taken at the sites of 13 of the 18 culvert structures. The samples are believed to be representative of the soil throughout the length of the project.

Liquid extractions were made from each soil sample and these were analyzed [4] for acidity, dissolved salts and organic matter. The results are reported in Table 2. The acid present was considered to be essentially CO_2. Quantitative tests for dissolved salts yielded only calcium carbonate and bicarbonate in weighable quantities. The lime was determined in the usual manner and all reported as $CaCO_3$. Organic matter was determined by deducting the weight of $CaCO_3$ found in a given volume of the soil water from the total weight of residue obtained by evaporating an equal volume of the same water to dryness and heating for 15 minutes at 110° C.

An outstanding characteristic of these soil waters is their extreme alkalinity, as indicated by the Ph values. It appears that nearly all the waters had about reached the point of saturation with regard to lime carbonate and consequently that the small quantity of free acid present might be expected to have a negligible corrosive effect on metal. Some corrosive action due to organic content might be anticipated, especially in the cases where appreciable quantities are indicated, but the high lime content should also mitigate against trouble from this source. That this is actually the case is indicated by the absence of any clear relationship, as will be shown later, between organic content and degree of corrosion. All the soil waters, with the exception of samples 19 and 20, were found to be very similar in regard to the quantity and quality of dissolved material. Sample 19 is exceptional on account of excess vegetable matter in the soil and sample 20 differs in being low in organic matter and acidity, owing to the high lime content.

CHECK ANALYSES OF CULVERT METALS MADE

At the time the culverts were installed, in 1915, samples of the metal were analyzed and the chemical analyses were presented in the previous published

[4] Analysis by Dr. E. C. E. Lord, associate petrographer, U. S. Bureau of Public Roads.

report. During the course of this survey check samples of the metal in each culvert pipe were taken and these were analyzed,[5] as a check on the original analyses and to insure the absence of error in the classification of the various metals. These check analyses are reported in Tables 3 and 4. As would be expected, there are some differences between the original analyses and the check analyses, the principal ones being in the carbon contents. These differences may be accounted for, at least partially, by the fact that in both series of analyses the amount of carbon was estimated by color comparison with standard samples. However, the agreement is sufficient for all practical purposes, since the slight discrepancies which exist are not sufficient to change the classification of the metal in any culvert pipe.

TABLE 3.—*Analyses of base metals of black (ungalvanized) culverts on the Austin-San Antonio Post Road. (Check samples)*[1]

Base metal	Culvert pipe number	Analysis of base metal: Carbon	Sulphur	Phosphorus	Manganese	Silicon	Total of the 5 elements	Copper	End of pipe sampled
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
Bessemer steel	62	0.055	0.048	0.096	0.360	0.002	0.561	Trace.	East.
Do	75	.050	.051	.100	.371	.005	.577	0.005	West.
Open-hearth steel	110-S	.045	.041	.016	.378	.006	.486	.005	East.
Do	131-N	.040	.041	.014	.385	.006	.486	.005	Do.
Copper-bearing steel.	98	.040	.036	.009	.434	.008	.527	.220	West.
Do	131-S	.040	.039	.010	.418	.008	.515	.220	East.
Do	143-S	.040	.043	.010	.434	.006	.533	.210	West.
Copper-bearing iron.	97	.015	.040	.009	.056	.008	.128	.140	Do.
Do	128-N	.020	.038	.009	.053	.006	.126	.140	Do.
Do	143-SC	.020	.041	.010	.056	.006	.133	.160	Do.
Ingot-iron	103	.010	.032	.006	.033	.004	.085	.005	East.
Do	148	.015	.032	.008	.037	Trace.	.092	.006	West.
Do	149-S	.020	.033	.008	.031	.005	.097	.006	Do.

[1] Analyses made of one sample from each culvert pipe.

TABLE 4.—*Analyses of base metals of galvanized culverts on the Austin-San Antonio Post Road. (Check samples)*[1]

Base metal	Culvert pipe number	Analysis of base metal: Carbon	Sulphur	Phosphorus	Manganese	Silicon	Total of the 5 elements	Copper	End of pipe sampled
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
Bessemer steel	65	0.050	0.050	0.102	0.350	0.004	0.556	0.004	West.
Do	68	.050	.056	.102	.357	.006	.571	.004	East.
Open-hearth steel	74	.045	.039	.024	.396	.004	.508	.005	Do.
Do	110-N	.040	.052	.016	.417	.004	.529	.005	Do.
Copper-bearing steel.	94	.040	.040	.009	.408	.006	.503	.195	West
Do	101	.035	.044	.011	.406	.007	.503	.180	East.
Do	143-N	.035	.042	.011	.411	.007	.506	.205	Do
Copper-bearing iron.	127-S	.015	.037	.010	.058	.006	.126	.120	Do.
Do	128-S	.025	.036	.009	.053	.004	.127	.140	Do.
Do	143-NC	.025	.039	.008	.051	.004	.127	.180	Do.
Ingot iron	127-N	.020	.041	.008	.018	.003	.090	.050	Do.
Do	134	.020	.042	.008	.028	Trace.	.098	.060	Do.
Do	149-N	.015	.042	.008	.018	Trace.	.083	.055	West.

[1] Analyses made of one sample from each culvert.

The five grades of sheet metal used in the fabrication of these corrugated pipe culverts were designated in the previous published report as Bessemer steel, open-hearth steel, copper-bearing steel, copper-bearing iron, and ingot iron.

The present standard requirements of the American Association of State highway officials for the base metals for corrugated metal pipe culverts are given in Table 5. These requirements are generally recognized by both sheet metal manufacturers and consuming interests as representing the essential chemical characteristics of the five grades of metal now considered suitable for use in metal culverts. It will be observed that Bessemer steel, and open-hearth steel without copper, are no longer used. Of the remaining metals used on the Austin-San Antonio Post Road, those designated as ingot iron and copper-bearing steel correspond, respectively, to the "pure iron" and "copper steel" of the association specification. The third, designated as copper-bearing iron, except for its deficiency in copper, corresponds closely to the "copper iron" of the association specification, although if account is taken of the tolerances permitted in the analyses of finished sheets, it might be considered to fall within the grade of "copper-bearing pure iron." However, the original designations are believed to be sufficiently descriptive of the grades of metal and are used throughout this report.

TABLE 5.—*Standard specifications for base metals for corrugated metal pipe culverts adopted by the American Association of State Highway Officials* [1]

Corrugated metal pipe culverts shall be fabricated from corrugated galvanized sheets, the base metal of which shall be made by the open-hearth process.

The base metal shall conform to the following chemical requirements:

Elements	Chemical composition by ladle analysis. Position of base metals does not indicate preference: Pure iron	Copper-bearing pure iron	Copper iron	Copper molybdenum iron	Copper steel	Tolerance by check analysis of finished sheets
Carbon, maximum per cent						
Manganese, maximum per cent						
Phosphorus, maximum per cent	0.015	0.015	0.015	0.015		
Sulphur, maximum per cent	.040	.040	.040	.040	0.050	0.010
Silicon, maximum per cent						
Copper, minimum per cent		.20	.20	.40	.20	.02
Molybdenum, minimum per cent				.05		
Sum of first 5 elements, maximum per cent		.10	.25	.25	.70	.04
Sum of first 6 elements, maximum per cent	.10					.04

[1] Department Circular 331, United States Department of Agriculture, "Standard Specifications for Corrugated Metal Pipe Culverts Adopted by the American Association of State Highway Officials and Approved by the Secretary of Agriculture for Use in Connection with Federal-aid Road Work," November, 1925; Article 1, revised June 1, 1928.

CULVERTS INSPECTED AND RATED

The inspection of the culverts by the 10 observers was made on two successive days early in November, 1929. The excavations which were required at the ends of a number of the filling culverts in order to uncover them sufficiently for inspection resulted in the formation of sumps at the ends of the structures and the heavy rains immediately preceding the inspection filled these with water. This resulted in some inconvenience, as it was necessary to remove the water with hand pumps, but it also proved to be a distinct benefit in that it made available the means for thoroughly cleansing the metal surfaces prior to inspection.

As previously mentioned, 13 of the 26 culvert pipes are in various stages of filling. On this account it was not practical to inspect the pipes for their full length. The condition of the metal, for both filling and self-cleaning culverts, was determined by inspec-

[5] Chemical analyses by L. G. Carmick, associate chemist, Bureau of Public Roads.

tion of from 2 to 3 feet of the interior at each end of the pipe.

Each observer was supplied with blank forms upon which to record his observations and a rating schedule to be used in designating the various stages of deterioration of the metal.

This rating schedule, suggested by Mr. R. W. Crum, was as follows:

Rating schedule

	Rating
SPELTER STAGE	
Spelter intact and spangles [6] clearly defined	90
Spelter dark and appreciably soft, spangles obliterated	75
Spelter practically gone, thin rust forming in spots, no pitting	70
METAL STAGE	
Uniform rust coat, extremely small pits	65
Uniform rust, deeper pits. Light warty or nodular growth	60
Deep pits, considerable loss of metal	50
Pits about half through	35
Heavy warty and nodular growth, metal very thin	25
Base metal perforated on invert	10
Base metal practically gone on invert	0

It has been customary, with rating schedules of this type, to assume a straight-line deterioration of the metal and to consider the rating of a given metal condition, on the basis of a rating of 100 for perfect condition, as indicative of a definite point in the life of the structure. In contrast to this practice the numerical ratings used in this survey were considered as indices or code designations of the various stages in deterioration which can be identified with some degree of precision. They were of practical advantage in permitting the observations of the different observers to be averaged, but, while the ratings are arranged in the descending numerical order for the advancing stages of corrosion, the numerical ratings themselves should not be considered as indicating definite points in the life of the structures rated or as giving an accurate indication of the rate of deterioration. Therefore, the ratings which are reported give no adequate basis for estimating the probable future life of the structures.

"BLACK" AND GALVANIZED GROUPS CONSIDERED INDEPENDENTLY

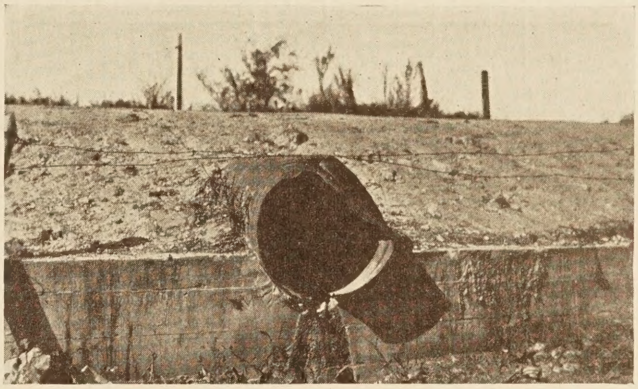
The rating schedule was based on a large amount of previous experience obtained in the examination of culverts fabricated from galvanized sheets. Since black (ungalvanized) sheets are not used in the manufacture of culverts of this type, there existed no information on which to base a schedule for use in rating the black culverts. Due to this fact, the same schedule was used in rating both the galvanized and black culverts with the result that the latter were always rated as being in the "metal stage." Therefore, in the ratings which are reported the maximum possible rating for a galvanized culvert is 90, while the maximum possible rating for a black culvert is 65. Because of the difference in the basis of rating and the fact that, when installed, the galvanized culverts had the advantage of a protective coating of zinc spelter, there exists no means for making direct comparisons of the behavior of the same metal in the two classes of culverts. Accordingly, the two classes, black and galvanized, are considered as independent groups.

[6] "Spangles" are the crystalline patterns in the zinc spelter, characteristic of new galvanized coatings.

TECHNIQUE OF INSPECTION ASSURED IMPARTIAL RESULTS

In making the inspection the observers, subsequently identified by the letters A, B, C, D, E, F, G, H, I, and J, traveled in a group. Each individual made such observations as he thought necessary, and, entirely independently of the others, reached his own conclusions as to the proper ratings to be applied and entered them on his record sheets. There was little or no discussion during the inspection of the ratings which were being given, and it was very apparent that the decisions of each were actually made independently of all others in the party. This independence of action is evidenced by the actual ratings which were reported.

INLET END (WEST)



OUTLET END (EAST)

FIGURE 2.—CULVERT NO. 103. INLET END COMPLETELY FILLED WITH DEBRIS, WHILE OUTLET IS UNOBSTRUCTED AND ENTIRELY FREE FROM FILLING MATERIAL

In order to avoid all suspicion of personal bias, the observers were not supplied with information relative to the grades of metal in the various culverts until after the ratings had been made. While this information had been public property for a number of years, it is believed that none of the observers had made an effort to become familiar with it and, with few exceptions, the culverts were rated without knowledge of the grade of metal which was being observed.

During the first day of the survey all observers inspected and rated all the culverts on the project. A second and more hurried inspection was made on the following day to permit a check of the first observations and any adjustment of the original ratings which might be thought necessary. The second inspection was made by observers A to F, inclusive, observers G, H, I, and J not being present. The light was better on the second day than on the first and made it possible for the surface condition of the metal to be seen somewhat more distinctly. Adjustments were made in some of the original ratings as a result of this second inspection. It may be said, therefore, that the final ratings as reported by observers A to F, inclusive, are based on a more extended inspection, a portion of which was made under more favorable conditions, than those of observers G to J, inclusive. However, it can not be said that the ratings of the former group are necessarily any more accurately indicative of the actual conditions.

The inlet and outlet ends of each pipe were rated, except in the cases of Nos. 94 and 103, where only one end was accessible for inspection. The ratings of the two ends were averaged to obtain the rating of the pipe. The final rating of all observers for all pipes, together with the average of the ratings of all observers for each pipe, are given in Tables 6 and 7.

TABLE 6.—*Ratings of black (ungalvanized) culverts on the Austin-San Antonio Post Road*

Pipe No.	62			75			97			98			103			110-S		
Observer	Inlet	Outlet	Average	Inlet	Outlet	Average	Inlet	Outlet	Average	Inlet	Outlet	Average	Inlet	Outlet	Average	Inlet	Outlet	Average
A	35	10	22½	10	35	22½	60	60	60	60	60	60	--	25	25	10	10	10
B	25	10	17½	10	35	22½	50	60	55	60	50	55	--	10	10	10	10	10
C	25	10	17½	10	35	22½	60	60	60	60	60	60	--	25	25	10	10	10
D	25	10	17½	10	25	17½	25	25	25	25	25	25	--	25	25	10	10	10
E	25	10	17½	10	35	22½	35	60	47½	60	50	55	--	10	10	10	10	10
F	25	10	17½	10	50	30	50	60	55	65	60	62½	--	25	25	10	10	10
G	35	35	35	10	25	17½	60	60	60	60	60	60	--	10	10	10	10	10
H	35	10	22½	10	25	17½	60	60	60	60	60	60	--	10	10	0	0	0
I	50	10	30	10	50	30	60	60	60	65	65	65	--	35	35	10	10	10
J	50	35	42½	50	60	55	65	65	65	60	60	60	--	35	35	10	10	10
Average	33	15	24	14	37½	25¾	52½	57	54¾	57½	55	56¼	--	21	21	9	9	9

Pipe No.	128-N			131-N			131-S			143-SC			143-S			148			149-S		
Observer	Inlet	Outlet	Average	Inlet	Outlet	Average	Inlet	Outlet	Average	Inlet	Outlet	Average	Inlet	Outlet	Average	Inlet	Outlet	Average	Inlet	Outlet	Average
A	60	50	55	60	50	55	60	50	55	65	65	65	65	65	65	60	60	60	60	60	60
B	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	65	62½
C	60	60	60	50	35	42½	50	50	50	65	65	65	65	60	62½	60	65	62½	65	65	65
D	50	50	50	60	50	55	60	50	55	60	60	60	60	60	60	60	60	60	60	65	62½
E	60	60	60	60	50	55	65	50	57½	65	60	62½	60	60	60	60	65	62½	60	65	62½
F	50	50	50	65	60	62½	65	60	62½	65	60	62½	65	60	62½	65	65	65	60	65	62½
G	60	60	60	65	60	62½	65	60	62½	60	60	60	60	60	60	60	65	62½	60	60	60
H	60	60	60	50	50	50	50	50	50	65	65	65	65	65	65	60	60	60	60	60	60
I	60	60	60	65	65	65	65	65	65	60	50	55	60	50	55	65	65	65	65	65	65
J	60	50	55	60	60	60	60	60	60	60	50	55	60	50	55	60	65	62½	60	65	62½
Average	58	56	57	59½	54	56¾	60	55½	57¾	62½	59½	61	62	59	60½	61	63	62	61	63½	62¼

TABLE 7.—*Ratings of galvanized culverts on the Austin-San Antonio Post Road*

Pipe No.	65			68			74			94			101			110-N		
Observer	Inlet	Outlet	Average	Inlet	Outlet	Average	Inlet	Outlet	Average	Inlet	Outlet	Average	Inlet	Outlet	Average	Inlet	Outlet	Average
A	90	90	90	65	70	67½	90	90	90	90	--	90	65	65	65	90	----	90
B	90	75	82½	60	70	65	90	90	90	90	--	90	65	60	62½	75	90	82½
C	90	90	90	65	70	67½	90	90	90	90	--	90	65	65	65	90	90	90
D	90	90	90	60	70	65	90	90	90	90	--	90	65	60	62½	90	90	90
E	90	90	90	75	70	72½	90	90	90	90	--	90	65	65	65	90	90	90
F	90	90	90	65	70	67½	90	90	90	90	--	90	65	60	62½	75	90	82½
G	75	75	75	75	70	72½	75	75	75	75	--	75	70	65	67½	90	90	90
H	90	90	90	70	70	70	75	75	75	90	--	90	70	70	70	90	90	90
I	75	75	75	60	70	65	90	90	90	90	--	90	70	70	70	90	90	90
J	75	75	75	70	75	72½	75	75	75	75	--	75	70	70	70	90	75	82½
Average	85½	84	84¾	66½	70½	68½	85½	85½	85½	87	--	87	67	65	66	87	88⅓	87¾

Pipe No.	127-N			127-S			128-S			134			143-N			143-NC			149-N		
Observer	Inlet	Outlet	Average	Inlet	Outlet	Average	Inlet	Outlet	Average	Inlet	Outlet	Average	Inlet	Outlet	Average	Inlet	Outlet	Average	Inlet	Outlet	Average
A	70	65	67½	70	65	67½	65	60	62½	70	70	70	75	75	75	70	75	72½	65	65	65
B	70	65	67½	65	65	65	65	60	62½	70	70	70	90	75	82½	70	70	70	65	65	65
C	70	65	67½	70	65	67½	70	70	70	70	70	70	90	90	90	75	75	75	70	70	70
D	70	70	70	70	65	67½	70	65	67½	70	70	70	90	75	82½	70	75	72½	65	60	62½
E	70	65	67½	70	65	67½	65	70	67½	70	70	70	90	75	82½	70	75	72½	60	70	65
F	70	70	70	70	60	65	65	65	65	70	70	70	90	90	90	65	70	67½	60	65	62½
G	70	70	70	75	75	75	70	70	70	75	75	75	75	75	75	70	70	70	70	70	70
H	75	75	75	75	75	75	70	90	80	75	75	75	90	90	90	75	75	75	70	70	70
I	75	75	75	75	75	75	75	75	75	90	90	90	90	90	90	75	75	75	65	70	67½
J	70	70	70	70	70	70	75	70	72½	75	75	75	75	75	75	75	75	75	70	70	70
Average	71	69	70	71	68	69½	69	69½	69¼	73½	73½	73½	85½	81	83¼	71½	73½	72½	66	67½	66¾

RESULTS DISCUSSED AND ANALYZED

An examination of the tabulated ratings shows generally excellent agreement between the different observers. This is rather conclusive evidence that the general principles involved in this method of measuring the behavior in service of this class of drainage structure are sound, since it shows that comparable results may be expected from the use, by different individuals, of the same scheme of rating or classification. This evidence is further strengthened by the fact that the majority of the observers who established these ratings were relatively inexperienced in the inspection and rating of metal culverts. It is logical to assume that even more concordant results might be expected from the experienced men who normally would conduct any large-scale survey of this type.

In examining the ratings for consistency, certain characteristics of the rating schedule itself should be given consideration since these are such as to make the same difference between the ratings of two observers of more significance at one place in the scale than in another. For instance, in the spelter stage the rating may be 90 or 75 depending entirely on the presence or absence of spangles. Since the first stage tends to shade rather imperceptibly into the second, there frequently may be a question as to the actual obliteration of the spangles, and the decision depends not only on power of observation but also on opinion as to what constitutes a clearly defined spangle. For this reason the fact that one group of observers may give a culvert a rating of 90 while another group may give the same culvert a rating of 75, does not necessarily indicate inaccuracy on the part of either group. On the other hand, a rating of 10 indicates the very definite and obvious stage in which the metal is actually perforated, while a rating of 25 indicates a very thin condition of the metal but one in which holes have not yet actually developed. Ratings, by different observers, of 10 and 25 for the same culvert therefore indicate actual error of observation.

It is obvious, from these examples and others which might be mentioned, that certain stages of deterioration defined in the rating schedule may be identified with more precision than others. The ratings, therefore, differ from other data of an experimental nature in that they do not lend themselves to a mathematical analysis for uniformity. For instance, figures showing mean deviations from average results are practically meaningless, since they give no adequate conception of the differences which may be significant and those which may not. It is believed that an appreciation of the degree of uniformity of the ratings can be obtained only by visual inspection of the tables, having in mind the charater of the rating schedule.

UNGALVANIZED CULVERTS SHOW SOME INCONSISTENCIES IN RATING

For the black culverts there are noticeable differences in the ratings of pipes Nos. 62, 75, 97, 98, and 103. As compared with ratings of the other observers, the ratings of observers G, I, and J are high for No. 62; that of observer J is high for No. 75; those of observers D and E are low for No. 97; that of observer D is low for No. 98; and those of observers I and J are high for No. 103. The differences are attributed largely to these observers failing to see conditions which were obvious to the majority, or detecting conditions which were unobserved by the other inspectors. In the cases of pipes Nos. 97 and 98 they may be due to a difference in the interpretation of conditions which were probably obvious to all. However, the elimination of the ratings which vary widely from those of the majority would not result in any marked change in the average ratings for the group.

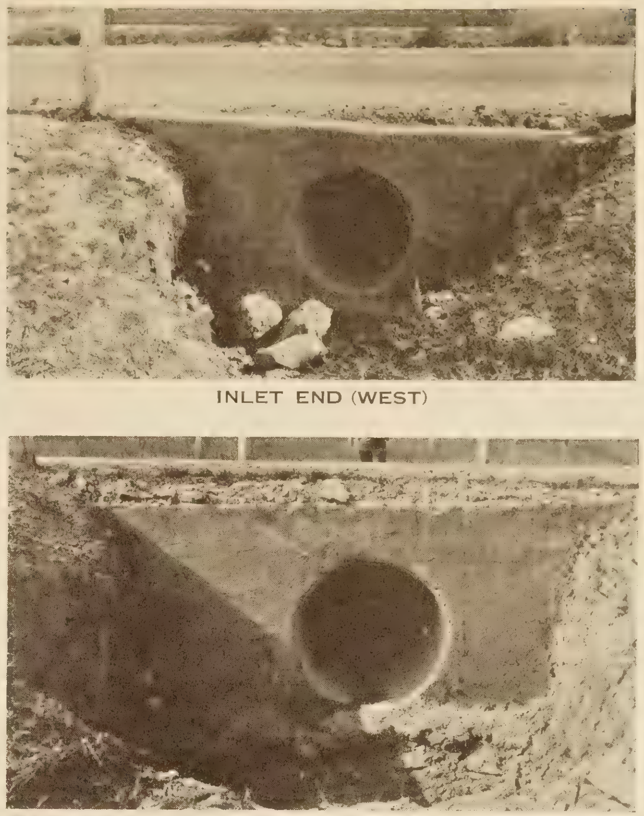
RATINGS OF GALVANIZED CULVERTS UNIFORMLY HIGH

The ratings of the galvanized culverts are much more consistent than those of the black culverts if the difference, already discussed, between the ratings of 90 and 75 is considered. In fact, there are no discrepancies of sufficient magnitude to warrant discussion.

The significant fact developed by the ratings of the galvanized pipes is their generally excellent condition after having been in service for more than 14 years. With the rating schedule used in this survey, 90 was the highest rating which could be given a galvanized pipe, while a rating of 70 indicated that the metal was still in the spelter stage. Having this in mind, it is interesting to note that 6 of the 13 galvanized pipes were given an average rating of 90 by one or more observers; that the lowest average rating given any pipe by any observer was 62½, only 2½ points below the highest rating which could be given a black pipe; and that for only 5 pipes were the averages of the ratings of all observers below 70. The conclusion which may be drawn from this is that up to the time of this inspection the performance of the galvanized culverts has constituted a test of spelter coatings and not of base metals. Corrosion had not progressed to a point which would permit of any comparison of the corrosion-resisting properties of the base metals in the galvanized pipes. Any comparison which may be made of the relative behavior of base metals in the culverts in this project must be based entirely on a consideration of the black pipes.

DATA NOT ADEQUATE TO GIVE DEFINITE CONCLUSIONS REGARDING BASE METALS

The major purpose of this experimental culvert installation was to determine the relative merits of the different grades of base metal which were used, and naturally considerable interest regarding this phase attaches to the findings of the present survey. Before undertaking any discussion of relative durability as indicated by the condition ratings, the inadequacy of the experiment, from the standpoint of evidence available, must be emphasized. If we consider only the three variables, grade of metal, protective coating and soil condition (damp and dry, for filling, and self-cleaning culverts, respectively), then there are 20 possible combinations of these variables, with only 26 culvert pipes in the project. In Table 8 the number of pipes for each of these 20 combinations of variables is given. It will be seen that there are four conditions for which there is no evidence whatever and that in no case are there more than three pipes for any one condition. Statistical studies of a large amount of data obtained in culvert condition surveys of this type have indicated that a considerable number of samples, possibly between 50 and 100 for each condition, must be available for study if results having any reasonable degree of accuracy are to be expected.



INLET END (WEST)

OUTLET END (EAST)

FIGURE 3.—CULVERT NO. 74. A TYPICAL SELF-CLEANING CULVERT

TABLE 8.—*Number of culvert pipes for each combination of variables*

Base metal	Black or galvanized	Number of culvert pipe: Total	Filling, soil condition generally damp	Self-cleaning, soil condition generally dry
Bessemer steel	Black	2	0	2
	Galvanized	2	2	0
Open-hearth steel	Black	2	1	1
	Galvanized	2	0	2
Copper-bearing steel	Black	3	1	2
	Galvanized	3	1	2
Copper-bearing iron	Black	3	1	2
	Galvanized	3	2	1
Ingot iron	Black	3	2	[1] 1
	Galvanized	3	3	0
Total		26	13	13

[1] Culvert pipe No. 103. See explanation of this classification in body of report.

The following discussion, therefore, concerns only the relative behavior of the limited number of pipe in this particular project. To assume either that the same trend of results would have been observed had a greater number of pipe been available for inspection, or that the same differences in behavior of the various metals would obtain in other localities, would be unwarranted.

TABLE 9.—*Summary of average ratings—ungalvanized pipe*

Culvert pipe No.	Average rating [1]	Base metal	Filling or self-cleaning	Organic content of soil [2]
				Parts per million
149-S	62¼	Ingot iron	Filling	144
148	62	do	do	158–167
143-SC	61	Copper-bearing iron	Self-cleaning	
143-S	60½	Copper-bearing steel	do	
131-S	57¾	do	Filling	126–170
128-N	57	Copper-bearing iron	do	
131-N	56¾	Open-hearth steel	do	126–170
98	56¼	Copper-bearing steel	Self-cleaning	
97	54¾	Copper-bearing iron	do	96
75	25¾	Bessemer steel	do	
62	24	do	do	40
103	21	Ingot iron	do.[3]	73–122
110-S	9	Open-hearth steel	do	62

[1] From Table 6.
[2] From Table 2.
[3] See explanation of this classification in body of report.

TABLE 10.—*Summary of average ratings—galvanized pipe*

Culvert pipe No.	Average rating [1]	Base metal	Spelter coating [2]	Filling or self-cleaning	Organic content of soil [3]
			Oz. per sq. ft.		*Parts per million*
110-N	87¾	Open-hearth steel	2.58	Self-cleaning	62
94	87	Copper-bearing steel	2.48	do	145–155
74	85½	Open-hearth steel	2.84	do	122
65	84¾	Bessemer steel	2.59	Filling	363
143-N	83¼	Copper-bearing steel	2.48	Self-cleaning	
134	73½	Ingot iron	2.41	Filling	98–118
143-NC	72½	Copper-bearing iron	2.02	Self-cleaning	
127-N	70	Ingot iron	2.44	Filling	
127-S	69½	Copper-bearing iron	1.90	do	
128-S	69¼	do	1.86	do	
68	68½	Bessemer steel	2.80	do	73
149-N	66¾	Ingot iron	2.50	do	144
101	66	Copper-bearing steel	2.59	do	118–125

[1] From Table 7. [2] From U. S. D. A. Bulletin No. 586. [3] From Table 2.

In Tables 9 and 10 are summarized the average ratings for black and galvanized pipes, respectively, the arrangement of the different pipes being in the descending order of excellence from the corrosion standpoint. In these tables are included the results, from Table 2, of the organic content analyses of the soils at the various locations. It is evident, as has been previously stated, that there is no clear relationship between organic content and degree of corrosion.

Table 9 shows that culvert pipe No. 103 has been classified as in a self-cleaning condition. The observers, without exception, in reporting their field observations, classified this pipe as in a filling condition, and it is believed that this classification was based entirely on the condition of the inlet end of the pipe which was so completely filled with débris that an inspection of this end could not be made. The rating of this pipe is based entirely on inspection of the outlet end which was unobstructed and contained no filling material. The condition of the two ends at the time of inspection is shown in Figure 2. The low rating of pipe No. 103, as compared with the high ratings of pipes Nos. 149–S and 148 of the same metal, suggests that a difference in service conditions may be at least partly responsible for the wide difference in behavior. It is believed that any comparisons may be made on a fairer basis if pipe No. 103 is classified as in the self-cleaning condition, which was the actual condition of the end which was rated, and for the purpose of this report this has been done.

In Table 11 are given, for the black culvert pipe, the averages of the average ratings for each base metal, the metals being arranged in the descending order of excellence. This table also shows the relative order of excellence as indicated by the average ratings of each observer. The generally good agreement between the trends of excellence shown by the ratings of the individuals and those shown by the average ratings of the whole group is worthy of note. The ratings of six observers show the same general order of excellence as is shown by the average ratings of the group and all observers are in agreement that the group of metals which includes copper-bearing steel, copper-bearing iron and ingot iron has proved superior in corrosion resistance to the group which includes open-hearth steel and Bessemer steel.

TABLE 11.—*Ungalvanized pipe. Average ratings on the basis of base metals, and relative order of excellence as indicated by these ratings and the average ratings of each observer*

Base metal	Average of all ratings	Relative order of excellence [1]—Observers					
		All	E, F, G, and I	A and B	C and H	D	J
Copper-bearing steel	58.2	1	1	1	2	2	1
Copper-bearing iron	57.6	2	2	1	1	3	1
Ingot iron	48.4	3	3	2	3	1	2
Open-hearth steel	32.9	4	4	3	4	4	4
Bessemer steel	24.9	5	5	4	5	5	3

[1] When the figures indicating order of excellence for any one observer are the same for more than one metal they signify that the average ratings of that observer are the same for all metals to which the same figure is assigned.

DATA ANALYZED BY GROUPS, ON THE BASIS OF SELF-CLEANING AND FILLING CONDITIONS

Visual inspection of Table 9 indicates a rather marked superiority for the black culverts in the filling condition while Table 10 indicates an equally marked superiority for the galvanized culverts in the self-cleaning condition. The average ratings for the black culverts are 59.2 for the filling condition and 39 for the self-cleaning condition; for the galvanized culverts the average ratings are 83.2 for the self-cleaning condition and 71 for the filling condition. These facts have suggested the presentation of the data in another form involving the separation of the culvert pipe into groups on the basis of self-cleaning and filling condition. This has been done in Tables 12 to 15, inclusive, which are of the same general form as Table 11.

Table 12, for black pipe in the self-cleaning condition, shows the same superiority of copper-bearing steel and copper-bearing iron that was indicated in Table 11. Ingot iron has lost its place among the first three metals on account of the poor condition of the one pipe, No. 103, included in this comparison. All observers are in agreement that, for the self-cleaning condition, copper-bearing steel and copper-bearing iron are superior to the other three metals and all are in agreement that the one open-hearth steel pipe has shown the least resistance to corrosion. However, as regards the relative positions of Bessemer steel and ingot iron, the ratings of only 5 observers of the 10 are in agreement with the average ratings of the group.

On the other hand, the same three metals which showed superiority in Table 11 also show superiority in Table 13, for black pipe in the filling condition, although in the latter table the order is changed, ingot iron occupying first position. The agreement between the trends of excellence shown by the ratings of the individuals and those shown by the average ratings of the whole group is not as good as that indicated in Tables 11 and 12 but this is not surprising in view of the small differences between the average ratings of the metals in Table 13.

The data available, as presented in Tables 11, 12, and 13, indicate that, for the black culverts under the

Table 12.—*Ungalvanized pipe—Self-cleaning condition. Average ratings on the basis of base metals, and relative order of excellence as indicated by these ratings and the average ratings of each observer*

Base metal	Number of pipe	Average of all ratings	Relative order of excellence [1]—Observers							
			All	A and D	B and G	F and I	C	E	H	J
Copper-bearing steel	2	58.4	1	1	1	1	2	1	1	2
Copper-bearing iron	2	57.9	2	1	1	2	1	2	1	1
Bessemer steel	2	24.9	3	3	2	4	4	3	2	3
Ingot iron	1	21	4	2	3	3	3	4	3	4
Open-hearth steel	1	9	5	4	3	5	5	4	4	5
Average		39.0								

[1] When the figures indicating order of excellence for any one observer are the same for more than one metal they signify that the average ratings of that observer are the same for all metals to which the same figure is assigned.

Table 13.—*Ungalvanized pipe—filling condition. Average ratings on the basis of base metals, and relative order of excellence as indicated by these ratings and the average ratings of each observer*

Base metal	Number of pipe	Average of all ratings	Relative order of excellence [1]—Observers						
			All	A and B	C and E	D, F, and J	G	H	I
Ingot iron	2	62.1	1	1	1	1	2	1	1
Copper-bearing steel	1	57.8	2	2	3	2	1	2	1
Copper-bearing iron	1	57	3	2	2	3	3	1	2
Open-hearth steel	1	56.8	4	2	4	2	1	2	1
Average		59.2							

[1] When the figures indicating order of excellence for any one observer are the same for more than one metal they signify that the average ratings of that observer are the same for all metals to which the same figure is assigned.

Table 14.—*Galvanized pipe—self-cleaning condition. Relative order of excellence as indicated by the average ratings of all observers and the ratings of each observer*

Culvert pipe No.	Average rating	Spelter coating	Relative order of excellence [1]—Observers							
			All	A, D, and E	C and I	B	F	G	H	J
		Oz. per sq. ft.								
110-N	87¾	2.58	1	1	1	2	2	1	1	1
94	87	2.48	2	1	1	1	1	2	1	2
74	85½	2.84	3	1	1	1	1	2	2	2
143-N	83¼	2.48	4	2	1	2	1	2	1	2
143-NC	72½	2.02	5	3	2	3	3	3	2	2
Average	83.2									

[1] When the figures indicating order of excellence for any one observer are the same for more than one culvert pipe they signify that all pipe to which that figure is assigned were given the same rating by the observer.

Table 15.—*Galvanized pipe—filling condition. Relative order of excellence as indicated by the average of the ratings of all observers and the ratings of each observer*

Culvert pipe No.	Average rating	Spelter coating	Relative order of excellence [1]—Observers										
			All	A	B	C	D	E	F	G	H	I	J
		Oz. per sq. ft.											
65	84¾	2.59	1	1	1	1	1	1	1	1	1	2	1
134	73½	2.41	2	2	2	2	2	3	2	1	3	1	1
127-N	70	2.44	3	3	3	3	2	4	2	3	3	2	3
127-S	69½	1.90	4	3	4	3	3	4	4	1	3	2	3
128-S	69¼	1.86	5	5	5	2	3	4	4	3	2	2	2
68	68½	2.80	6	3	4	3	4	2	3	2	4	5	2
149-N	66¾	2.50	7	4	4	2	5	5	5	3	4	4	3
101	66	2.59	8	4	5	4	5	5	5	4	4	3	3
Average	71.0												

[1] When the figures indicating order of excellence for any one observer are the same for more than one culvert pipe they signify that all pipe to which that figure is assigned were given the same rating by the observer.

conditions obtaining in this locality, the filling condition is more favorable to long life than is the self-cleaning condition, and that the group of metals which includes copper-bearing steel, copper-bearing iron, and ingot iron is superior, in resistance to corrosion, to the group which includes open-hearth steel and Bessemer steel.

INLET END (EAST)

OUTLET END (WEST)

Figure 4.—Culvert No. 128. A typical filling culvert

As has been pointed out previously, the ratings of the galvanized culverts give no indication of the corrosion resisting properties of the base metals. For this reason the average ratings of the individual pipe are given in Tables 14 and 15, for galvanized pipe in the self-cleaning and filling conditions, respectively, and the pipe have not been grouped with respect to base metals as was done in Tables 11 to 13, inclusive. It is apparent, therefore, that Tables 14 and 15 can disclose no new facts in addition to those already shown in Table 10, except a possible relationship between weight of spelter coat and resistance to corrosion, and the degree of agreement between the trends of excellence shown by the ratings of individual observers and those shown by the average ratings of the group.

It seems reasonable to assume that the weight of the spelter coating should have an influence on the behavior of galvanized pipe, the heavier coatings being more favorable to long life than the lighter ones. However, the data in Tables 14 and 15 show no consistent relationship between weight of spelter and culvert rating and permit no conclusion to be drawn.

The agreement between the trends of excellence shown by the ratings of the individual observers and those shown by average ratings of the whole group is not as good for the galvanized pipe as for the black. This is doubtless due to the smaller range in average

(Continued on page 184)

METHODS FOR THE MEASUREMENT OF WATER FOR CEMENT BRIQUET TESTS

TWO methods for the measurement of quantities of water used in mixing of cement mortar for the standard briquet test are described in the following articles. In each case a burette of special design is employed, and methods of filling the burette to a constant predetermined level are used. The amount of water drawn from the burette is, however, dependent on the operator and in this respect the measurements described are subject to variation. In addition, a fully automatic method of measuring water is suggested in one article.

METHOD USED IN THE MISSOURI STATE HIGHWAY LABORATORY

By F. V. Reagel, Engineer of Materials, Missouri State Highway Department

A simple method for measuring the water used in gauging mortar batches for briquet tests, which has been used in the laboratory of the Missouri State Highway Department for several years, has assisted in promoting the accuracy and speed of these tests. Primarily, the device is merely an adaptation of the automatic burette having an intake, an outlet, and an overflow of small diameter which drains into a sump. The intake is connected, through a brass turncock, to a large bottle of distilled water. A rubber tube, with a pinch cock at its lower end, extends from the outlet to the work table. The sump drains into a small overflow bottle. The burette bulb has a volume of 100 cubic centimeters from the upper graduation on the neck to the mouth of the overflow; the neck has a volume of 10 cubic centimeters with graduations every

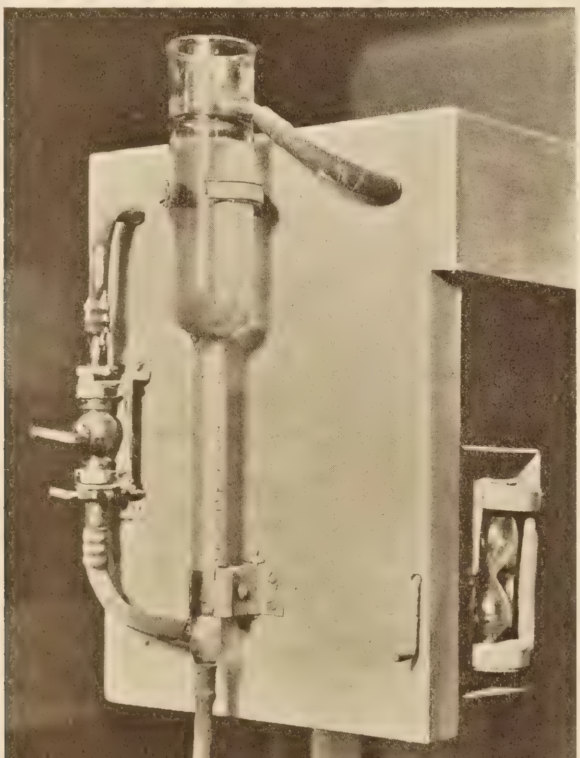


FIGURE 1.—BURETTE FOR ACCURATE MEASUREMENT OF WATER

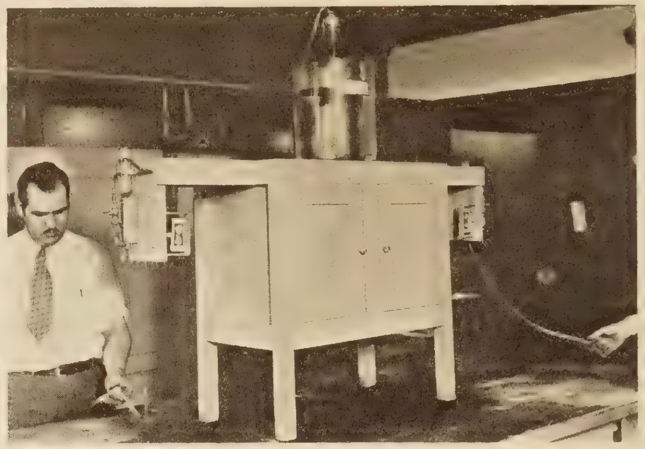


FIGURE 2.—APPARATUS AS INSTALLED IN THE MISSOURI LABORATORIES

0.5 cubic centimeter which are approximately 5 millimeters apart. This permits measurement of any quantity of water from 100 to 110 cubic centimeters to within 0.25 cubic centimeter.

In operation, the intake cock is turned on until water overflows and is then shut off. The pinch cock is then opened and the proper amount of water, as indicated by the burette graduations, is permitted to flow into the dry cement-sand mixture. The intake cock is then immediately opened so that the burette will fill while the operator is mixing the batch. Much less time is consumed by this method than by the use of the ordinary graduated cylinder, as the filling is done automatically while the operator is doing something else, and the measurement is merely a matter of releasing the pinch cock when the water level reaches the proper graduation. Furthermore, the measurements are more accurate, as the burette is easily read to 0.25 cubic centimeter (about one-fourth of 1 per cent), whereas it is not possible to measure closer than 2 cubic centimeters (2 per cent) with a graduated cylinder. The burette was made to order at a relatively small cost.

The equipment as used in this laboratory is shown in Figures 1 and 2. This arrangement with a burette at each end of the rack accommodates four operators. The method of suspending the minute-glass is also a useful innovation, as it keeps the minute-glass out of the operator's way, on a level with and immediately in front of his eyes.

METHOD USED IN THE LABORATORY OF THE BUREAU OF PUBLIC ROADS

By D. O. WOOLF, Associate Materials Engineer, Bureau of Public Roads

The apparatus for measuring water for mortar which has been recently installed in the laboratory of the Bureau of Public Roads is an adaptation of the constant-level water bottle employed in connection with the steam chest for testing the soundness of cement. As shown in Figure 3, a burette of special design is connected by rubber tubing with a five gallon water bottle. This bottle is closed with a rubber stopper through which a length of ¼-inch glass tubing passes. The bottom of the tubing is placed in the same horizontal plane with the zero mark on the burette.

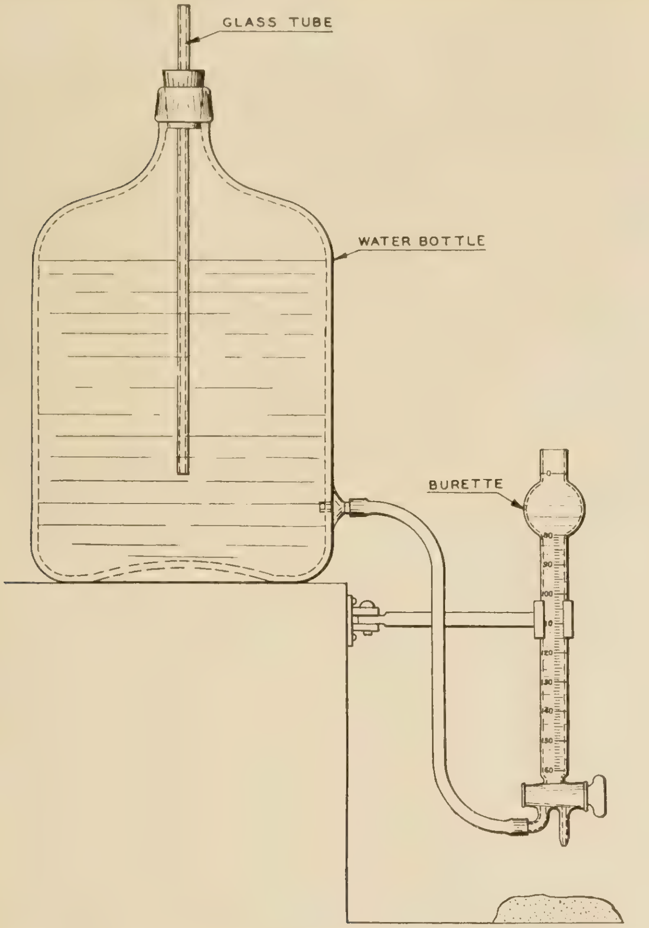


FIGURE 3.—SEMI-AUTOMATIC APPARATUS FOR MEASURING WATER

As the mouth of the water supply bottle is closed, the effective water level is at the bottom of the glass tube which enters the bottle. If water is permitted to flow from the bottle to the burette, the water level in the burette will rise until it reaches the same height as the bottom of the tube in the bottle.

In operation, either the burette or the glass tubing is adjusted so that the bottom of the tube is in the same horizontal plane with the zero mark on the burette. This may readily be accomplished by sliding the burette up or down in its support as is necessary, or by changing the height of the tube. The two-way stopcock on the burette is then opened to permit water to flow into the burette. After the latter is filled the required amount of water is drained out and the stopcock turned to the filling position. The water will again rise to the zero mark on the burette without attention of the operator. If the burette is drained completely, it will refill in about one minute.

The chief advantage of this installation is that it relieves the operator of making one of the two readings necessary for each quantity of water drawn from the burette. The apparatus is relatively simple, and in normal operation the results are accurate. The only feature which must be guarded against is loss of the partial vacuum in the supply bottle. If, after the burette has been adjusted to position, leakage of air occurs around the stopper of the supply bottle, the water level in the tube will rise due to the increase in pressure of the air entrapped in the bottle. This will permit a larger amount of water to enter the burette than is desired. It is necessary, therefore, to note that no water is in the glass tube prior to filling the burette. If there is, a preliminary filling and draining of the burette will restore the proper balance of operating pressures.

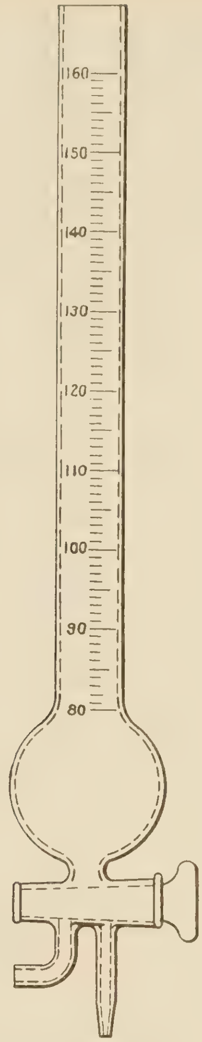


FIGURE 4.—SUGGESTED BURETTE FOR AUTOMATIC MEASUREMENT OF WATER

MODIFICATION FOR AUTOMATIC OPERATION

The apparatus described above is of most value in laboratories where a large number of batches of mortar are mixed each day. For laboratories doing a large amount of routine testing in which a large number of batches of mortar are prepared each day requiring the same amount of water in each batch, a modification of this apparatus to permit the entirely automatic measurement of water may be used. In this case the same water supply bottle and glass tube are used, but the burette has inverted readings. An example of such a burette is shown in Figure 4. The zero mark is at the glass stop cock, and the 160 cubic centimeter reading at the top of the burette. The enlarged portion of the burette is immediately above the stop cock. In operation, the adjustment should be made so that the desired amount of water will enter the burette. The operator then needs only to drain the burette and turn the stop cock to the filling position, and the same amount of water will again enter the burette.

The same principle may also be applied to apparatus used in measuring water for concrete mixes.

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ratings for the galvanized pipe, to the relatively large influence of the opinion as to whether spelter condition should be rated 90 or 75, and, in Table 15, to the fact that the trend is based on eight ratings rather than on four or five as in preceding tables.

However, Table 14 shows that seven observers are not in disagreement with the trend shown by the average ratings although the ratings of the individuals, being in a number of instances the same for more than one pipe, do not permit of the fine distinctions in order of excellence which result from a grouping on the basis of average ratings. Eight observers are in agreement that the first three pipe in this table are not inferior to either of the last two and all observers agree that the last pipe in the table is not superior to any of the first four.

Table 15 shows that seven observers agree that the first pipe, No. 65, is superior to all others and two additional observers agree that this pipe is at least the equal of any others in the table. Eight observers are in agreement that the first two pipe, if not actually superior, at least are not inferior to any of the others and eight observers agree that the last pipe is not superior to any of the other seven. This agreement between indicated trends of excellence is considered good in view of the small range in average ratings.

CONCLUSIONS AND INDICATIONS OUTLINED

The only definite conclusions which may be drawn as a result of this investigation are:

1. That the rating schedule used in this survey for measuring the relative behavior in service of corrugated sheet-metal culverts is sound in principle.
2. That the use of such a schedule may be expected to yield results having a degree of accuracy sufficient for the purpose and its use by different observers may be expected to yield comparable results.

Having in mind the manifest inadequacy of the data as a basis for any definite conclusions, certain indications applying only to metal culverts installed under the conditions peculiar to this locality appear to be worthy of note. These indications are that from the standpoint of resistance to corrosion:

1. Galvanized pipe is superior to ungalvanized pipe.
2. The group of metals which includes copper-bearing steel, copper-bearing iron and ingot iron is superior to the group which includes open-hearth steel and Bessemer steel.
3. For galvanized pipe the self-cleaning condition appears to be more favorable than the filling condition, while the reverse is true for the black (ungalvanized) pipe. This may have some significance as indicating a difference in the rates of deterioration of spelter coating and base metal under different conditions of service.

RESULTS OBTAINED BY THE USE OF CEMENT

REPORT OF AMERICAN ENGINEERS TO SIXTH INTERNATIONAL ROAD CONGRESS

By FRANK T. SHEETS, *Chief Highway Engineer, Department of Public Works and Buildings of Illinois;* ROY W. CRUM, *Director, Highway Research Board, National Academy of Sciences;* E. M. FLEMING, *Manager, Highways and Municipal Bureau, Portland Cement Association;* ARTHUR N. JOHNSON, *Dean, College of Engineering, University of Maryland;* CLIFFORD OLDER, *Consulting Engineer, Chicago, Ill.,* and RAYMOND E. TOMS, *Principal Highway Engineer, United States Bureau of Public Roads*

AT the end of 1928 there had been constructed in the United States on strictly rural highways approximately 59,000 miles of Portland cement concrete pavement, or more than four times the mileage which existed at the end of 1920. During the year 1928 alone, 8,756 miles were built. Such intensive construction has necessarily called for the rapid development of design and construction practices. This report outlines the present methods employed in the design, construction, and maintenance of concrete pavements.

Considerable advance has been made in the structural design of pavements. The report calls attention to certain fundamentals which should be observed in the construction of the subgrade, and reference is made to new developments in the design of the cross section, as well as important features in the proportioning of the reinforcing steel and the construction of expansion joints.

The trend is toward intensive research as to the effect of various characteristics of constituent materials on the quality of the concrete. Recent investigations indicate that the characteristics of the aggregates have more influence on the tensile and flexural strength of the concrete than upon the compressive strength.

The design of concrete mixtures by the water-cement ratio and mortar-void methods is rapidly gaining in favor. To secure the benefits of proper design of mixtures, the ingredients must be accurately measured and the water content closely controlled. These important features are described and references given to more complete information.

Rapid strides have been made in the development of equipment for handling materials and for mixing and placing concrete. Rigid inspection and modern equipment have aided in securing improved quality, smoother surfaces, and better production. The curing problem still needs much study.

The rapidly increasing mileage of concrete pavement has stressed the problem of maintenance. Much study has been given organization, methods, and equipment. Some of the more important methods are described. One new development is the use of high early strength concrete for repair work.

INTRODUCTION

The extensive construction of cement concrete roads in the United States during the past decade has done much to standardize design and construction methods. Great progress has been made in the development of equipment. Complete control of every phase of design and construction in order that pavements of the highest quality may be obtained is now generally recognized.

These reports are designed to summarize the present practice in design, construction, and maintenance methods and have been prepared by engineers whose experience and achievements have gained merited recognition.

STRUCTURAL DESIGN OF CONCRETE PAVEMENTS

By CLIFFORD OLDER

The subgrade.—It is generally recognized that the most vital single consideration in the preparation of the subgrade is uniformity. If necessary to secure this condition old crusts are completely loosened and the material distributed uniformly over the area to be paved or otherwise disposed of. When areas of yielding soil are encountered, it has been found desirable to remove the soft material and replace with earth of the general character of that of the surrounding subgrade.

Tile drains are used to eliminate free water from areas supplied by underground sources. In heavy clay soils a well drained layer of granular material is used by some engineers although its need is not universally recognized.

Rollers weighing from 3 to 5 tons are generally preferred for final finishing and it is usual to prohibit the filling of low spots after final rolling. Excessive rolling and uneven compaction are avoided in so far as feasible.

Inasmuch as the accuracy with which the subgrade surface is finished to the specified contour determines the uniformity of the pavement thickness and strength, much attention is given to this item. It is usual to prohibit high but not low areas in order that the thickness of the pavement may at no point be less than that specified.

Design of cross section.—It is all but universally recognized that the thickness of the mid portion of a concrete pavement need be but about seven-tenths of that near the edges in order that the flexural strength throughout may be approximately balanced. The thickness determined for the edge is usually continued for a distance of about 2 feet and then diminished to 0.7 at a distance from the edge somewhat greater than one-half the standard spacing of wheels on an axle.

It is generally believed that if the edge thickness be proportioned in accordance with the formula $t=\sqrt{\frac{3W}{.5m}}$, reasonable freedom from structural failure will result. In this formula t = edge thickness, W = maximum expected wheel load, and m = the modulus of rupture of the concrete.

Much attention is given to methods of proportioning the ingredients in order to secure the highest possible modulus of rupture consistent with economy of construction. It is customary to prepare sample test beams as the work progresses in order to provide means for checking the final result.

It is obvious that a greater factor of safety would result in using a smaller percentage of "m" in the above formula. It is the author's practice to make an additional reduction of one pound for each foot of slab length or width between edges, in order to allow for the tension set up by subgrade friction during periods of falling temperature.

More nearly rational formulæ for edge, corner, and mid portion thickness are available for design, for which see "Computation of Stresses in Concrete Roads," by H. M. Westergaard, Proceedings of the Fifth Annual Meeting of the Highway Research Board, Part I.

Steel reinforcement and joints.—A comprehensive survey of existing plain and reinforced concrete pavements has shown the advantages that accompany the judicious use of reinforcing steel, for which see Report of Investigation of the Economic Value of Reinforcement in Concrete Roads, by C. A. Hogentogler, Proceedings of the Fifth Annual Meeting of the Highway Research Board, Part II.

The most common method of proportioning reinforcing steel is to assume that a crack may occur halfway between the side or end margins, and that the area of steel throughout should be ample to prevent the crack from widening when the temperature falls and the pavement contracts. Thus the stress in the steel is assumed to equal the weight of one-half the slab times the coefficient of friction of the pavement on the subgrade. This coefficient is usually taken as 1.5 or 2.

It is generally recognized that the principal function of reinforcing steel so proportioned is to cause a dowelling or shear action between the pavement edges across which it passes. Excepting at predetermined joints where stiff dowel bars or other means are often used, this is accomplished more by the roughness of the concrete held in close contact than because of the stiffness of the small reinforcing members usually selected.

It has been determined by experience that in a climate where the ground freezes more than a few inches in depth, irregular longitudinal cracks will appear unless the pavement is divided into strips having a width of about 10 feet or less. In pavements of ordinary width the adjacent strips are held together with deformed dowel bars and the joint is of the tongue-and-groove type.

Transverse expansion joints are inserted in order to avoid excessive compressive stresses when the pavement expands.

It is usual to provide for a movement of about 1 inch per 100 feet of pavement length after taking into consideration the degree of compressibility of the material used in the joint.

It is not generally considered the best practice to concentrate the expansion provisions at wide intervals as in such case subgrade friction may cause troublesome compressive stresses halfway between expansion joints.

Attempts have been made entirely to prevent transverse cracks by forming transverse joints at various intervals.

The Bates road tests and general experience indicate that for heavy traffic roads, at least, the interval between joints must be relatively short if transverse cracks are to be avoided in pavements of ordinary thickness.

MATERIALS

By A. N. JOHNSON

During the past three years, since the last report was presented, the advance that has been made in the art of concrete road construction as the result of extensive researches has increased the use in the field of the water-cement-ratio law, the proportioning by weight of aggregates, and the use of flexural tests as a measure of concrete strength.

The effect of various characteristics of the aggregates upon the concrete is still a matter of investigation.

The injurious effect of organic impurities in fine aggregate is well established, and to detect such impurities 25 State highway departments now prescribe the sodium hydroxide test, which is readily applied in the field. Neither the fine nor the coarse aggregates should contain material that increases greatly in volume under exposure to moisture.

In general, it has been found that while a wide variety of aggregates showed little variation in comparative crushing strength, this is not true of flexural and tensile strength.

Investigations on this subject are mostly recent. A symposium on mineral aggregates was held at the

Thirty-second Annual Meeting of the American Society for Testing Materials in June, 1929. A recent investigation of the effect of various characteristics of aggregates upon the strength of concrete is published in "Public Roads," the magazine of the United States Bureau of Public Roads, June, 1929, as reported by Mr. W. F. Kellermann. These investigations indicated that while the compressive strength may not be greatly affected by the variation in the nature of the aggregates, this is not always the case with the flexural and tensile strength of concrete.

In a report by Mr. R. W. Crum on "The Control of Methods and Mixtures for Concrete for Pavements" presented at the Ninth Annual Meeting of the Highway Research Board, December, 1929, it is stated that for mixtures that contained the same absolute volume of aggregates and cement the strengths were the same. It is further stated that these data do not disclose any constant relation between the transverse and compressive strengths.

Reports from other investigations bear out the conclusion that the characteristics of the aggregates have more influence on the tensile and flexural strength than upon the compressive strength. A recent meeting of the executive committee of the Highway Research Board called attention to this subject:

"The need of coordinated research in this field was strongly emphasized in the Symposium on Aggregates at the recent meeting of the American Society for Testing Materials. It is plain that owing to the wide variations in the natural materials, as well as in the conditions of use in road work, a mass of sound information as to the effects of different characteristics upon results in use is greatly needed. Standard specifications for aggregates can not be much more than forms indicating the important points to be covered. It is necessarily left to the individual user to specify test limits to meet his local conditions as to materials and use. The information needed by him concerning the effects of different characteristics of the aggregates is far from complete at the present time."

It is evident that before we can interpret the results of investigations of the effect of characteristics of aggregates, there must be accumulated more comparative data to determine the practice that will make for the greatest practical economy in road construction.

The use of reinforcement is increasing. Structural steel is generally prescribed (standard specifications of the American Society for Testing Materials, serial designation A 15–14). In addition, some State specifications permit rerolled steel (American Society for Testing Materials specifications, serial designation A 16–14), while mesh reinforcement shall meet the requirements of the American Society for Testing Materials specifications for cold-drawn steel wire (serial designation A 62–27).

Attention is invited to the report of investigation of the effect of steel reinforcement in concrete roads which is to be found in the Proceedings of the Fifth Annual Meeting of the Highway Research Board of the National Research Council, Washington, D. C., December, 1925. This report was made by Mr. C. A. Hogentogler.

The importance of rigid control of the water, cement, and mineral aggregates, both as to quality and quantity, has made closer and more expert inspection necessary. The call is for men as inspectors who have special skill and experience.

DESIGN OF CONCRETE MIXTURES AND METHODS OF PROPORTIONING

By R. W. CRUM

Design.—Specifications for concrete mixtures stated arbitrarily by loose volumes of materials are still in common use in the United States. They are in many cases limited by requirements based upon recognized principles of design, and in some States specifications are based throughout on these principles. The use of specifically designed mixtures in work involving the possibility of using materials from many different sources necessitates flexibility in specifications. The difficulty of incorporating this flexibility into contracts let on competitive bidding delays more general adoption of scientific principles of mixture design on pavement work.

Principles of design are based upon the facts that the strength of concrete depends primarily upon the amount of solid material present in a given vloume of concrete and upon the extent to which the solid particles are bonded together by the cement (*1*).[1] It has been demonstrated that the resultant of these factors is measured by the ratio of absolute volumes of cement to cement plus aggregates or of cement to void space (*2*). Since void space is practically controlled by the amount of mixing water used in plastic mixtures, the ratio of water to cement is also a measure of the strength of any combination of the same materials.

The water-cement-ratio method of design consists in selecting the water-cement ratio corresponding to the required strength and finding the most suitable combination of aggregates to give the desired workability (*3, 4*).

The mortar-void method is based upon the principle that the strength depends upon the ratio of cement to voids in the concrete and that the greatest strength will result for a given void-cement ratio when the amount of mixing water is such that the mortar part of the concrete will occupy the least volume (*5*).

Mixtures of definite amounts of water with given cement, fine and coarse aggregate can be designed by either method to produce concrete of the required strength (*2*).

Each prospective material should be separately studied through laboratory tests in designing mixtures for specific purposes, because a design made for certain materials will not necessarily apply to other materials. The strength of the concrete, particularly flexural strength, may be affected by the quality of the cement used and by such characteristics of the aggregates as shape and size of particle, mineralogical composition, texture, porosity, and strength (*6, 7*).

Workability is a primary factor in design. However, laboratory tests indicative of workability under modern placing and finishing methods on pavement work have not yet been devised. Until some test for field workability is developed the mixtures designed by these methods will be subject to cut-and-try modification in the field.

Proportioning (*measuring*).—In order to secure the benefits of proper design of mixtures it is necessary for the various ingredients to be accurately measured. Measurement of aggregates by weight is rapidly increasing on highway work. It has been found that these materials can be weighed accurately and rapidly without extra cost and that more uniform concrete is produced.

[1] Figures in parentheses refer to the references given at the end of this section.

The water-measuring tanks on the latest paving mixers give accurate results when supplied with water under constant pressure and free from entrained air. Inaccuracies in water measurement are often caused by frequent changes in pipe-line pressure and the inclusion of air in the water incident to conditions of the work. This trouble has been eliminated by means of a double-tank arrangement for keeping the measuring tank under atmospheric pressure only (*8*).

In order to secure the benefits from accurate measurement of water and aggregates it is necessary that correction be made for the water carried by the aggregates or that which will be absorbed by them. Rapid methods have been devised for making frequent determinations of this moisture factor (*9*).

It is necessary also that attention be given to the uniformity of the aggregates and that weight corrections be made for oversize particles in the fine aggregate and for undersize particles in the coarse aggregate (*9*).

It has been demonstrated that very uniform concrete can be produced in pavement work when each of the details of measurement is faithfully carried out (*9*).

Cement continues to be measured as packed by the manufacturers except when shipped in bulk. One possibility for improving in handling cement lies in protection from incidental losses during loading and transportation.

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CONSTRUCTION OF CONCRETE PAVEMENTS

By E. M. FLEMING

Equipment and methods of construction.—Concrete road construction is particularly adapted to quantity production as most of the operations lend themselves readily to the use of machinery. Competition among contractors is so keen that only the best managed and equipped outfits can hope to be uniformly successful.

Locomotive or caterpillar cranes unload the aggregates from freight cars, deposit them in stock piles and at the same time keep adjacent overhead bins filled. From these bins the materials flow by gravity to volume measuring hoppers or to weighing hoppers, suspended below the bins. Trucks or narrow-gage railroad cars are filled by gravity from the hoppers. Weighing aggregates is a comparatively new development and one which promises to supersede other methods of proportioning. Weighing equipment has been refined so that the operation can be performed as quickly as the materials were formerly measured by volume.

In about 85 per cent of the cases, raw materials are transported to the mixer in short wheel-base trucks hauling either one or two batches, including cement. These trucks are equipped with pneumatic tires, should be of rugged construction and easily and quickly dumped. Narrow-gage industrial railroads are also used.

Self-propelling concrete mixers mounted on caterpillar treads and operated by gasoline engines, and turning out approximately 1 cubic yard of mixed concrete every 75 seconds, are the most common. A recent improvement in mixers is the development of a water-measuring device which will control the quantity of water to within 1 pint.

Concrete should be mixed to such a consistency that it will slowly settle when deposited on the subgrade. It is then leveled off a little high with shovels, struck off and compacted by a power finishing machine, after which the surface is floated or scraped with long-handled floats or straightedges, tested for surface smoothness with straightedges and then finally belted. Finishing machines that shape and compact the surface by screeding have practically superseded the older tamping machine. The frequency of passage of the finishing machine over a given area is now reduced to a minimum.

Field control of quality, quantity, and smoothness.—Proper control of these items depends on rigid and intelligent inspection backed by penalties enforceable on the contractor.

Quality of concrete depends on the correct design of the mix, uniform quantities of materials per batch, proper mixing time, adequate curing and the amount of mixing water. Beams and cylinders should be cast at the road and tested at stated periods. Cores should be drilled from the finished slab and tested.

Securing the correct depth of slab depends on good form installation, subgrade preparation and on finishing methods which shape the surface closely to the theoretical section. Forms should be of steel, have adequate bearing and be rigidly pinned in place. The subgrade should be checked for depth by templates immediately before the concrete is placed. Cross sections of the subgrade and of the finished surface taken at the same point at frequent intervals will provide an immediate check. Cores are drilled after the slab has cured, and then measured for depth. Penalties for failure to secure correct depth are assessed against the contractor.

Surface smoothness is a function of correct form construction, concrete of uniform workability and consistency, good finishing methods, and frequent straightedging of the surface. A number of road-building departments now require that surface roughness must not exceed one-eighth inch in 10 feet, although one-fourth inch in 10 feet is still the most common requirement. The contractor is penalized the price of 1 square yard of pavement for each irregularity exceeding the limits.

Curing.—Early curing is accomplished by placing one or two layers of burlap on the green concrete. This is kept damp by light sprinkling.

After 24 hours the burlap is removed and the final curing agent applied. One of the following methods is used:

1. Ponds of water.
2. Wet earth or wet hay cover.
3. Spraying with water.
4. Surface application of calcium chloride.
5. Surface application of sodium silicate.

Water curing is continued for at least eight days. Difficulties in securing proper application of the water have resulted in attempts to find more easily applied curing agents. A recent development is the use of an asphalt or tar seal coat sprayed on the surface immediately after the final belting. This method, as well as the use of calcium chloride and sodium silicate, has met with varying success. Test results and opinions of engineers vary as to the merits of these methods. The use of water is still the one sure method.

MAINTENANCE OF CONCRETE PAVEMENTS

By R. E. Toms

Maintenance of concrete pavements consists of filling cracks or joints, correcting surface depressions, and replacing areas which have disintegrated or been shattered by traffic.

Cracks or joints should be filled with bituminous material once a year or oftener, depending upon the amount of traffic. They should be well cleaned with brooms or compressed air, to a depth of 3 inches, of all dirt, dust, or foreign material before filling. After cleaning they should be filled with hot tar or asphalt by means of pouring cans and covered with clean sand or stone chips to prevent the bituminous material from being picked up by traffic. Wide cracks or joints should be filled with a bituminous mixture, preferably a standard hot-mix bituminous concrete.

Shallow surface depressions may be corrected by painting the depressed area with crack-filling bituminous material and covering with crushed aggregate, ranging from three-quarters inch to one-half inch in size. Successive applications of bituminous material and covering should be used to secure the desired thickness. Surface depressions of greater depth than three-quarters inch should be corrected with bituminous concrete mixtures containing graded coarse aggregate. Such mixtures may be prepared without heating by using an emulsified asphalt or a cut-back tar. Standard hot-mix bituminous concrete is also used for this purpose. The area to be covered by the mixture is usually given a paint coat of tar or asphalt. The bituminous mixture should be tamped into place and every precaution taken to secure a level surface. After compaction the graded coarse aggregate mixtures are usually given a seal coat of tar or asphalt and covered with fine stone chips or coarse sand.

Replacement of areas must be undertaken where the concrete slab is so broken that it will not support traffic when patched with bituminous materials. All broken and disintegrated concrete should be removed and the old slab cut back to good solid concrete. The top edge of the old concrete should be chiseled to a vertical edge for a depth of at least 1 inch below the surface. The remainder of the old concrete face should be left as rough as possible. The subgrade for the patched area should be excavated so that the new concrete will extend several inches under the old slab and have a depth of from 2 to 4 inches greater than the original slab. In soft, spongy soil, granular material such as cinders, gravel, or broken stone tamped into the subgrade serves to reduce capillary action and give added stability.

The concrete used in replacing pavement areas should be machine mixed. A dry mix should be used to prevent subsidence after placing. The time of mixing for dry mixes should not be less than two minutes. The concrete should be thoroughly tamped in place and finished with a screed, template, and wood float to a regular and uniform surface to fit the crown and edge of the surface of the old pavement. A straightedge should be used longitudinally at either end of the patch to insure a smooth junction with the old concrete. Curing should be by means of wetted burlap placed over the patch as soon as it is finished. The burlap may be replaced with an earth covering at the end of 24 hours, or if it can conveniently be kept wet for three or four days no further curing is necessary. The use of calcium chloride integrally with the concrete mix obviates the necessity for curing.

The concrete used in replacing pavement areas should be a standard pavement mix, or if it is not convenient to keep traffic off of the new patch for the time required for the curing and hardening of ordinary concrete, a quick-hardening" concrete may be used. Quick-hardening concrete made of alumnite cement hardens sufficiently in 24 hours to permit it to be opened to traffic. Alumnite cement is mixed in the same proportions and manipulated in the same manner as Portland cement. It hardens in the presence of water. Particular attention must therefore be given to curing. For several hours after setting all exposed surfaces must be kept damp to prevent incomplete hydration. Quick-hardening concrete which attains sufficient strength to be opened to traffic in three days may be made with ordinary cement by approximately doubling the cement content of a standard mix, using a minimum of water, increasing the time of mix and adding calcium chloride with the mix to accelerate the hardening. These factors together with high atmospheric temperatures for curing enable major repairs to be undertaken with ordinary cement and opened to traffic in comparatively short periods.

Where a large mileage of concrete pavement is to be maintained the maintenance operations are usually performed by two different units; one handling bituminous materials for filling cracks and joints and correcting surface depressions, and the other doing major repairs such as replacing pavement areas. A two or three ton truck and a portable asphalt heater together with small tools constitute the equipment generally used for filling cracks and joints and correcting surface depressions. A supply of bituminous material and covering material may be carried on the truck, or a light truck used to supply these materials from convenient storage places along the road. If standard hot-mix bituminous concrete is used it is usually obtained as needed from asphalt plants operating in near-by cities. For major repairs the organization is less mobile and more equipment is required. A portable mixer of one or two bag capacity, together with the necessary trucks to haul the cement, fine and coarse aggregate from the nearest source of supply or delivery point will be required. A water tank mounted on a truck should be provided also, as water is not always available at the locations of the replacements. The work of an organization of this kind is generally confined to selected locations instead of attempting to cover a designated mileage of pavement as is usually the case with the lighter and more flexible units used for crack filling and correcting surface depressions.

U. S. GOVERNMENT PRINTING OFFICE: 1930

GASOLINE TAXES—FIRST HALF OF 1930

Total tax earned on motor vehicle fuel, etc., refunds, disposition of fund, and gallons taxed

[From reports of State authorities]

State	Gross tax assessed prior to deduction of refunds	Exemption refunds: (Deducted from gross tax)	Total tax earnings on fuel for motor vehicles	Other receipts under tax law (licenses)	Grand total earnings (tax and other receipts)	Collection costs	Disposition of grand total earnings: Construction and maintenance of rural roads: State highways	Disposition: Construction and maintenance of rural roads: Local roads	Disposition: State and county roads bond payments [1]	Disposition: For miscellaneous purposes	Tax rates, 1930, cents per gallon: Jan. 1	Tax rates, 1930, cents per gallon: June 30	Net gallons of gasoline taxed and used by motor vehicles
Alabama	$3,423,724		$3,423,724	$1	$3,423,725	$17,647	$767,277	$1,699,822	$938,979		4	4	85,593,106
Arizona	1,524,516	$182,442	1,342,074	6	1,342,080	(2)	853,509	488,571			4	4	33,551,860
Arkansas	3,157,552	275,000	2,882,552		2,882,552	67,500	701,786	844,516	[3] 1,268,750		5	5	57,651,044
California	18,040,284	1,797,792	16,242,492		16,242,492	25,749	10,811,162	5,405,581			3	3	541,416,391
Colorado	3,161,987	207,797	2,954,190		2,954,190	[4] 24,955	2,050,464	790,894		[5] $87,877	4	4	73,854,743
Connecticut	2,107,560	[6] 76,645	2,030,915	39,578	2,070,493	(7)	2,070,493				2	2	101,545,770
Delaware	493,691	23,425	470,266		470,266	(8)	470,266				3	3	15,675,528
Florida	7,229,997		7,229,997	10,420	7,240,417	7,051	2,409,999	401,667	[9] 2,409,999	[10] 2,011,701	6	6	120,499,948
Georgia	6,432,781		6,432,781		6,432,781	4,200	4,285,721	1,071,430		[11] 1,071,430	6	6	107,213,018
Idaho	1,250,557	76,741	1,173,816	477	1,174,293	6,217	1,168,076				4	5	[12] 24,486,855
Illinois	13,377,556	444,623	12,932,933		12,932,933	[13] 267,551	8,443,588	4,221,794			3	3	431,097,782
Indiana	8,524,791	533,749	7,991,042		7,991,042	19,157	5,978,913	1,494,729		[14] 498,243	4	4	199,776,038
Iowa	5,458,225	462,328	4,995,897		4,995,897	16,355	2,941,542	2,038,000			3	3	166,529,913
Kansas	5,086,834	592,513	4,494,321		4,494,321	(15)	3,644,321	850,000			3	3	149,810,701
Kentucky	3,870,979		3,870,979	2,889	3,873,868	12,472	3,861,396				5	5	77,419,583
Louisiana	3,594,441	479	3,593,962		3,593,962	(16)	3,033,962		560,000		4	4	89,849,038
Maine	1,602,424	213,483	1,388,941	[17] 53,371	1,442,312	32,352	881,225	528,735			4	4	34,723,518
Maryland	3,306,579	117,774	3,188,805		3,188,805	4,500	2,517,444			[18] 666,861	4	4	79,720,113
Massachusetts	4,820,680	66,343	4,754,337		4,754,337	(19)	[20] 4,754,337				2	2	237,716,821
Michigan	11,046,931	1,077,343	9,969,588	395	9,969,983	23,889	5,800,584	2,927,292	1,182,654	[21] 35,564	3	3	332,319,601
Minnesota	5,052,173	378,434	4,673,739		4,673,739	(22)	3,115,826	1,557,913			3	3	155,791,314
Mississippi	3,373,150		3,373,150	[23] 62,273	3,435,423	2,700	1,314,705	2,020,270		[23] 97,748	5	5	67,463,005
Missouri	4,122,351	102,613	4,019,738		4,019,738	26,195	3,993,543				2	2	200,986,879
Montana	1,618,701	257,810	1,360,891		1,360,891	12,071	1,348,820				5	5	27,217,819
Nebraska	4,282,605	34,080	4,248,525		4,248,525	3,750	3,183,581	1,061,194			4	4	106,213,125
Nevada	329,932	30,915	299,017		299,017		299,017				4	4	7,475,422
New Hampshire	1,029,187	47,204	981,983		981,983		736,487		245,496		4	4	24,549,580
New Jersey	4,967,626		4,967,626	13,608	4,981,234	8,000	4,928,234			[24] 45,000	2	2	248,381,311
New Mexico	1,277,033		1,277,033	4,557	1,281,590	25,632	823,958		432,000		5	5	25,540,650
New York	13,396,516	275,899	13,120,617		13,120,617	[25] 133,965	9,702,489	2,587,330		[26] 696,833	2	2	656,030,864
North Carolina	6,281,527	322,662	5,958,865		5,958,865	6,000	2,111,692	1,191,173	2,650,000		5	5	119,177,300
North Dakota	1,237,078	453,978	783,100		783,100	18,100	510,000	255,000			3	3	26,103,326
Ohio	18,652,809	900,495	17,752,314	315	17,752,629		11,095,393	3,550,526		[27] 3,106,710	4	4	443,807,845
Oklahoma	6,187,523	11,558	6,175,965		6,175,965	(28)	4,631,974	1,543,991			4	4	154,399,130
Oregon	3,047,008	255,598	2,791,410		2,791,410	6,015	2,785,395				[29] 4	[29] 4	[30] 70,042,779
Pennsylvania	16,045,671	93,084	15,952,587	[31] 187,478	16,140,065	[32] 170,024	12,475,968	1,994,073	1,500,000		4	[33] 4	398,814,666
Rhode Island	814,393	18,326	796,067	372	796,439	(34)	601,911		194,528		2	2	39,803,346
South Carolina	3,389,057	12,809	3,376,248	751	3,376,999	(35)	2,814,166	562,833			6	6	56,270,799
South Dakota	2,052,487	787,747	1,264,740		1,264,740	5,250	871,501		387,989		4	4	31,618,494
Tennessee	4,941,567		4,941,567		4,941,567	24,708	2,950,115	983,372	983,372		5	5	98,831,344
Texas	15,383,741	1,320,670	14,063,071		14,063,071		10,547,303			[36] 3,515,768	4	4	351,576,762
Utah	1,000,078		1,000,078	476	1,000,554	1,727	611,877		386,950		3½	3½	28,573,651
Vermont	716,720		716,720		716,720	(37)	716,720				4	4	17,918,003
Virginia	5,203,712	301,971	4,901,741		4,901,741	16,987	3,256,503	1,628,251			5	5	98,034,819
Washington	3,597,870	319,023	3,278,847		3,278,847	(38)	2,185,898	1,092,949			3	3	109,294,898
West Virginia	2,442,012	97,600	2,344,412	4,677	2,349,089		621,652		1,727,437		4	4	58,610,300
Wisconsin	3,835,680	323,594	3,512,086		3,512,086	5,000	1,291,419	1,962,610		[14] 253,057	2	2	175,604,292
Wyoming	558,211		558,211		558,211		418,558	139,653			4	4	13,955,258
District of Columbia	751,495	5,000	746,495		746,495					[14] 746,495	2	2	37,324,724
Total			230,600,455	381,644	230,982,099	995,719	157,390,770	44,894,169	14,868,154	12,833,287	Average rate 3.39		6,809,863,076

1 For state highway bonds, except as noted.
2 From State highway fund, approximately $7,000.
3 Divided between State and county road bonds, approximately 50 per cent to each.
4 Includes all expenses of State inspector of oils.
5 For town and city streets.
6 Exemption made at time of sale.
7 State appropriation of $14,000 deducted from motor vehicle fees.
8 Appropriation for State treasurer's office.
9 For county and town bonds.
10 Includes $2,008,332 for public schools: remainder, $3,369, reserve for gasoline tax collection.
11 For public schools.
12 Includes 5,052,717 gallons at 4 cent tax, and 19,434,138 gllaons at 5-cent tax.
13 2 per cent of gross tax receipts allowed to distributors.
14 For city streets.
15 From State general fund, $7,500 for half year.
16 State appropriation, $3,750 for half year.
17 Tax of 1 cent on 5,337,079 gallons of gasoline sold for uses other than for motor vehicles.
18 Includes $629,361 for Baltimore streets, and $37,500 for oyster conservation work.
19 Reported as "no cost."
20 Credited to highway fund, which is later appropriated to State highways, local roads and State bond payments.
21 Includes $35,169 for city streets, and $395 to State general fund from dealers' licenses.
22 From State treasury, as part of inspection service: Appropriation about $8,250.
23 For sea-wall protection of road: Partly paid by special gasoline tax of adjacent counties, amounting to $62,273 (other receipts).
24 For inland waterways under State Department of Commerce and Navigation.
25 1 per cent of gross tax receipts allowed distributors for collection of tax: In addition $28,126 from State general fund for administration.
26 For New York City, $646,833, and for refund reserve $50,000.
27 For streets of townships and municipalities.
28 From State general fund by appropriation.
29 "Distillate" taxed 3½ cents per gallon.
30 Includes about 1,949,450 gallons of distillate.
31 Consists of delinquent taxes of previous years, with fines and penalties.
32 Dealers allowed commission of 1 per cent on first $1,000 of tax collected, and one-half per cent on remainder.
33 Gasoline tax rate reduced to 3 cents on July 1.
34 From motor vehicle fund, $5,000.
35 State tax commission appropriation.
36 For free school fund.
37 From motor vehicle fund, $1,000.
38 From motor vehicle fund, $2,500.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

CURRENT STATUS OF FEDERAL-AID ROAD CONSTRUCTION

AS OF

OCTOBER 31, 1930

STATE	COMPLETED MILEAGE	UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FEDERAL-AID FUNDS AVAILABLE FOR NEW PROJECTS	STATE
		Estimated total cost	Federal aid allotted	MILEAGE			Estimated total cost	Federal aid allotted	MILEAGE				
				Initial	Stage[1]	Total			Initial	Stage[1]	Total		
Alabama	2,196.6	$ 1,457,591.49	$ 714,054.55	70.9	8.2	79.1	$ 1,981,827.41	$ 926,375.44	82.7	8.8	91.5	$ 5,722,926.91	Alabama
Arizona	883.0	3,492,782.50	2,640,927.84	107.6	131.1	238.7	853,163.90	811,619.79	48.3		48.3	2,460,561.70	Arizona
Arkansas	1,773.2	6,370,756.11	2,981,601.94	204.6	45.1	249.7	1,634,640.99	806,688.06	40.7	18.7	59.4	2,752,806.02	Arkansas
California	1,908.0	9,307,726.11	4,063,411.74	227.4	19.0	246.4	786,816.53	285,411.29	1.7	13.1	14.8	4,619,406.63	California
Colorado	1,236.6	4,556,622.93	2,439,302.71	156.0	70.4	226.4	985,791.05	543,673.67	27.8	29.7	57.5	3,951,911.03	Colorado
Connecticut	243.3	3,084,889.11	1,294,964.40	19.4		19.4	668,308.20	131,085.00	8.7		8.7	1,262,645.45	Connecticut
Delaware	273.0	884,880.75	427,483.87	45.9		45.9	167,677.95	83,838.97	8.0		8.0	617,586.72	Delaware
Florida	533.8	4,680,361.00	2,229,234.31	76.0	5.5	81.5	438,506.31	204,991.28	21.7		21.7	2,689,853.34	Florida
Georgia	2,639.8	6,279,884.98	2,994,627.24	159.8	123.8	283.6	1,211,743.13	524,234.81	29.1	24.4	53.5	5,265,235.14	Georgia
Idaho	1,248.6	2,785,414.78	1,675,724.22	182.5	14.8	197.3	417,697.04	248,500.00	29.3	8.2	37.5	1,719,413.88	Idaho
Illinois	2,101.9	21,438,919.36	9,686,063.63	613.1	59.8	672.9	3,018,350.10	1,386,847.33	85.2	12.6	97.8	7,032,824.13	Illinois
Indiana	1,500.9	4,560,726.70	2,213,573.73	143.4		143.4	903,188.23	375,647.33	26.2		26.2	5,311,033.11	Indiana
Iowa	3,113.2	3,553,462.98	1,481,309.20	28.6	92.7	121.3						3,342,943.55	Iowa
Kansas	2,893.8	5,317,660.90	2,488,703.63	254.4	53.3	307.7	808,606.93	393,031.84	29.5	36.7	66.2	4,383,034.41	Kansas
Kentucky	1,362.5	8,470,356.91	3,694,645.55	177.8	190.3	368.1	1,241,963.99	482,852.17	13.0	59.6	72.6	1,937,610.38	Kentucky
Louisiana	1,397.3	4,177,364.05	2,018,690.73	150.8	20.9	171.7	872,117.68	396,929.89	31.1	7.1	38.2	2,598,458.35	Louisiana
Maine	555.9	2,861,315.12	1,065,232.79	71.0		71.0	974,630.61	399,268.09	8.4		8.4	1,899,835.21	Maine
Maryland	647.4	1,950,432.02	935,710.32	37.8	16.9	54.7						1,036,835.06	Maryland
Massachusetts	698.2	5,536,825.46	1,329,640.32	54.6		54.6	806,166.36	358,539.90	3.8		3.8	3,167,644.98	Massachusetts
Michigan	1,683.9	10,544,301.27	4,206,512.83	240.8	28.9	269.7	1,750,614.80	779,175.00	53.6	6.4	60.0	4,719,842.41	Michigan
Minnesota	4,038.0	9,493,816.06	3,373,063.71	149.1	232.8	381.9	500,431.65	213,000.00	10.8	42.5	53.3	3,299,753.06	Minnesota
Mississippi	1,839.8	639,084.13	319,245.57	36.1	7.7	43.8	319,042.54	159,521.27		13.5	13.5	5,592,293.28	Mississippi
Missouri	2,541.1	8,286,692.51	2,785,739.32	131.7	53.7	185.4	3,650,885.87	1,363,983.40	64.7	26.0	90.7	3,451,438.80	Missouri
Montana	1,816.2	7,528,253.63	4,243,719.44	587.2	40.9	628.1	1,467,029.39	807,318.51	125.4	19.3	144.7	4,858,502.96	Montana
Nebraska	3,781.1	5,038,913.07	2,402,338.70	254.1	128.8	382.9	1,123,809.33	471,800.80	28.6	29.3	57.9	4,210,656.51	Nebraska
Nevada	1,229.2	1,064,373.70	923,821.23	23.2	112.1	135.3	322,783.14	286,792.78	29.2	.7	29.9	1,887,644.63	Nevada
New Hampshire	364.9	1,699,321.63	586,708.93	35.0	1.6	36.6						598,242.63	New Hampshire
New Jersey	533.4	4,379,066.90	1,093,726.32	41.2		41.2						2,547,196.76	New Jersey
New Mexico	1,938.0	3,772,999.14	2,542,770.74	195.4	56.3	251.7	699,518.26	493,498.20	14.8	1.7	16.5	2,428,310.58	New Mexico
New York	2,589.9	23,384,721.76	4,510,305.00	301.3		301.3	4,167,316.00	987,595.50	71.4		71.4	12,197,655.54	New York
North Carolina	1,878.8	3,571,160.99	1,732,884.07	136.6	28.8	165.4	645,865.88	317,731.43	43.0	9.2	52.2	4,469,803.59	North Carolina
North Dakota	4,400.3	2,424,190.93	1,247,330.77	327.7	201.2	528.9	977,253.47	488,332.92	130.8	104.6	235.4	2,647,096.11	North Dakota
Ohio	2,317.9	21,111,281.88	7,049,364.05	356.5	35.9	392.4	1,080,353.50	324,569.00	9.6		9.6	4,547,759.25	Ohio
Oklahoma	1,872.6	6,290,897.80	2,977,428.53	191.8	97.4	289.2	114,374.41	59,565.37	15.6		15.6	2,899,336.18	Oklahoma
Oregon	1,185.2	6,208,963.98	3,657,807.07	262.9	85.2	348.1	300,260.40	182,772.27	19.5		19.5	1,941,114.05	Oregon
Pennsylvania	2,567.8	12,537,921.09	3,800,548.95	118.4		118.4	1,398,175.36	545,887.13	18.3		18.3	5,359,238.34	Pennsylvania
Rhode Island	200.2	2,251,318.84	917,014.74	35.8		35.8						619,426.42	Rhode Island
South Carolina	1,842.2	6,107,146.93	2,347,085.69	115.3	116.5	231.8	1,169,195.41	557,871.88	9.4	26.1	35.5	1,293,875.39	South Carolina
South Dakota	3,631.3	4,039,291.15	2,193,748.37	351.0	96.3	447.3	843,395.18	489,101.48	83.5	55.3	138.8	2,527,887.38	South Dakota
Tennessee	1,302.2	4,490,569.10	2,016,498.08	180.1	43.9	224.0	986,185.36	491,112.39	16.8		16.8	3,350,733.27	Tennessee
Texas	6,836.6	14,766,525.06	6,147,590.87	515.2	214.4	729.6	2,820,495.95	1,105,639.59	110.7	46.8	157.5	10,488,476.79	Texas
Utah	973.0	1,587,554.23	1,150,181.01	114.9	28.5	143.4	763,297.13	549,291.41	22.9	71.4	94.3	1,492,728.52	Utah
Vermont	274.5	1,572,665.78	483,333.34	29.3	2.6	31.9						624,276.71	Vermont
Virginia	1,546.4	4,600,321.27	2,185,470.61	196.3	6.0	202.3	1,020,020.56	453,299.43	32.6	14.2	46.8	2,267,039.96	Virginia
Washington	978.5	2,798,789.14	1,231,100.00	49.9	36.3	86.2	699,621.18	224,900.00	14.7		14.7	2,868,191.86	Washington
West Virginia	709.3	5,063,098.32	1,846,479.98	120.3	41.3	161.6	851,788.19	363,021.27	9.7		9.7	1,093,807.72	West Virginia
Wisconsin	2,293.5	8,569,758.50	3,496,816.95	212.4	52.8	265.2	1,287,640.85	574,000.00	37.8		37.8	2,624,034.41	Wisconsin
Wyoming	1,680.1	2,791,682.28	1,852,902.71	212.3	120.2	332.5	190,568.49	125,108.19	12.0	15.2	27.2	1,731,460.10	Wyoming
Hawaii	41.2	882,655.31	374,008.63	21.7		21.7	197,730.75	98,865.37	9.0		9.0	1,852,769.59	Hawaii
TOTALS	86,074.1	288,265,306.63	120,070,429.03	8,325.1	2,721.9	11,047.0	47,118,849.46	20,872,289.45	1,489.6	701.1	2,190.7	162,263,158.78	TOTALS

[1] The term stage construction refers to additional work done on projects previously improved with Federal aid. In general, such additional work consists of the construction of a surface of higher type than was provided in the initial improvement.

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