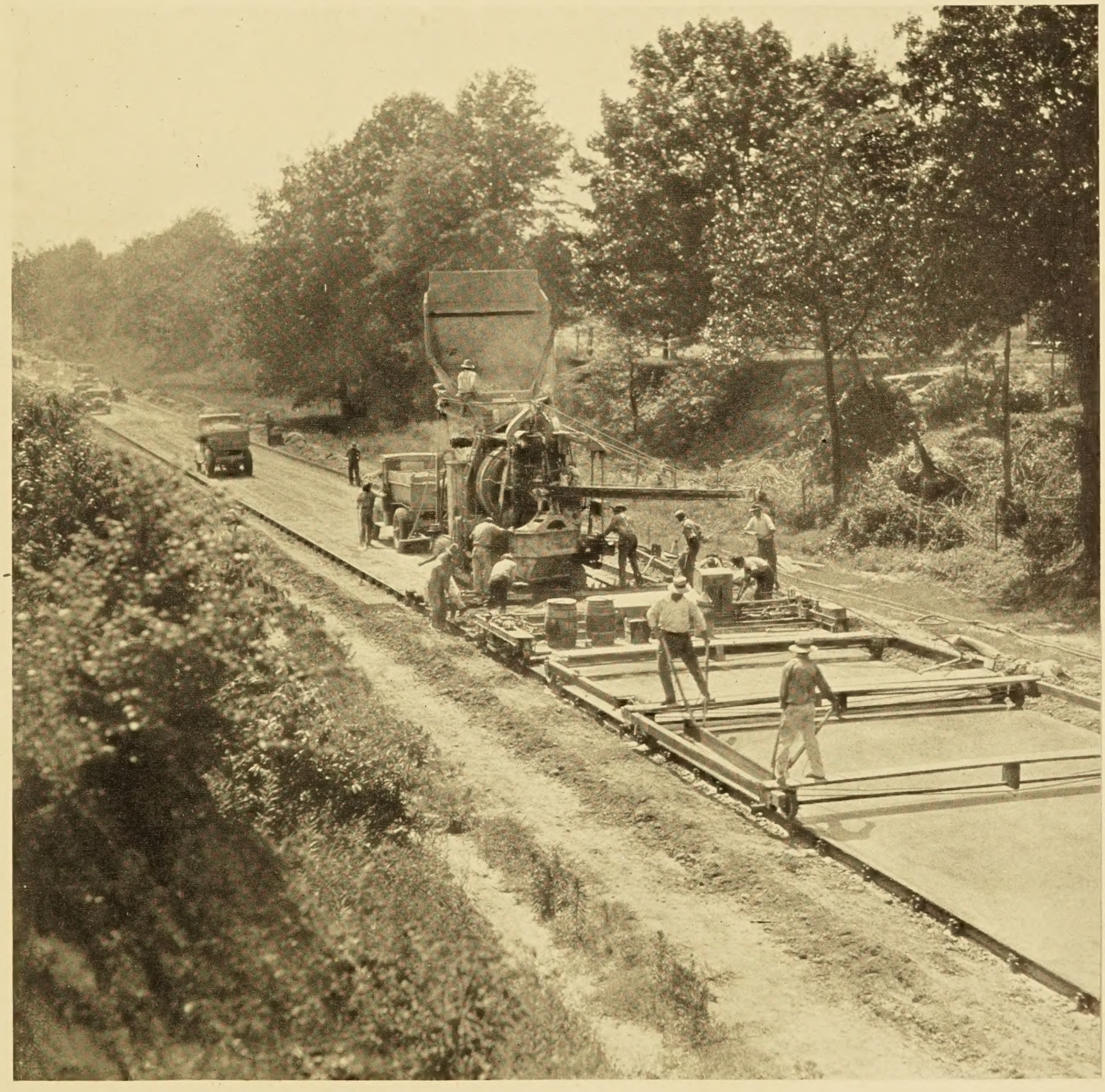
PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 15, NO. 5 JULY 1934



LAYING A CONCRETE ROAD SURFACE

For sale by the Superintendent of Documents, Washington, D.C. - - - - - - - - - - - - - - See page 2 of cover for prices

PUBLIC ROADS ▸▸▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

G. P. St. CLAIR, *Editor*

Volume 15, No. 5 July 1934

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions

In This Issue

THE BUREAU OF PUBLIC ROADS - - - - - - - - Willard Building, Washington, D.C.

REGIONAL HEADQUARTERS - - - - - - - - - - - Mark Sheldon Building, San Francisco, Calif.

▾

DISTRICT OFFICES

DISTRICT No. 1. Oregon, Washington, and Montana.
Post Office Building, Portland, Oreg.

DISTRICT No. 2. California, Arizona, and Nevada.
Mark Sheldon Building, 461 Market St., San Francisco, Calif.

DISTRICT No. 3. Colorado, New Mexico, and Wyoming.
237 Custom House, Nineteenth and Stout Sts., Denver, Colo.

DISTRICT No. 4. Minnesota, North Dakota, South Dakota, and Wisconsin.
907 Post Office Building, St. Paul, Minn.

DISTRICT No. 5. Iowa, Kansas, Missouri, and Nebraska.
Saunders-Kennedy Building, Omaha, Nebr.

DISTRICT No. 6. Arkansas, Louisiana, Oklahoma, and Texas.
Old Post Office Building, Fort Worth, Tex.

DISTRICT No. 7. Illinois, Indiana, Kentucky, and Michigan.
South Chicago Post Office Building, Chicago, Ill

DISTRICT No. 8. Alabama, Georgia, Florida, Mississippi, South Carolina, and Tennessee.
Federal Building, P.O. Box 60, Montgomery, Ala.

DISTRICT No. 9. Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.
Federal Building, Troy, N.Y.

DISTRICT No. 10. Delaware, Maryland, North Carolina, Ohio, Pennsylvania, Virginia, and West Virginia.
Willard Building, Washington, D.C.

DISTRICT No. 11. Alaska.
Room 419, Federal and Territorial Building, Juneau, Alaska.

DISTRICT No. 12. Idaho and Utah.
Federal Building, Ogden, Utah.

Because of the necessarily limited edition of this publication it is impossible to distribute it free to any person or institutions other than State and county officials actually engaged in planning or constructing public highways, instructors in highway engineering, and periodicals upon an exchange basis. At the present time additions to the free mailing list can be made only as vacancies occur. Those desiring to obtain PUBLIC ROADS can do so by sending $1 per year (foreign subscription $1.50), or 10 cents per single copy, to the Superintendent of Documents, United States Government Printing Office, Washington, D.C.

SOME ASPECTS OF PORTLAND CEMENT CONCRETE PAVEMENT CONSTRUCTION

BY THE DIVISION OF MANAGEMENT, UNITED STATES BUREAU OF PUBLIC ROADS

Reported by WILLIAM A. BLANCHETTE, Highway Engineer

STUDIES of production in highway construction have been made by the Division of Management of the Bureau of Public Roads from 1923 to the present year. These studies have included grading and surfacing of nearly all types of highways in practically all sections of the United States.

The number and mileages of concrete roads constructed and the magnitude of the funds invested in them justify considerable study. During 1930 approximately 10,000 miles of portland cement concrete pavements were laid on rural highways of which 8,500 miles were on State systems. In 1930 the average cost per mile of a 20-foot concrete surface, exclusive of engineering, drainage structures, and rough grading, was about $22,500, a total cost of approximately $225,000,000 for the year. A greater efficiency in such large-scale production will result in correspondingly lessened costs to the public.

In the studies here reported, data were collected relative to personnel, equipment, and efficiency of operation. The causes of efficiency on certain projects were analyzed. Between 1923 and 1929 numerous changes were made in types and sizes of equipment used and in methods of construction. From 1929 to June 1934 changes have not been so extensive. This discussion is based upon investigations made during the latter period.

EFFICIENCY IN CONSTRUCTION GREATLY IMPROVED IN RECENT YEARS

The following observations and conclusions are a result of these studies:

1. The equipment used in concrete surfacing is reasonably well standardized as to type, capacity, and number of units.
2. The number of men employed on a concrete paving job varies between wide limits. The average personnel, exclusive of truck drivers, on the 34 projects analyzed numbered 68 men with a minimum of 42 and a maximum of 98.
3. The combination of personnel and equipment on concrete paving projects observed was usually adequate to the handling of the maximum possible production of the key equipment.
4. There is considerable difference in the over-all efficiency with which different contractors operate the major or key equipment. The average over-all efficiency of operation of key equipment on projects studied in 1929 and 1930 was 78 percent, with a minimum of 47 percent and a maximum of 97 percent. The average efficiency of operation of key equipment on 10 projects studied between 1923 and 1928 was 55 percent, with a minimum of 42 percent and a maximum of 66 percent. There appears to have been an increase in efficiency in recent years.
5. The efficiency of operation of major equipment is a reasonably accurate measure of the efficiency with which the entire paving organization is operated. It is an indication of the type of supervision employed.
6. Unnecessary interference by inspectors tends to lower operating efficiency and to discourage employment of adequate supervision.
7. About 30 percent of the total cost of a concrete pavement is for cement delivered to the project. Twenty-nine percent is for aggregates delivered to the project. Thirty-seven percent of the cost of cement and aggregates delivered is for transportation. The equipment cost is 9 percent and the labor cost is 11 percent of the total cost of a concrete pavement (exclusive of rough grading, etc.) The daily cost for labor and equipment is almost constant regardless of quantity of production. The unit cost for these two items varies almost inversely with the efficiency of operation.
8. The cement factors used on the projects analyzed varied from 1.23 to 2.10 barrels of cement per cubic yard of concrete.
9. The present method of combining the cement, aggregates, and water into concrete does not produce a homogeneous mass in which these ingredients are uniformly distributed throughout the mass.
10. Present methods of placing and finishing the concrete require fairly wet mixtures, resulting in excess water which decreases the potential strength of the concrete.

PERSONNEL AND EQUIPMENT DESCRIBED

The construction of a concrete pavement requires several separate operations. The subgrade must be prepared. The forms must be set in place. Cement, fine and coarse aggregate and water must be delivered to the paver and mixed. The mixed concrete must be deposited on the subgrade, spread, finished, and cured. These major operations are performed on all concrete paving projects.

Minor operations such as the delivery and placing of reinforcing steel, joints, etc., must be performed also. Each operation requires certain pieces of equipment. Table 1 shows the equipment used on 38 concrete paving projects studied during 1929 and 1930. These projects were located in 18 States and represent nearly every section of the United States. The equipment listed in table 1 is typical of equipment used generally in concrete paving. This table shows the average length of haul from the material yard to the paver in miles during the period of the production study.

Trucks were used for hauling batches except on one project where an industrial railway was used. Single-batch trucks were used on 12 projects; 2-batch trucks on 13 projects; 3-batch trucks on 12 projects, and 4-batch trucks on 2 projects on which 2- and 3-batch trucks were also used.

The mixing on all of the projects was done in standard pavers of the 27–E type. A finishing machine was used on all but 5 projects. On these 5 projects, 4 in 1 State and 1 in another, all finishing was done by hand.

Table 2 shows the personnel employed on the 38 projects. On 34 of them the mixing was done by one 27–E paver. On the remaining 4 projects, two 27–E

TABLE 1.—*Summary of equipment used on projects studied in 1929 and 1930*

	Arkansas no. 1	California no. 1	California no. 2	California no. 3	California no. 4	California no. 5	Colorado no. 1	Illinois no. 1	Iowa no. 1	Louisiana no. 1	Louisiana no. 2	Louisiana no. 3	Louisiana no. 4	Maine no. 1	Michigan no. 1	Missouri no. 1	Missouri no. 2	Nebraska no. 1	New Jersey no. 1
GENERAL INFORMATION																			
Length of project, miles	15.4	11.4	8.5	4.4	5.4	5.2	15.6	9.0	8.8	26.8	10.1	6.8	9.5	3.8	9.5	9.8	37.2	14.6	7.7
Width of pavement, feet	18	20	30	30	30	40	18	18	18	20	18	18	18	20	20	20	20	20	20
Average length of haul during study, miles	6.4	2.7	1.6	1.0	10.0	3.6	2.4	3.5	6.4	5.3	4.2	3.5	1.2	2.8	1.6	2.4	2.5	3.3	3.7
FINE GRADING																			
Blade graders, number and length of blade, feet	1-12 1-10	1-12	2-10	1-8	1-8	1-12 1-8	1-6 1-8		1-12	1-12	1-10	1-12	1-4 1-12			1-5 1-12	1-8 1-10	[1] 1	1-6
Tractors, number and horsepower	1-30 1-60	1-30 1-60	2-60	1-60	2-30	1-30 1-60			1-60	1-60	1 1-30	1-60	1 1-60			1-60	2-20 1-30 1-60	1-60	1-30
Motor patrols, number and length of blade, feet								1-8	1-10						1-10			1-8	
Scarifiers, number	1	1	1	1	2	2		1	1	1	1	1	1			1	1	1	1
Subgraders, number	1	1	1	1	2	2		1	1	1	1	1	1			1	1	1	1
Subgrade planers, number	1						1	1	1	1	1	1	1	1	1	1	1	1	1
Rollers, number and size, tons	1-10	1-15	1-13	1	1-12	1-10		2	1-5	1-10	1	1-5	1	1-12	1-10	1-3		1-6	1-10
Fresno teams, number	2		1	1	2	2		2		2	1	2	1		1	5	2	3	2
HANDLING FORMS																			
Lineal feet	4,500	8,000	20,000	8,500	16,000	12,000	3,300	3,000	6,800	4,000	4,200	5,000	4,000	4,000	3,000	4,200	3,300	4,500	6,000
Forms, kind	Steel	Steel	Wood	Wood	Wood	Wood	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel
Wagon teams, number	2								2	1	2	1	2		1	1	2	1	
Trucks, number		1	1	1	1	1	1	1						1					1
Mechanical form trenchers, number	1							1				1	1		1	1		1	
HANDLING MATERIALS																			
Cranes, number and capacity, cubic yards	1-1	1-1	1-1¼	1-1	(2)	(2)	1-1	1-1¼	1-1	1-¾	1-¾	1-1	1-1	1-⅝	1-1	1-1	2-¾	1-1	1-¾
Batcher bins, number	1	1	1	1		1	1	3	1	1	1	1	1	1	1	1	1	1	1
Tractors, number																1			
Cement houses, number			1						1		1	1				1	1		1
Pumps, number	1	2	2	1	1	1	2	1	2	1	1	1	1	1	1	1	1	2	1
Pipe:																			
3-inch, lineal feet			40,000		31,000	27,000		5,000										23,760	
2½-inch, lineal feet		26,500					5,280	16,000	21,000	35,000	6,000	16,000	15,000	6,000		26,400	42,000		21,000
2-inch, lineal feet	26,400			23,000			15,840		31,500		11,000				17,000				
Hose:																			
2-inch, lineal feet	200							400	300			200		200	150	200		300	200
1½-inch, lineal feet				225		600				250	300		100				300		
1-inch, lineal feet		300	200		400														
Service trucks, number		1	1	1	2	3	1	1	2	2	1	2	2	3		1	2	1	1
HAULING BATCHES																			
Trucks:																			
4-batch, number					3			(3)											
3-batch, number		7	7	4	17	18								8	11				7
2-batch, number																			
1-batch, number	17						18		34	29	17	13	11			18	35	27	
Turntables		1	1		1						1	1		1		1	1	1	
MIXING																			
Paving mixers (all 27-E), number	1	1	1	1	1	2	1	2	1	1	1	1	1	1	1	1	2	1	1
FINISHING																			
Strike boards, number and length, feet																			
Finishing machines, number and width, feet	1-18	2-10	1-10	2-10	1-20	2-20	1-18	1-18	1-18	1-20	1-18	1-18	1-18	1-10	1-20	1-20	1-20	1-20	1-10
Longitudinal floats, number and length, feet	2-16	1-16	2-16	1-16	2-16	1-20		1-14	1-10	1-8	1-8	1-10	1-10			1-10	1-10	1-14	
Transverse floats, number and length, feet																			
Rollers, number			1																
Belts or flexible floats, number and length, feet		1-16	1-16	1-16	1-16	1-20	1-18	1-18	2-18	2-18	2-18	2-18	2-18	1-10		1-18	1-20	2-20	
Joint machines, number and width, feet						1-20											1-20		
Hand floats, number			2		2	4		1	7	2	2	2	2		2	2	1	2	3
Straight edges, number								1		2	2	2	2					1	
CURING																			
Burlap, length, feet	1,500	2,000	1,700	1,500	1,200	2,000	500	1,500	2,000	1,000	1,000	800	1,000	700	900		1,800	5,280	
Hose, ¾-inch, feet	200	200	200	200	200	600	350	300	1,000	400	300	200	200	200	300			1,450	
Curing spray apparatus, nnmber								[4] 1		1			1			1	[4] 1		1

[1] Elevating grader. [2] Commercial aggregate plants. [3] All batches hauled by industrial railway. [4] Calcium chloride.

pavers were used either parallel or in tandem. Table 2 shows a wide variation between projects both as to the total number of men employed and the number employed to perform various operations. The major operations are relisted in table 3 which gives, for purposes of comparison, analyses of the numbers of men required for each operation on 34 paving projects using a single paver and those required on 4 projects using 2 pavers each.

The size of the crew necessary for fine grading is affected by several factors: The amount and character of the material to be moved, the amount and kind of equipment used, the efficiency of operation, and the rate at which pavement is being laid. The fine-grading crew varies considerably from job to job as is shown in table 2, with a minimum of 3 men on one project and a maximum of 23 men on another project. The average number of men on all 34 projects was 13.

The handling and setting of forms consists in removing the forms from the finished and hardened pavement, transporting and distributing them where they are to be reset, shaping the form trench, setting, lining up and pinning the forms to the subgrade, and, finally, checking the form line. The number of men used to perform this operation varies considerably, although the methods are more or less standardized. The average number of men required was 11. The chief reasons for variation in the number of men employed are the

TABLE 1.—*Summary of equipment used on projects studied in 1929 and 1930*—Continued

	Ohio no. 1	Oregon no. 1	South Carolina no. 1	Tennessee no. 1	Tennessee no. 2	Tennessee no. 3	Tennessee no. 4	Tennessee no. 5	Tennessee no. 6	Tennessee no. 7	Tennessee no. 8	Texas no. 1	Texas no. 2	Washington no. 1	Washington no. 2	Washington no. 3	Washington no. 4	Washington no. 5	Wisconsin no. 1
GENERAL INFORMATION																			
Length of project, miles	4.9	4.7	19.8	13.8	12.0	14.2	8.1	12.4	10.4	4.7	10.9	13.9	30.4	8.1	7.8	6.4	4.1	6.6	14.7
Width of pavement, feet	30	20	18	18	18	18	18	18	18	18	18	18	18	20	20	18	18	20	20
Average length of haul during study, miles	2.4	2.3	2.2	2.0	2.6	2.3	5.8	8.0	6.0	2.0	2.5	1.9	1.7	0.9	7.3	4.0	4.5	6.4	2.4
FINE GRADING																			
Blade graders, number and length of blade, feet	1-10	2-8	1-8	1-12	1-12	1-12	1-12	1-10	1-10	2-10	1-10	1-10	1-8 1-10	1-12	1-10	1-10	1-10		1-10
Tractors, number and horsepower	1-30	1-20	1-20	1-60	1-75	1-60	1-50	1-60	2-30	1-50	1-50	1-30	1-30 1-60	1-30 1-60	1-30	1-30	1-30		1-30 1-60
Motor patrols, number and length of blade, feet																		1	
Scarifiers, number	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1
Subgraders, number	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1
Subgrade planers, number	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Rollers, number and size, tons	2	1-10	1-10	2	1-5	1-10	1-10	2	1-10	1-5	1-5	1-3	1-5	1-10	1-12	1-12	1-14	1-12	1-5
Fresno teams, number	1	1		1	1	1	1	1	1	4	3	2		2	1	2		1	1
HANDLING FORMS																			
Lineal feet	2,176	4,600	3,000	5,000	3,500	5,200	3,940	4,600	5,000	5,500	2,060	4,000	4,400	28,600	42,000	15,000	20,000	40,000	38,500
Forms, kind	Steel	Wood	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Wood	Wood	Wood	Wood	Wood	Steel
Wagon teams, number			2		2	1	1		1			1	1						
Trucks, number	1	1		2						1	1			1	1	1	1	1	
Mechanical form trenchers, number		1						1				1							
HANDLING MATERIALS																			
Cranes, number and capacity, cubic yards	2-1	1-2	2-¾	1-1	1-¾	1-½	1-¾	1-1	1-¾	1-¾	1-1	1-1	1-1¼	1-1¼	1-1¾	1-1¼	1-1	1-1¾	1-1¾
Batcher bins, number	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Tractors, number	1		1																
Cement houses, number	1		1			1	1	1		1	1	2				1			
Pumps, number	1	1	1	1	1	2	2	1	2	1	1	1	2	3	1	1	1	1	
Pipe:																			
3-inch, lineal feet						10,000								26,400	31,000	15,000	13,200		
2½-inch, lineal feet	40,000	22,000	21,000		5,300	19,040	21,120			21,120	20,000	22,000	40,000					19,000	
2-inch, lineal feet				15,935	15,800			25,000	42,400			10,000							40,000
Hose:																			
2-inch, lineal feet		300		200	200	200				100	150		300	300				300	200
1½-inch, lineal feet	200		300		100				150						550	350	300		
1-inch, lineal feet												175							
Service trucks, number		1	1	1	1	1	2	1	1	1	1	1	3	1			1	1	2
HAULING BATCHES																			
Trucks:																			
4-batch, number																		3	
3-batch, number	12	5						16	10										
2-batch, number			10	10	11	10	13			9	10			5	13	10	10	8	10
1-batch, number			2									15	24						
Turntables				1		1	1	1				1							1
MIXING																			
Paving mixers (all 27-E), number	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FINISHING																			
Strike boards, number and length, feet		1												1-20	1-20	1-20		1-20	
Finishing machines, number and width, feet	2-20		1-18	1-18	1-18	1-18	1-18	1-18	1-18	1-18	1-18	1-18	1-18				1-18		1-20
Longitudinal floats, number and length, feet		1-11	1-12	2-16	1-16	2-16	2-16	2-16	2-16	1-10	1-10		1-18	1-16	1-16	1-16	1-16	1-16	1-10
Transverse floats, number and length, feet						1-18	1-18	1-18	1-18					1-20	1-20	1-18	1-18	1-20	1-20
Rollers, number												1		1	1	1		1	
Belts, or flexible floats, number and length, feet			1-18	1-18	1-18	1-18	1-18	1-18	1-18	1-20	1-20	1-18	1-18	1-20		1-16		1-18	2-20
Joint machines, number and width, feet	1-20																		1-20
Hand floats, number	2	2		2	2	2	2	2	2	3	3	2	2	4	9	5	3	5	2
Straight edges, number												1		1	1	1	1	1	
CURING																			
Burlap, length, feet	1,500	1,000	2,000	1,000	825	1,200	2,000	1,000	1,500	1,500	1,500	1,200	1,500	1,000	1,000	800	1,100	1,000	1,000
Hose, ¾-inch, feet	300	300		300	300	200	300	300	1,000	600	300	350	300	700	700	400	450	900	400
Curing spray apparatus, number													1						

method used in trenching, the accuracy with which form trenching is done, the rate at which forms must be set to keep pace with paving, the character of the soil, and the efficiency of form-handling and setting operations.

The average number of men employed in handling materials is 14. This includes the men operating the water-supply system.

The number of men, including truck drivers, truck checkers, dumpers, and turntable operators employed to deliver batches to the paver ranged from 5 to 30. Reasons for this wide variation are length of haul, condition of hauling road, condition and capacity of hauling equipment, rate of paver operation, and efficiency of hauling equipment operation. On an average, 15 men were employed in hauling batches on the 34 projects on which the average length of haul during the period of study varied from 0.9 mile on one project to 10 miles on another, and on which 1-, 2-, 3-, and 4-batch trucks were used.

The men connected with the mixing operation are the foreman, who usually has charge of mixing, placing, finishing, and curing, and the paver operator.

The men employed in finishing, which in this summary includes puddlers, spaders, finishing machine operators, strikeboard laborers, hand finishers on slab

Table 2.—*Summary of personnel on 38 concrete paving projects, 1929–30*

	Arkansas no. 1	California no. 1	California no. 2	California no. 3	California no. 4	California no. 5[1]	Colorado no. 1	Iowa no. 1	Louisiana no. 1	Louisiana no. 2	Louisiana no. 3	Louisiana no. 4	Maine no. 1	Michigan no. 1	Missouri no. 1	New Jersey no. 1	Ohio no. 1[1]	Oregon no. 1
Fine grading:																		
Foremen	1	---	1	---	1	1	---	1	1	1	1	1	1	1	1	1	1	1
Tractor operators	1	---	2	1	2	2	---	1	1	1	1	1	---	1	2	1	1	1
Blade-grader operators	1	---	1	1	1	2	---	1	1	1	1	1	---	1	1	1	1	1
Roller operators	1	---	1	---	1	1	---	1	1	---	1	1	1	1	1	1	1	1
Teamsters or drivers	2	---	1	1	2	2	---	2	---	---	3	2	---	---	5	---	---	---
Laborers ahead of mixer	8	3	3	---	6	6	6	4	8	2	7	3	11	8	9	6	6	---
Laborers rear of mixer	---	---	2	---	---	---	5	2	2	2	3	1	---	2	---	---	4	---
Total	14	3	11	3	13	14	11	12	14	7	17	10	13	14	19	10	14	4
Handling and setting forms:																		
Foremen	1	1	1	---	1	1	---	1	---	---	---	---	---	1	---	1	1	1
Form setters	3	2	2	2	3	2	2	4	3	4	3	4	1	1	3	4	2	2
Helpers	3	2	2	2	3	2	2	4	3	3	2	3	1	1	3	3	2	1
Teamsters	2	---	---	---	---	---	---	2	---	2	2	---	---	1	1	---	2	---
Truck drivers	---	1	1	1	1	1	1	---	2	---	1	1	1	---	---	1	1	1
Laborers	7	6	14	---	8	10	2	10	1	5	1	4	---	1	2	4	---	2
Total	16	12	20	5	16	16	7	21	9	14	9	12	3	5	9	13	8	7
Handling materials:																		
Foremen at plant	---	---	1	---	1	1	---	1	---	---	---	---	---	1	---	---	---	1
Crane operators	2	1	1	1	1	---	1	2	2	1	1	1	1	1	1	1	---	2
Batcher operators	1	1	1	1	1	2	1	1	1	2	1	2	1	1	1	2	2	1
Laborers in cars	---	2	---	1	---	---	3	2	---	2	1	2	1	3	3	2	2	---
Cement handlers, loading	5	---	3	3	5	4	---	---	2	2	3	4	2	3	3	2	---	---
Cement handlers, dumping	2	4	3	3	4	4	4	6	3	2	3	2	3	2	2	3	6	---
Sack shakers, balers	1	1	---	---	1	---	---	---	---	1	---	---	---	---	1	---	---	---
Pump operators	1	---	1	1	1	---	1	2	1	1	1	1	1	1	1	1	1	1
Laborers on pipe line	2	---	---	---	---	2	2	3	---	---	1	---	1	---	2	---	---	---
Laborers	---	---	2	---	---	3	---	---	---	---	---	1	1	---	1	3	7	---
Service truck drivers	---	1	---	1	2	2	1	2	2	---	1	---	---	---	1	---	1	---
Total	14	10	12	11	16	18	13	19	11	11	12	13	11	12	16	14	19	5
Hauling batches:																		
Truck foremen	---	1	---	---	---	---	---	---	---	---	---	---	---	---	---	---	1	---
Truck drivers	17	7	7	4	20	18	18	34	29	17	13	11	8	11	17	7	12	5
Truck checkers	1	---	---	---	---	---	1	1	1	---	1	---	---	---	1	---	---	---
Turntable operators	1	1	1	---	1	---	1	1	---	1	2	---	---	---	2	---	---	---
Truck dumpers	1	1	1	1	2	2	2	1	1	2	1	1	2	1	1	1	4	1
Total	20	10	9	5	23	20	22	37	31	20	17	12	10	12	21	8	17	6
Mixing:																		
Foremen	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mixer operators	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	2	1
Total	2	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	3	2

	Tennessee no. 1	Tennessee no. 2	Tennessee no. 3	Tennessee no. 4	Tennessee no. 5	Tennessee no. 6	Tennessee no. 7	Tennessee no. 8	Texas no. 1	Texas no. 2	Washington no. 1	Washington no. 2	Washington no. 3	Washington no. 4	Washington no. 5	Wisconsin no. 1	Illinois no. 1[2]	Nebraska no. 1	Missouri no. 2[1]	South Carolina no. 1
Fine grading:																				
Foremen	1	1	1	1	1	2	1	1	---	1	1	1	1	1	1	1	1	1	1	1
Tractor operators	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	2	---	1	2	1
Blade-grader operators	1	1	1	1	1	1	1	1	1	2	1	1	1	1	---	1	1	1	2	---
Roller operators	1	1	2	1	1	2	1	1	1	1	---	1	1	1	1	1	1	1	---	1
Teamsters or drivers	---	---	---	---	---	---	4	3	2	---	2	1	2	---	1	---	2	3	---	---
Laborers ahead of mixer	7	8	12	9	8	5	15	10	5	10	5	4	1	9	8	6	11	4	4	12
Laborers rear of mixer	2	---	---	---	2	2	2	2	2	4	4	3	3	4	4	2	2	2	4	4
Total	13	12	17	13	14	13	25	19	12	20	15	12	10	17	16	13	18	13	13	19
Handling and setting forms:																				
Foremen	1	1	1	1	1	---	1	1	---	---	1	---	1	---	1	---	---	---	---	---
Form setters	3	4	4	3	4	5	4	3	2	2	2	2	2	3	2	1	6	3	1	4
Helpers	---	3	3	3	3	---	3	3	2	2	1	2	1	2	1	1	4	4	8	3
Teamsters	---	2	2	2	2	2	---	---	1	1	---	---	---	---	---	---	---	2	3	2
Truck drivers	2	---	---	---	---	---	1	1	---	---	1	1	1	1	1	2	1	---	---	---
Laborers	4	4	4	7	7	1	3	10	4	1	---	3	1	3	1	2	5	5	7	1
Total	10	14	14	16	17	8	12	18	9	6	5	8	6	9	6	6	16	14	19	10
Handling materials:																				
Foremen at plant	1	1	---	---	---	---	---	1	---	1	---	1	---	---	1	---	1	1	1	1
Crane operators	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	2	1	2	2	2
Batcher operators	1	1	1	1	1	2	1	1	1	2	1	1	1	1	1	1	3	1	1	1
Laborers in cars	3	2	2	2	2	2	2	2	3	2	2	1	1	---	1	---	---	---	---	---
Cement handlers, loading	2	3	3	4	3	3	3	3	2	4	2	---	6	---	---	3	2	---	7	6
Cement handlers, dumping	3	3	3	2	3	3	2	2	2	2	3	3	2	3	3	3	1	7	4	6
Sack shakers, balers	2	1	---	---	1	1	---	1	---	---	---	---	---	1	1	1	---	---	---	---
Pump operators	1	1	2	1	1	1	2	1	1	1	1	1	1	---	1	1	1	1	---	1
Laborers on pipe line	---	2	4	---	3	---	---	2	---	3	3	2	---	---	2	---	2	2	---	---
Laborers	3	---	2	---	---	---	---	4	3	1	1	1	1	1	1	---	3	2	---	6
Service truck drivers	1	1	1	2	1	1	1	1	1	---	1	---	---	1	---	1	2	1	1	1
Total	18	16	19	13	16	15	12	19	14	17	15	11	13	8	12	12	16	17	16	24
Hauling batches:																				
Truck foremen	---	---	---	---	---	---	---	---	1	---	---	---	---	---	---	---	6	---	1	---
Truck drivers	11	11	10	13	15	9	9	10	15	24	5	13	10	10	11	10	2	27	35	11
Truck checkers	---	1	1	---	---	---	---	---	---	1	---	---	---	---	---	---	---	---	---	---
Turntable operators	1	---	2	2	1	---	---	---	1	1	---	---	---	---	---	---	8	---	2	1
Truck dumpers	1	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	---	1	2	---
Total	13	13	14	16	17	10	10	11	18	30	6	14	11	11	12	11	16	28	40	12
Mixing:																				
Foremen	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Mixer operators	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	2	1
Total	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	5	2	3	2

Finishing:																																						
Foremen	1																	1	1			1					1	1							1			
Puddlers	4	3	5	5	4	5	2	4	2	3	3	3	5	4	4	5	5	2	3	4	3	3	3	3	2	4	4	7	5	3	4	3	3	3	6	2	6	5
Spaders		2			1	2											2								2	2	2										6	
Finishing-machine operators	1	2	1	2	1	2	1	1	1	1	1	1	1	1	1	1	2		1	1	1	1	1	1	1	1	1	1				1		1	1	1	1	1
Strikeboard laborers																		2							2	6			2	2	2	4	2				4	
Finishers, floating slab	4	4	9	4	10	6	4	2	7	2	4	2	4	2	2	4	2	3	4	4	4	4	4	4	5	4	2	4	4	7	5	2	7	4	2	4	6	2
Finishers, joints and edging	2	5	4	3	7	6	2	3						1	2		3	3				1					1	2	2	2	2	2	2	4	1	6	1	3
Total	12	16	19	14	23	21	9	10	10	6	8	6	10	8	9	10	14	11	9	9	8	10	8	8	12	17	11	15	13	14	13	12	14	12	11	13	24	11
Setting steel:																																						
Laborers, reinforcement		3	4	2	5	7		1						4		2	2										2	3						3				
Laborers, longitudinal joints	2								2	2	2	2	4		1			4	2	2	2	2	1	2	1	2	1	1						2	1	1	2	
Total	2	3	4	2	5	7		1	2	2	2	2	4	4	1	2	2	4	2	2	2	2	1	2	1	2	3	4						5	1	1	2	
Curing:																																						
Foremen		1			1	1	1												1	1					1	1	1		1	1								
Laborers on burlap	2	2	2	2	2	2	3	2	2	2	2	4	1	2			2	2	2	2	2	2	2	2	2	2	2	3	2	2	2	2	2	5	1	2	2	2
Laborers, covering and sprinkling	8	5	9	5	10	9	9	12	2	2	5	2	1	3	2	1	5	3	12	2	9	5	6	11	4	3	7	9	11	2	3	2	3	4	2	3	2	8
Total	10	8	11	7	13	12	13	14	4	4	7	6	2	5	2	1	7	5	15	5	11	7	8	13	7	6	10	12	14	5	5	4	5	9	3	5	4	10
Supervision:																																						
Superintendent	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Timekeepers	1	1	1	1	2	1	1	2	1	1	1	1	1	1	2	1	2	1	1		1	1	1	1	1	1	1	1	2	1				1	1	2	1	1
Total	2	2	2	2	3	2	2	3	2	2	2	2	2	2	3	2	4	2	2	1	2	2	2	2	2	2	2	2	3	2	1	1	1	2	2	3	2	2
Miscellaneous:																																						
Laborers	3			1	2		2		2			1			1	1	12				7				7		1			2		3		1	4	1	1	1
Watchmen	2						1	1	1	1		1		1		1	2		1	1	2	1	1	1	1	1	2	1	1	1					2	2	1	
Mechanics	1	1	1	1	2									1																				1	1	2	4	1
Waterboys	1							1		1		1	1	1	1	1	2	1	2	2	2	2	2		2	3		1		1			1		2	1		1
Total	7	1	1	2	4		3	2	3	2		3	1	3	2	3	16	1	3	3	11	3	3	1	10	4	3	2	1	4		3	1	2	9	6	6	3
Total, excluding truck drivers, steel crew, and miscellaneous	73	56	79	45	89	88	61	84	54	49	61	52	45	49	64	53	74	37	71	61	77	66	69	62	73	84	63	80	68	55	51	54	57	57	71	68	86	79
Total, excluding truck drivers and steel crew	80	57	80	47	93	88	64	86	57	51	61	55	46	52	66	56	90	38	74	64	88	69	72	63	83	88	66	82	69	59	51	57	58	59	80	74	92	82
Total, excluding truck drivers	82	60	84	49	98	95	64	87	59	53	63	57	50	56	67	58	92	42	76	66	90	71	73	65	84	90	69	86	69	59	51	57	58	64	81	75	94	82
Grand total personnel	99	67	91	53	118	113	82	121	88	70	76	68	58	67	84	65	104	47	87	77	100	84	88	74	93	100	84	110	74	72	61	67	69	74	97	102	129	93

[1] 2 pavers were used on project.
[2] 2 pavers were used and an industrial railway was used for hauling batches. Under personnel for "Batch hauling" are listed 6 operators, 2 brakemen, and 8 in section crew.

A, shaping the subgrade with a tractor-drawn grader; *B*, excavating trench for forms; *C*, setting and lining up forms; *D*, the "subgrader" does the final shaping, leaving excess material in furrows for removal by hand shovels or fresnos.

STEPS IN SHAPING THE SUBGRADE.

and on joints, varied from a minimum of 6 to a maximum of 23 with an average of 11.

Setting steel, which includes both the longitudinal steel joint and reinforcing steel, required an average of 2 men on each of the 34 projects. The number varied from 1 to 7 for individual projects. On several projects neither longitudinal joint steel nor reinforcing steel was used.

The number of men employed in curing the concrete varied from 1 to 15, depending on the method of curing, the amount of slab to be cured and the efficiency with which the curing operation was performed. An average of 8 men was used for this work.

TABLE 3.—*Analysis of number of men required for different operations*

Operation	For 34 projects using a single paver							Average number of men on 4 projects using 2 pavers
	Number of projects employing numbers of men between						Average number of men	
	0–5	6–10	11–15	16–20	21–25	26–up		
Fine grading	3	4	18	8	1		13	15
Handling and setting forms	4	15	8	6	1		11	15
Handling materials	1	2	20	10	1		14	17
Hauling batches	1	8	12	6	3	4	15	23
Mixing	34						2	3
Finishing		16	14	3	1		11	18
Setting steel	34						2	3
Curing	13	12	9				8	7
Miscellaneous	30	3	1				3	8
Supervision	34						2	2
Grand total all personnel							81	111
Total exclusive of truck drivers							68	90

TABLE 4.—*Labor and equipment required on average concrete paving project as estimated from study of 34 projects*

FINE GRADING

	Number and type of equipment units	Number and class of men employed
Blade grader	1, 8 to 12-foot blade	1 foreman.
Tractors	1, 30 to 75 horse-power	1 tractor operator.
Scarifiers	1	1 blade grader operator.
Subgraders	1	1 roller operator.
Subgrade planers	1, heavy, metal	2 teamsters.
Rollers	1, 3 to 15-ton	2 laborers in rear of paver.
Fresnos	2, 3-foot	
Fresno teams	2, 2-horse	5 Laborers ahead of paver.
Total		13

HANDLING AND SETTING FORMS

Forms, lineal feet	4,300 steel	1 form foreman.
Teams	1, 2-horse	2 form setters.
Trucks	1	2 form setters' helpers.
Form trenchers	1	1 teamster or truck driver.
		1 teamster's helper.
		4 laborers.
Total		11

HANDLING MATERIALS

Crane	1, ½ to 2 cubic yard capacity.	1 plant foreman.
Batcher bins	1	1 crane operator.
Cement house	1	1 batcher operator.
Pumps (water)	1 to 3	2 laborers in cars.
Pipe line, lineal feet	25,000, 2, 2½, 3-inch	6 cement handlers, load, dump.
Hose, lineal feet	250	
Truck service	1	1 laborer on pipe line.
		1 pump operator.
		1 truck driver, service.
Total		14

HAULING BATCHES

Trucks	Variable 1 to 4 batches	13 truck drivers, variable.
Turntable	1	1 truck dumper.
		1 turntable operator or truck checker.
Total		15

MIXING

Pavers	1, 27-E	1 foreman.
		1 paver operator.
Total		2

TABLE 4.—*Labor and equipment required on average concrete paving project as estimated from study of 34 projects*—Continued

FINISHING

	Number and type of equipment units	Number and class of men employed
Finishing machine	1	4 puddlers and spaders.
Floats	1 to 3	1 finishing machine operator
Belts	1	3 hand finishers, slab.
Small tools		2 hand finishers, joints.
Bridges	1	1 hand finisher, edging.
Total		11

SETTING STEEL

		2 laborers.

CURING

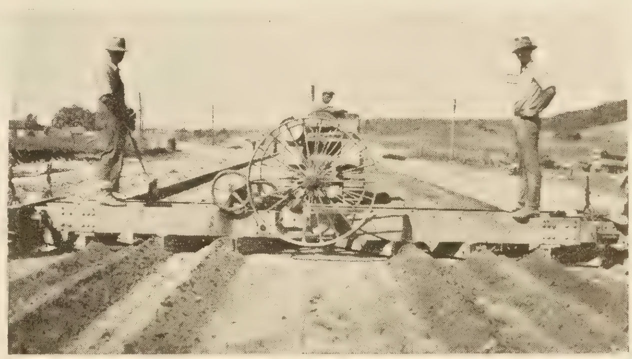
Burlap, road feet	1,300	2 laborers, burlap
Hose, ¾-in., lineal feet	400	6 laborers, covering.
Curing agent apparatus		
Total		8

MISCELLANEOUS

		1 watchman.
		1 water boy.
		1 mechanic.
Total		3

SUPERVISION

		1 superintendent.
		1 timekeeper.
Total		2
Total exclusive of truck drivers		68
Grand total		81



SHAPING THE SUBGRADE.

The equipment and the personnel on the average project, as judged from 34 projects, are shown in table 4, which gives the approximate distribution of personnel performing each operation. This table shows an average of 68 men employed to operate a modern paving outfit exclusive of the operators of hauling equipment. "Miscellaneous" as used in table 4 includes watchman, water boy, and mechanic. "Supervision" includes the superintendent and timekeeper.

Table 2 shows that the total personnel exclusive of truck drivers and steel crew on the paving projects employing a single 27-E paver varied between 38 and 93, a difference of 55 men.

In general, the number of men employed to operate a concrete paving outfit should be sufficient to perform all of the operations when the paver is working at maximum production. Considerable physical exertion is required of workers and assignments should be such that the work can be accomplished by uniform sustained effort and without injury to the men.

The type of supervision exercised over workers varies considerably. Some operations require a definite number of men regardless of the amount of work they have to do. Utilization of the capacity of workmen performing various operations may vary considerably. Again, the number of men that the contractor must employ to perform an operation may be and sometimes is regulated by arbitrary requirements of the engineer or inspector rather than by the amount of work to be done.

The number of men employed is regulated by a combination of the following influences: The maximum possible rate of production of the paver, the volume and character of fine grading, the lineal feet of transverse joints to be finished per square yard of pavement, methods employed, arbitrary requirements, type of supervision given, and extent to which machinery is used. It is believed that the combination of personnel and equipment employed on the majority of projects studied was sufficient to handle full paver production, and that the personnel in many instances was more than sufficient.

NO CONSISTENT RELATION FOUND BETWEEN NUMBER OF MEN EMPLOYED AND EFFICENCY OF OPERATION

To analyze the interrelation that may exist between number of men employed, maximum possible production, and over-all efficiency of paver operation, table 5 has been prepared, based on 23 of the projects studied. The information contained in this table is shown also in figure 1. There is a general relation between the number of men employed and the maximum possible rate of production although this relation is by no means definite. The relation between number of men and efficiency of paver operation is even less definite, showing that there are other factors besides production and efficiency which regulate the size of a working force.

TABLE 5.—*Comparison of number of men employed, over-all efficiency, and maximum possible production*

Project	Men employed exclusive of truck drivers and steel crew	Over-all efficiency, percent	Maximum possible production in cubic yards per hour [1]
Maine no. 1	46	66.4	40.7
California no. 3	47	47.4	50.6
Louisiana no. 2	51	82.1	39.6
Washington no. 3	51	81.8	42.5
New Jersey no. 1	56	76.0	38.6
Louisiana no. 1	57	87.2	41.0
Washington no. 4	57	96.8	51.5
Washington no. 2	59	87.9	51.2
Louisiana no. 3	61	80.3	44.0
Tennessee no. 6	63	86.4	44.7
Colorado no. 1	64	87.4	51.1
Tennessee no. 2	64	81.8	52.4
Louisiana no. 4	55	91.0	43.7
Texas no. 1	66	50.9	52.8
Tennessee no. 4	69	65.6	49.4
Washington no. 1	69	93.5	50.2
Tennessee no. 5	72	83.2	44.0
Nebraska no. 1	74	79.6	47.7
California no. 2	80	95.3	49.6
Texas no. 2	82	75.7	58.6
Tennessee no. 8	88	59.1	48.6
California no. 4	93	95.5	59.4
South Carolina no. 1	93	90.1	34.3

[1] The maximum possible production is regulated by the specified mixing time, the size of batch and the time constants of the paver for charging and discharging.

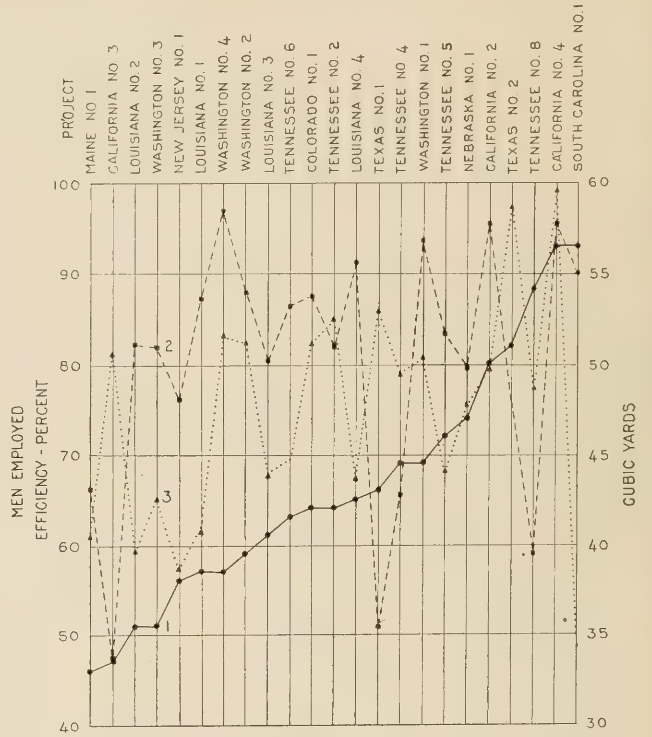


FIGURE 1.—RELATION BETWEEN SIZE OF FORCE, EFFICIENCY AND PRODUCTION.

TABLE 6.—*Comparison of number of finishers (finishing machine operator, spaders, and puddlers), lineal feet of transverse joint per square yard of pavement and maximum possible production*

Project	Number of finishers including finishing machine operator, spaders, and puddlers	Lineal feet of transverse joint per square yard	Maximum possible production in cubic yards per hour
Louisiana no. 2	6	None	39.6
Louisiana no. 4	6	None	43.7
Louisiana no. 3	8	None	44.0
Tennessee no. 3	8	0.018	48.0
Tennessee no. 5	8	.018	44.0
Tennessee no. 6	8	.018	44.7
Michigan no. 1	8	.09	44.9
Tennessee no. 1	9	.018	49.0
Tennessee no. 2	9	.018	52.4
Missouri no. 1	9	.09	36.8
Colorado no. 1	9	.15	51.1
Iowa no. 1	10	None	43.4
Louisiana no. 1	10	None	41.0
Tennessee no. 4	10	.018	49.4
Maine no. 1	10	.23	40.7
New Jersey no. 1	10	.26	38.6
Texas no. 1	11	.11	52.8
South Carolina no. 1	11	.22	34.3
Oregon no. 1	11	.45	40.6
Tennessee no. 7	12	.018	49.5
Arkansas no. 1	12	.18	47.5
Wisconsin no. 1	12	.18	44.0
Washington no. 4	12	.45	51.5
Nebraska no. 1	13	None	47.7
Washington no. 1	13	.45	50.2
Washington no. 3	13	.45	42.5
California no. 3	14	.45	50.6
Washington no. 2	14	.45	51.2
Washington no. 5	14	.45	52.7
Texas no. 2	15	.11	58.6
California no. 1	16	.45	52.0
Tennessee no. 8	17	.018	48.6
California no. 2	19	.45	49.6
California no. 4	23	.45	59.4

Table 6 gives the relation between the number of finishers (finishing machine operator, spaders, and puddlers), the lineal feet of transverse joint per square

A, crane unloading aggregates from cars to batcher bins or stockpiles as conditions require; *B*, unloading cement from cars to batch compartments of trucks; *C*, bin for handling bulk cement and batcher plant; *D*, batcher plant; *E*, a good plant arrangement; *F*, handling bulk cement in "buggies."

ARRANGEMENTS FOR HANDLING CEMENT AND AGGREGATES.

yard of pavement and the maximum possible paver production on 34 projects. Figure 2 also shows this information. No direct relation between these factors is evident.

EFFICIENCY OF PAVER OPERATION IS GENERALLY AN INDICATION OF EFFICIENCY OF ENTIRE ORGANIZATION

The efficiency with which concrete paving is placed is indicated by the studies. It is true that the efficiency with which the paver is operated may or may not measure the efficiency of the paving outfit as a whole. The efficiency of the entire organization is of primary interest to the contractor in that it regulates his unit costs for personnel and equipment. It sometimes happens that, although the paver operates with a high degree of efficiency, it does so with an oversupply of hauling equipment. Other operations than hauling may also be over-equipped or over-manned. It may happen that the personnel and equipment for hauling, subgrade preparation, and other operations have a high degree of efficiency, while the paver has a low degree of efficiency. Or it may be that the paver operates at a consistently low rate, but because of that consistency the production can be handled by a reduced personnel. These conditions are the exception rather than the rule.

In general, the efficiency of the paver is a close indication of the efficiency of the entire organization which is in turn an index of the type of supervision employed. The contractor or superintendent who operates the paver efficiently is likely to be equally efficient in all operations. Similarly, inefficiency in paver operation is often attended by inefficiency in most other operations.

The paver is the key equipment on a concrete paving project and should set the pace for the entire paving organization. It has a maximum capacity of a definite number of batches per hour for the specified mixing time. It cannot exceed this production. When the production of the paver falls below this maximum number of batches the efficiency of the organization in general is lowered.

A definite number of men is required to operate the equipment and to perform nearly every operation. This number of men cannot be changed as the rate of production changes. The number required to operate the outfit at maximum production of the key equipment must be employed, for on the most inefficient jobs studied, there were times during nearly every day when the paver was operating at close to its maximum production.

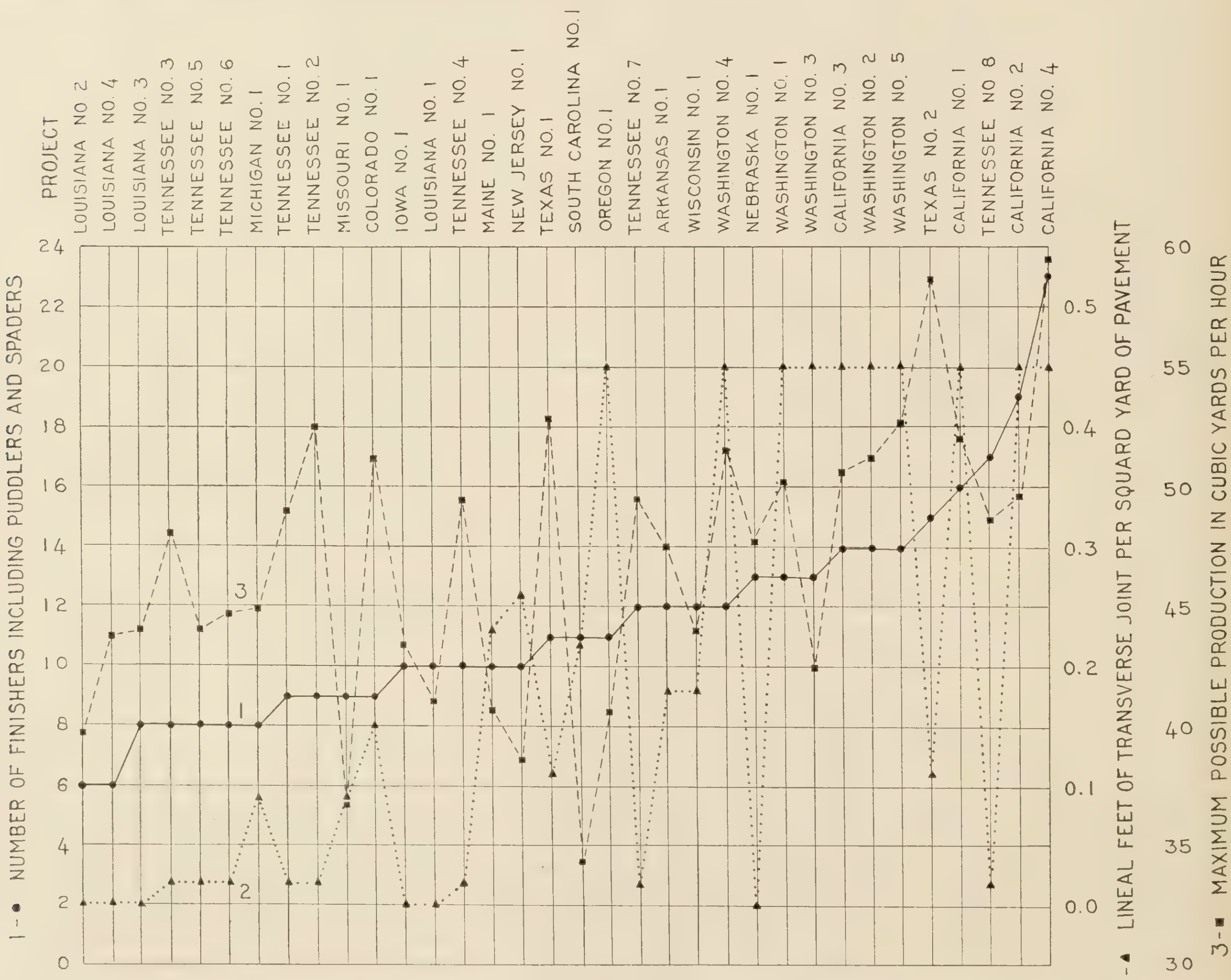


FIGURE 2.—RELATION BETWEEN NUMBER OF FINISHERS, JOINT SPACING AND POSSIBLE PRODUCTION.

Failure of outfits to maintain a high rate of production was not the result of insufficient personnel, but of intermittent delays of varying lengths. A high rate of production requires no greater rate of physical exertion on the part of workers than does a low and fluctuating rate of production.

Before discussing the efficiency of operation of major equipment, an outline will be given of the manner in which efficiency was determined. An engineer with one or more assistants was assigned to the project to be studied. In general, the duration of the study was from 1 to 2 months. During the study an accurate record was kept of the total available working time. The term "available working time" is defined as the time a crew was actually on the job, or the time it would have been on the job had there been no interference by the elements or other contingencies, consideration being given to the customs of the region and the practices of the contractor in regard to length of working day, holidays, etc. If a 9-hour day is customary with 7 hours work on Saturday, and holidays off, the available working time for a week in which no holiday occurs, will be 52 hours plus any overtime, regardless of how much time was actually lost because of rain, breakdowns, or other causes.

An accurate record was kept of all major delays. The term "major delays", as used throughout this report, indicates a delay of 15 minutes or more during the available working time. A delay of less than 15 minutes is termed a "minor delay." The division between major delay and minor delay at 15 minutes is chosen arbitrarily. In general, the major equipment will cease to operate during a major delay or the outfit may be shut down entirely as is usually the case during delays due to rain or wet subgrade. During the shorter major delays the entire organization may be on the job and drawing pay. The total available working time minus the total major delays gives the time the major equipment actually operated.

Minor delays are intermittent interruptions that range from a few seconds up to 15 minutes. Such delays are determined by stop-watch studies of operations. A stop-watch study period was usually of 1 hour's duration. From 2 to 4 such studies were made each day that the paver operated. The results of 2 stop-watch studies, 1 on a project operating with high efficiency and the other on a project operating with low efficiency, are shown in tables 7 and 8.

PREVENTABLE DELAYS FOUND ON MANY PROJECTS

Analysis of these tables shows characteristics of paver operation and the factors affecting the rate of production. The production of a batch of concrete consists of three operations: Raising the paver skip to charge the drum, mixing the batch, and discharging the batch from the drum to the paver bucket. In correct operation the raising of the skip overlaps the discharge of the preceding batch. Whenever the paver ceases to perform one of the three operations its efficiency is lowered. The project reported in table 7 was operated with high efficiency. With a mixing cycle of 74.1 seconds, representing the time to charge, mix, and discharge, the maximum production possible was 48.5 batches per hour. The over-all efficiency on this project during the entire production study was 96.8 percent.

TABLE 7.—*Result of typical stop-watch study of project operating with high efficiency*

[Drum revolutions, 16.5 per minute.]

						Delay due to			
Charge	Mix	Discharge	Charge	Mix	Discharge	Operator	Mechanical causes	Miscellaneous causes	Split discharge
Sec.	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*
11	59	5	10	60	2	6	8	22	
10	59	5	11	61	3	3	38		7
10	58	2	11	61	3	1			
10	60	2	11	61	3				
10	61	3	10	61	2				
11	61	3	10	62	5				
11	61	3	11	58	3				
11	61	3	10	60	2				
11	60	2	11	62	2				
10	61	3	10	62	2				
10	60	5	11	62	3				
10	59	1	11	60	2				
10	59	2	11	62	5				
10	60	2	10	61	3				
11	61	5	11	62	2				
10	61	2	11	62	2				
10	62	2							
11	61	3							
11	60	2							
11	61	3							
11	61	2							
10	61	3							
10	61	3							
10	60	5							
11	60	1							
10	61	3							
10	61	5							
11	61	3							
11	61	2							
10	62	5							
11	61	4							
10	61	2							
Total			494	2,913	149	10	46	22	7
Average			10.5	60.7	2.9				

Length of study, 60.53 minutes.
Number of batches mixed, 48.
Total time lost, 85 seconds or 2.3 percent.
Time per batch, 74.1 seconds.

TABLE 8.—*Result of typical stop-watch study of project operating with poor efficiency*

[Drum revolutions 15.5 per minute]

						Delay due to—					
Charge	Mix	Discharge	Charge	Mix	Discharge	Split discharge	Dumping or turning	Subgrade unprepared	Operation of hauling equipment	Moving turntable	Changing hose
Sec.	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*
9	64	3	9	62	3	25					
9	62	3	9	62	3	27	25				102
9	62	3	9	63	3	26	24				51
9	63	3	9	63	3	24		87			
9	64	3	9	62	3	23					
9	62	3						70			
8	61	3							28		
9	62	3							27		
8	62	3				21					
8	62	3				17		22			
9	68	3				16					
9	63	3								251	
9	62	3				18					
8	62	3				21					
8	62	3						27			
8	62	3						19			
9	63	3				21					
8	62	3						19			
9	62	3						15			
8	62	3						31			
8	62	3							24		
9	62	3				13					402
9	63	3									
Total			243	1,750	84	252	49	290	79	251	[illegible]
Average			8.7	62.5	3.0						

Length of study, 59.2 minutes.
Number of batches mixed, 28.
Total time lost, 24.6 minutes or 41.5 percent.
Time per batch, 74.2 seconds.

A, a standard type of paver with subgrade planer attached for smoothing irregularities in subgrade; *B*, depositing concrete on subgrade; *C*, finishing machine in operation; *D*, "straight-edging" the surface.

Mixing and Placing Concrete.

Table 8 shows stop-watch data taken on a project where the efficiency was low. Small intermittent delays ranging from a few seconds to several minutes account for the low efficiency. Nearly all of the delays could have been eliminated under good supervision such as was found on the first job mentioned. The mixing cycle was 74.2 seconds. The maximum production could have been close to 48 batches per hour. During the study period the production rate was 28.4 batches per hour. The over-all efficiency during the entire period of the production study was 50.9 percent.

Delays of 15 minutes or more occurring during a stop-watch study, were recorded as major delays and were excluded from the stop-watch study period. Periods of study were of such length and at such times that the minor delays recorded are typical of those occurring throughout the working day. The total minor delays recorded during study periods for a day were extended to cover the working time for that day. The time that the major equipment actually operated minus the minor delays is considered to be the time of operation at full efficiency.

Both the major and minor delays are divided into two classes. Class A delays, in general, include those time losses arising from the weather and other causes which could not have been anticipated and prevented under good management. The class B delays are those which should have been eliminated under good management, due allowance being made for conditions affecting the particular project.

The efficiency of operation of major equipment is indicated by expressing the time that the major equipment actually operated at full efficiency as a percentage of the time that it could have operated at full efficiency had all class B or avoidable delays, both major and minor, been eliminated. There are factors which may affect efficiency and which are not taken into consideration in this method of determining over-all efficiency. The specified mixing time is one of them. The operations which must be performed during the mixing period, such as movement of hauling equipment at the paver, dumping batches, filling water tank, changing hose, preparing subgrade in rear of paver, making provision for joints, and placing steel, are less likely to cause delays to the paver when it is operating with mixing time of 75 or even 60 seconds, than when operating with a 50-second mixing time. A paving outfit with a full season's work ahead of it is in a much more advantageous position and has a greater incentive to use a better type of equipment and more specialized personnel, and to attempt efficient operation than is the outfit at work on a project of only a few weeks' duration. This advantage is not generally appreciated as is evident from table 9 and figure 3, which show a lack of relation between length of project and over-all efficiency of operation of major equipment on 24 projects.

Another factor in this method of determining over-all efficiency is the ability of observers to classify delays as avoidable or unavoidable according to the definitions previously given. A classification of this kind is essential if efficiency of operation is to be determined with any high degree of accuracy. The total available working time is no indication of the time in which it was possible to operate, when delays beyond the control of the contractor have occurred or when it would not be profitable to avoid delay. The observers in these studies had investigated paving projects and are thought to have been well trained for the work. The classifications made by the observers depended on judgment and therefore may not always be correct but there was no practicable way of eliminating the personal factor.

Table 9.—*Comparison of over-all efficiency and length of project*

Project	Over-all efficiency	Length of project
	Percent	*Miles*
California no. 3	47	4.4
Texas no. 1	51	13.9
Tennessee no. 8	59	10.9
Tennessee no. 4	66	8.1
Maine no. 1	66	3.8
Texas no. 2	76	30.4
New Jersey no. 1	76	7.7
Nebraska no. 1	80	14.6
Louisiana no. 3	80	6.8
Tennessee no. 2	82	12.0
Washington no. 3	82	6.4
Louisiana no. 2	82	10.1
Tennessee no. 5	83	12.4
Tennessee no. 6	86	10.4
Louisiana no. 1	87	26.8
Colorado no. 1	87	15.6
Washington no. 2	88	7.8
South Carolina no. 1	90	19.8
Louisiana no. 4	91	9.5
Washington no. 1	94	8.1
California no. 2	95	8.5
California no. 4	96	5.4
Washington no. 4	97	4.1

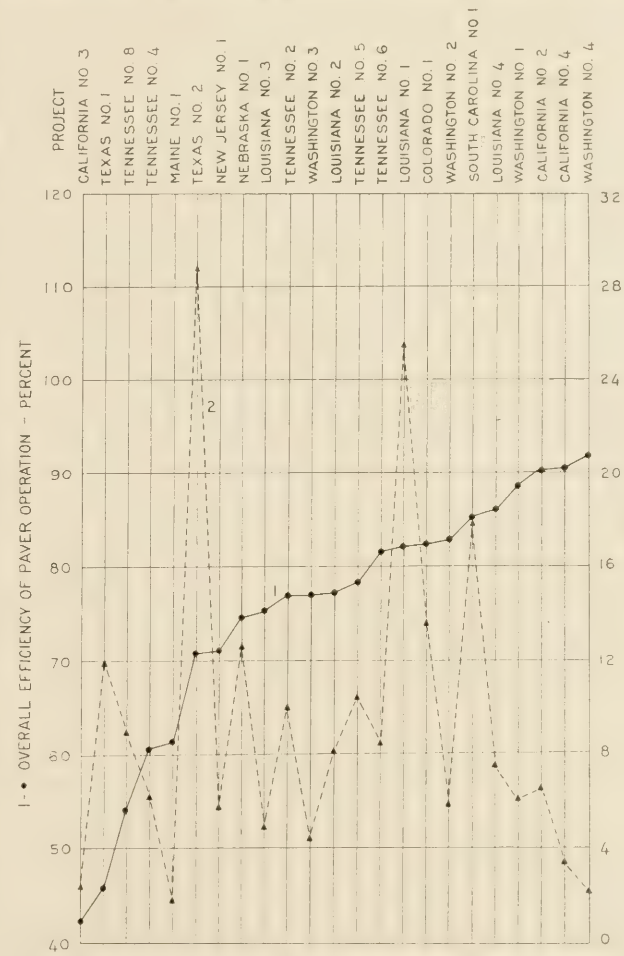
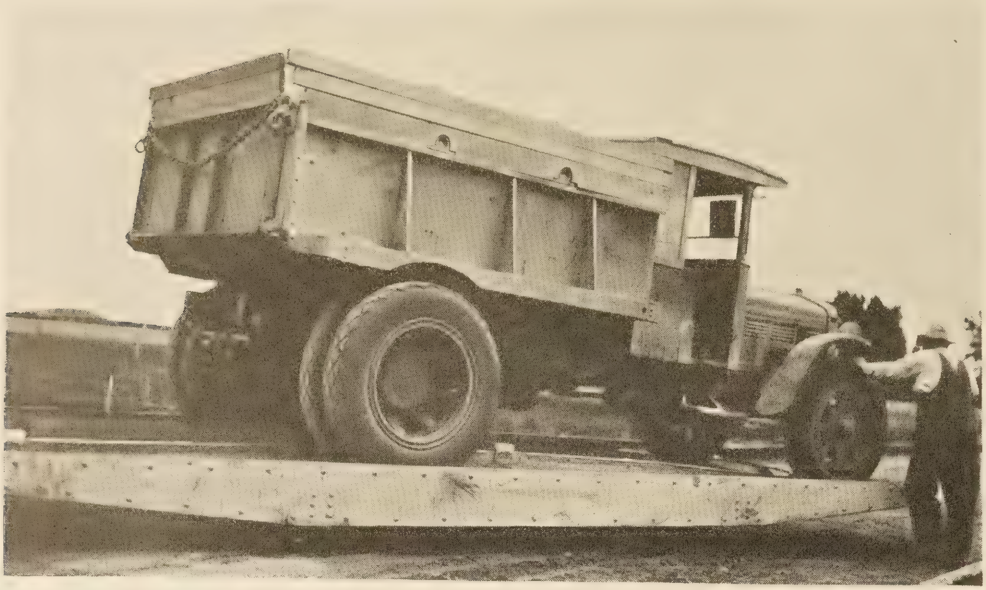
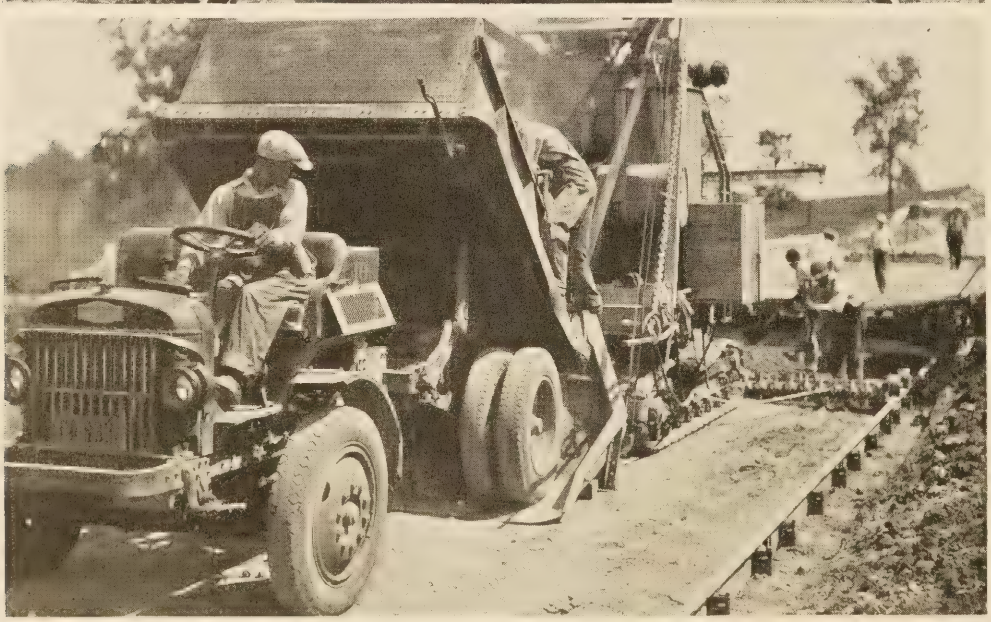


Figure 3.—Comparison of Efficiency and Length of Project.



Turntable for Trucks.

Trucks Ready to Back to Paver.



Dumping into Skip of Paver.

MINOR DELAYS RESULT FROM NUMEROUS CAUSES

Table 10 is a typical weekly summary of time losses and their effect on production. It shows the total available working time for the week, the time lost through avoidable and unavoidable major and minor delays, the production obtained, and the over-all efficiency of operation of major equipment.

Table 11 is a summary of weekly summaries covering the production studies on 23 projects using a single 27–E paver each and on 4 projects using two 27–E pavers each. The over-all efficiency of paving outfits ranges from 47.4 percent to 96.8 percent. Of the 10,651 hours that were available for paving on projects using a single paver, the paver operated at full efficiency only 4,973 hours, or 47 percent of the total available working time. Had the class B delays, those which could be eliminated under proper management, been eliminated, full production could have been maintained for 6,366 hours. The over-all efficiency of these 23 paving outfits representing nearly every section of the United States is 78 percent. The causes for the major delays and the time losses resulting from them are shown in table 12. The causes for the minor delays are shown in table 13. The results of these studies are believed to be a fairly accurate estimate of the efficiency with which major concrete paving equipment is operated in the United States.

Table 11 shows considerable difference in the over-all efficiency with which different contractors operated the major equipment. Table 1 indicates that the major and auxiliary equipment was about the same on all projects. Concrete paving equipment is fairly well standardized and in most cases the auxiliary equipment has a capacity corresponding to maximum paver production.

TABLE 10.—*Typical weekly summary of time losses and their effect on production*

[Project, Maine No. 1; equipment, one 27–E mixer, batcher, trucks, finishing machine; available working hours, 57.17; estimated production, 1,640 batches, or 6,500 lineal feet]

MAJOR DELAYS OCCURRING DURING AVAILABLE WORKING TIME

Source of delay	Class A		Class B		Total major delays	
	Hours	Percent	Hours	Percent	Hours	Percent
Hauling equipment supply			0.40	0.7		
Water supply			.25	.4		
Hose line			.28	.5		
Placing special steel	0.54	0.9				
Mechanical trouble at plant	1.24	2.2				
Waiting for finishers	2.95	5.2				
Total	4.73	8.3	.93	1.6	5.66	9.9

MINOR DELAYS OCCURRING DURING TIME OF ACTUAL OPERATION

Source of delay	Class A Hours	Class A Percent	Class B Hours	Class B Percent	Total Hours	Total Percent
Hauling equipment operation			4.18	8.1		
Operator			1.10	2.1		
Handling cement			.63	1.2		
Placing steel			2.74	5.3		
Wet aggregate sticking in trucks			2.15	4.2		
Shifting hose and pipe line trouble			1.95	3.8		
Water supply			.38	.7		
Trouble at plant	0.29	0.4	.82	1.6		
Hauling equipment supply			.19	.4		
Mixer, mechanical	.14	.3				
Lack of subgrade and waiting for finishers	1.82	3.5				
Total	2.16	4.2	14.17	27.5	16.33	31.7

Major equipment operated 51.51 hours or 90.1 percent of available time.

Major equipment operated at 100 percent efficiency 35.18 hours or 68.3 percent of operating time. Possible operating time with all class B losses eliminated 50.28 hours. With all class B losses eliminated production would have been 2,344 batches. Over-all efficiency of operation of major equipment, 70 percent.

TABLE 11.—*Summary of time losses and efficiency of operation of major equipment*

PROJECTS USING A SINGLE 27–E PAVER

	Total available working time	Major delays as percentages of total available working time: Class A [1]	Major delays as percentages of total available working time: Class B [2]	Percentage of total available working time that major equipment actually operated	Minor delays as percentage of the time that major equipment actually operated: Class A [1]	Minor delays as percentage of the time that major equipment actually operated: Class B [2]	Percentage of actual operating time that major equipment operated at full efficiency	Time major equipment operated at full efficiency	Possible operating time, all class B delays eliminated	Over-all efficiency of major equipment operation
	Hours							*Hours*	*Hours*	*Pct.*
California no. 2	456.0	32.1	0.5	67.4	1.1	3.9	95.0	292.0	306.2	95
California no. 3	168.0	9.5	41.9	48.6	5.1	9.0	85.9	70.1	147.8	47
California no. 4	370.7	12.9	0.0	87.1	3.4	4.3	92.3	298.1	312.0	96
Colorado no. 1	417.0	9.9	1.8	88.3	4.9	10.2	84.9	312.5	357.5	87
Louisiana no. 1	336.0	66.2	0.3	33.5	4.4	11.3	84.3	95.3	109.1	87
Louisiana no. 2	448.0	64.9	0.5	34.6	8.0	15.3	76.7	118.4	144.2	82
Louisiana no. 3	544.6	43.6	2.0	54.4	7.2	15.2	77.6	229.7	285.3	80
Louisiana no. 4	240.4	31.3	1.3	67.5	5.6	6.7	87.7	142.1	156.1	91
Maine no. 1	225.0	31.3	3.0	65.7	5.7	28.6	65.8	97.3	146.5	66
New Jersey no. 1	889.7	47.8	5.5	46.7	5.2	13.7	81.1	338.0	444.4	76
Tennessee no. 2	517.6	23.6	1.3	75.1	15.3	14.1	70.6	274.6	336.0	82
Tennessee no. 4	672.0	39.4	7.9	52.7	2.9	23.6	73.5	260.4	397.0	66
Tennessee no. 5	475.0	17.9	2.0	80.1	2.2	14.5	83.3	316.9	381.7	83
Tennessee no. 6	413.4	50.7	0.5	51.3	6.4	14.9	78.7	158.5	190.7	83
Tennessee no. 8	293.0	28.1	12.6	59.3	8.0	25.1	66.9	116.2	196.6	59
Texas no. 1	1,055.4	51.8	7.6	40.6	0.0	39.5	60.5	258.9	508.0	51
Texas no. 2	1,431.6	48.5	2.9	48.6	8.7	17.6	73.7	512.2	676.6	76
Washington no. 1	117.0	2.9	2.0	95.1	4.7	4.3	91.0	101.1	108.3	94
Washington no. 2	185.7	12.5	4.6	82.8	1.0	7.3	91.7	141.4	160.9	88
Washington no. 3	89.0	0.0	8.2	91.8	0.0	10.9	89.1	72.9	89.0	82
Washington no. 4	99.5	3.7	0.6	95.7	2.4	2.5	95.1	90.5	93.5	97
Nebraska no. 1	812.6	24.4	4.9	70.6	3.2	14.2	82.6	475.0	595.7	80
South Carolina no. 1	394.1	42.0	0.5	57.5	2.6	8.7	88.7	201.2	222.9	90
Total	10,651.3	37.3	4.2	58.5	5.0	15.2	79.8	4,973.3	6,366.0	78

PROJECTS USING 2 27–E PAVERS

California no. 5 [3]	191.6	16.1	3.6	80.3	1.1	2.8	96.1	147.8	159.1	93
California no. 5 [3]	191.7	15.3	3.3	81.5	1.7	3.9	94.4	147.4	159.8	92
Missouri no. 2 [4]	305.4	45.5	3.4	51.1	3.8	17.7	78.5	122.9	160.6	76
Ohio no. 2 [4]	321.7	40.9	9.6	49.5	4.9	21.1	74.0	117.8	182.0	65
Illinois no. 1 [5]	211.4	26.3	3.8	69.9	16.3	5.7	78.1	115.4	131.9	88
Total	1,221.8	31.4	5.1	63.5	5.4	10.4	84.2	651.3	793.4	82

[1] Unavoidable.
[2] Avoidable.
[3] One of two pavers operating side by side.
[4] Two pavers side by side.
[5] Two pavers, one behind the other. Material is delivered to first paver and mixed for part of required time and then fed to second paver for completion of mixing.

TABLE 12.—*Distribution of the major delays on 23 paving projects having a total available working time of 10,651 hours; the percentages are based on the total available working time*

Cause of delay	Major delays: Class A		Major delays: Class B	
	Hours	Percent	Hours	Percent
Rain	1,290.0	12.1		
Wet subgrade	1,006.8	9.4		
Cold weather or snow	482.8	4.6		
Moving outfit	421.1	4.0		
Lack of prepared subgrade	240.4	2.3	128.5	1.2
Lack of materials	152.7	1.4	76.4	.7
Mixer trouble, mechanical	106.3	1.0	11.7	.1
Inadequate water supply	46.4	.4	21.7	.2
Stopping work early before regular stopping time	36.9	.4		
Finishing machine trouble, mechanical	21.0	.2		
Hauling equipment, operation			14.7	.2
Hauling equipment, shortage			30.3	.3
Miscellaneous	168.9	1.5	159.5	1.5
Total	3,973.3	37.3	442.8	4.2

Total major delays, 4,416.1 hours or 41.5 percent.

Time major equipment actually operated, 6,235.2 hours or 58.5 percent.

TABLE 13.—*Distribution of minor delays on the 23 paving projects during the 6,235 hours that the major equipment was operating; the percentages shown are based on the actual operating time*

Cause of delay	Minor delays			
	Class A		Class B	
	Hours	Percent	Hours	Percent
Wet subgrade	16.0	0.3		
Lack of prepared subgrade	12.8	.2	95.2	1.5
Hauling equipment, operation	17.1	.3	191.6	3.1
Hauling equipment, shortage	72.1	1.2	282.5	4.5
Inadequate water supply	27.4	.4	48.3	.8
Mixer trouble, mechanical	71.8	1.1	20.0	.3
Mixer trouble, operative			94.6	1.5
Moving mixer	9.2	.1		
Waiting on finishing operation			13.2	.2
Handling cement			15.3	.2
Placing joints and reinforcing steel			46.6	.8
Shifting hose at mixer			15.9	.3
Miscellaneous	85.6	1.4	126.7	2.0
Total	312.0	5.0	949.9	15.2

Total minor delays, 1,261.9 hours or 20.2 percent.
Time major equipment operated at full efficiency, 4,973.3 hours or 79.8 percent.

Table 14 is a summary of time losses on a project having a high type of supervision and correspondingly efficient operation. On this project work was carried on during the winter months under unfavorable weather conditions, but even with this handicap a high rate of production was maintained during periods in which it was possible to work.

Table 15 shows the results of a study made on a project with inadequate supervision and a resulting low efficiency. Avoidable delays were forestalled on the first job, but were allowed to happen and to reduce efficiency on the second project.

TABLE 14.—*Summary of time losses on an efficiently managed project during entire period of study*

[Project, South Carolina no. 1; available working time, 394.1 hours; estimated production, 6,898 batches or 39,461 square yards]

MAJOR DELAYS OCCURRING DURING AVAILABLE WORKING TIME

Cause of delay	Class A		Class B		Total major delays	
	Hours	Percent	Hours	Percent	Hours	Percent
Wet subgrade	59.88	15.20				
Rain	52.75	13.40				
Cold weather	51.53	13.10				
Mixer trouble, mechanical	.50	.14				
Water supply	.25	.06	0.28	0.07		
Truck operation	.50	.14	1.54	.39		
Totals	165.41	42.04	1.82	.46	167.23	42.50

MINOR DELAYS OCCURRING DURING TIME OF ACTUAL OPERATION

Shortage of hauling units	1.62	0.71	0.97	0.43		
Hauling units, operation	1.26	.56	8.67	3.81		
Mixer operator			7.08	3.11		
Subgrade			2.20	.97		
Mixer, mechanical	1.25	.55				
Setting joints			.18	.08		
Water supply	.75	.33	.59	.26		
Miscellaneous	.96	.42	.21	.09		
Totals	5.84	2.57	19.90	8.75	25.74	11.32

Major equipment operated 226.9 hours or 57.5 percent of available time.
Major equipment operated at 100 percent efficiency 201 hours or 88.7 percent of operating time. Possible operating time with all class B losses eliminated, 222.9 hours. With all class B losses eliminated production would have been 7,643 batches. Over-all efficiency of operation of major equipment 90.3 percent.

TABLE 15.—*Summary of time losses on an inefficiently managed project during entire period of study*

[Project, Texas no. 1; available working time, 1,055.3 hours; estimated production 12,352 batches or 77,831 square yards]

MAJOR DELAYS OCCURRING DURING AVAILABLE WORKING TIME

Cause of delay	Class A		Class B		Total major delays	
	Hours	Percent	Hours	Percent	Hours	Percent
Rain and wet subgrade	295.07	27.9				
Cold weather	212.12	20.1				
Moving	23.50	2.2				
Mixer, mechanical	16.67	1.6				
Lack of subgrade			13.26	1.3		
Lack of materials			12.00	1.1		
Water supply			11.42	1.1		
Truck supply			5.08	.5		
Truck operation			.63	.1		
Miscellaneous			37.71	3.5		
Totals	547.36	51.8	80.10	7.6	627.46	59.4

MINOR DELAYS OCCURRING DURING TIME OF ACTUAL OPERATION

[No class A minor delays]

Cause of delay	Class B	
	Hours	Percent
Truck supply	38.1	8.9
Truck operation	41.6	9.7
Truck turning and backing operation	8.5	2.0
Mixer, mechanical	6.0	1.4
Mixer, operative	5.1	1.2
Water supply	8.5	2.0
Lack of subgrade	24.8	5.8
Finishing	8.1	1.9
Expansion joints	6.0	1.4
Miscellaneous	13.3	3.1
Charge and discharge mixer, mechanical	9.0	2.1
Totals	169.0	39.5

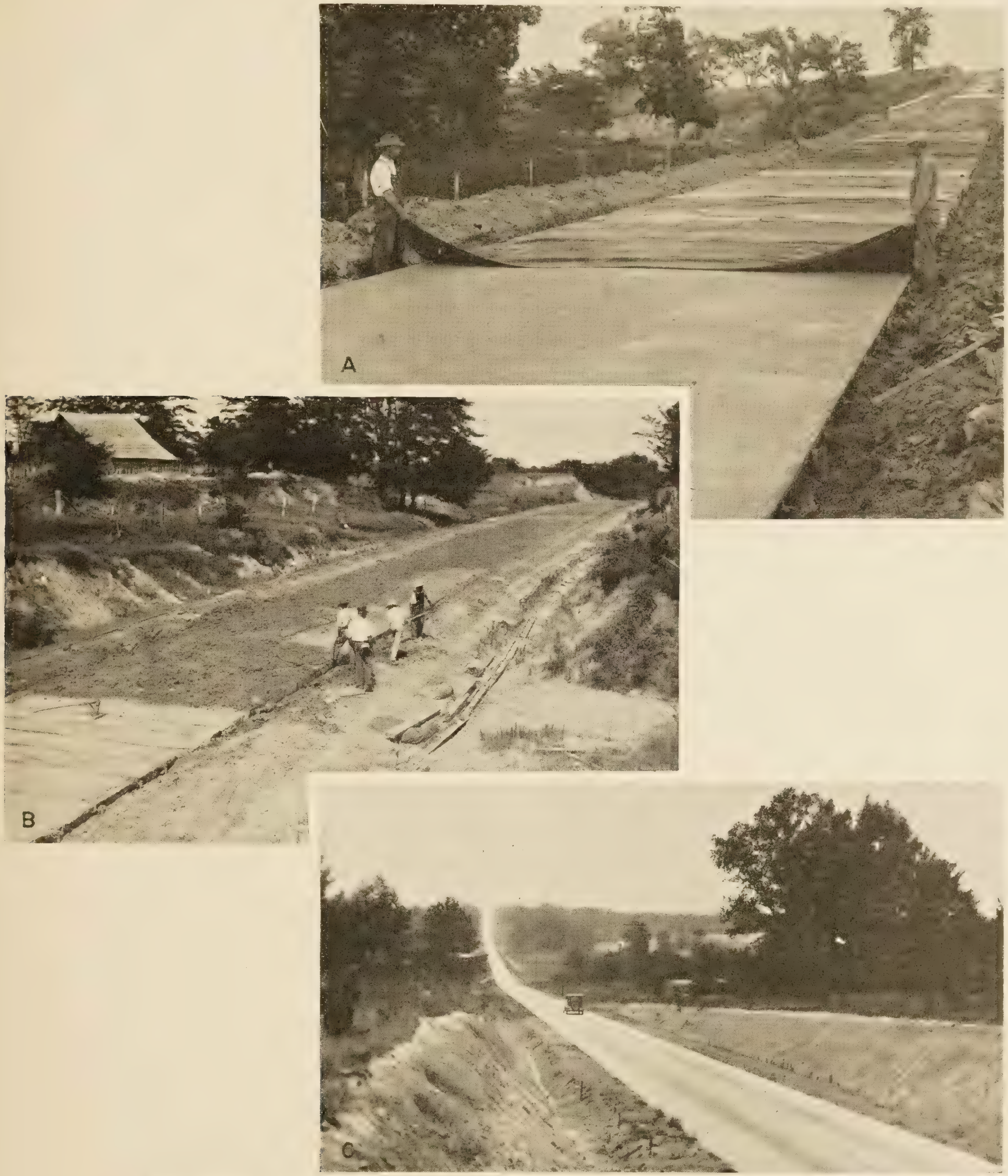
Major equipment operated 427.9 hours or 40.6 percent of available time.
Major equipment operated at 100 percent efficiency 259 hours or 60.5 percent of operating time. Possible operating time with all class B losses eliminated, 508 hours. With all class B losses eliminated production would have been 24,238 batches. Over-all efficiency of operation of major equipment 50.9 percent.

CAUSES OF INEFFICIENCY DISCUSSED

Constant and proper supervision is the key to efficient operation. The type of supervision on nearly every project listed in table 11 is indicated with fair accuracy by the figure for over-all efficiency of operation of major equipment. A superintendent who understands highway construction, who realizes the importance of utilizing available working time to the fullest extent, and who has the ability to foresee and to prevent delays, is highly valuable.

It is evident that adequate supervision has not always been employed. The first reason that comes to mind is that contracting firms, in general, have not always realized the value of adequate supervision of construction. Administrative officers devote a major portion of their time to obtaining contracts and purchasing materials and partially neglect measures for attaining efficiency in construction. It has been customary to refer to highway construction as a "risky business", and there has been a tendency on the part of highway contractors to place much of the blame for inefficient operation on the element of risk rather than on a lack of proper supervision.

Another reason for low efficiency may be that there is no large supply of highway superintendents who have



A, covering concrete with burlap after finishing; *B*, placing earth covering after surface has hardened; *C*, the finished surface.

STEPS IN CURING.

a natural aptitude for the work, together with adequate experience in methods of construction and such special training in production work as enables them to appreciate the value of advance planning and of full use of available working time. Possibly the seasonal and intermittent character of concrete road construction has led qualified men to seek continuous employment in other lines of work.

Another factor affects the efficiency with which highway construction work is done. This can be termed "inspectional interference."

Inspectional interference is not to be confused with proper and adequate action in the enforcement of specifications. Proper inspection is a necessity. It is a factor which can be evaluated with reasonable accuracy in preparing bid prices. Inspectional interference, on the other hand, is the overstepping of the engineer's or inspector's authority to enforce specifications. Arbitrary requirements may be imposed on the contractor. An element of risk may be introduced which cannot usually be evaluated, but which must be considered in arriving at bid prices.

The reasons for such interference are natural ones. In some instances specifications do not state clearly what is desired. They may be contradictory also. Unnecessary interference has been found on many of the projects studied. The actual extent to which it has lowered operating efficiency is not shown in the results of the production studies. The lost time caused by such interference has been reported under the type of delay which it caused.

Unnecessary interference causes a loss of working time and also tends to discourage the employment of adequate supervision when the efforts and planning of a competent superintendent can be easily frustrated by a well-meaning but over conservative and autocratic resident engineer or inspector.

Many examples of unnecessary interference could be cited. Contractors are sometimes required to mix the concrete longer than the specified mixing time, because, in the inspector's opinion, it results in better concrete. It actually results, however, in decreased production and increased costs for labor and equipment. The hours of work are sometimes arbitrarily regulated. Instances have been observed where production has been stopped for extended periods in order that the templates and finishing-machine screeds might be checked although there was ample opportunity for checking during nonoperating time.

A rather absurd instance of interference was observed not long ago. Laborers emptying sacks of cement on trucks were required by the engineer to leap through the air from one truck to the next rather than to descend to the ground after the dumping operation. This was done to prevent the loss on the ground of cement adhering to the laborers' shoes. The laborers, after dumping cement on one truck could not start on the next truck until it came alongside so that they could jump to it. With two trucks abreast between the forms there was not sufficient room for the empty truck at the paver skip to proceed without delay. The empty truck had to wait its turn to pick its way between loaded trucks engaged in this maneuver. The hauling service was badly disrupted. Hauling costs were increased and paver production was decreased.

The daily operating cost for labor and equipment on a concrete paving project is approximately $580 as will be shown later. The cost varies but little whether the production per day is 250 or 500 cubic yards of concrete. The importance of efficient operation in reducing unit costs should not be overlooked. Neither should the fact be lost sight of that an efficient organization is in a much more favorable position to produce concrete of good and uniform quality than is the inefficient and intermittently operated outfit. Inspectional interference will be difficult to eliminate so long as both the results desired and the methods by which the contractor must obtain these results are specified, and so long as authority over the operation of the contractor's personnel and equipment, without responsibility for the finished product, is assumed by the inspector.

UNIT COSTS PER SQUARE YARD ANALYZED

State practices vary with regard to pavement thickness, cement factor, length of mixing time, size of batch, amount of reinforcing, and joint material used, etc., and it is difficult to calculate accurately the unit cost for concrete pavements for the country as a whole. During 1930, 10,600,000 square yards of plain cement concrete pavement were laid on Federal-aid projects at an average cost of $1.78 per square yard. Five and one-half million square yards of reinforced concrete pavement were laid on Federal-aid projects at an average cost of $2.16 per square yard. This gives a weighted average for all Federal-aid concrete pavements of approximately $1.90 per square yard. On the assumption that these unit prices are representative of prices for concrete pavements built by State and local authorities and that the proportions of plain and reinforced pavements for the total mileage built are about the same as for the Federal-aid mileage, the price of $1.90 per square yard will be used in the detailed analysis of costs.

The distribution of this unit cost in respect to the various items of expense is shown in table 16. The percentages have been calculated from data collected in cost studies. On individual projects, costs and their distribution will vary considerably from these figures, but the table is believed to be representative of average conditions.

TABLE 16.—*Distribution of average cost of cement concrete pavements on Federal-aid projects in 1930 of $1.90 per square yard* [1]

	Cost	Percent
Cement	$0.435	23
Transportation of cement [2]	.135	7
Total	.570	30
Coarse aggregate	.190	10
Transportation of coarse aggregate [2]	.190	10
Total	.380	20
Fine aggregate	.075	4
Transportation of fine aggregate [2]	.095	5
Total	.170	9
Cost and transportation of cement and aggregate	1.120	59
Reinforcing steel, joint material, etc	.115	6
Depreciation of equipment	.170	9
Labor and supervision	.210	11
Batch delivery (labor and equipment)	.135	7
Overhead, interest, bond, cost of set-up, etc	.075	4
Return to contractor, including salary	.075	4
Total	1.900	100

[1] Based on bid prices and includes cost of fine grading.
[2] Transportation to batching plant.

During 1930, approximately 10,000 miles of portland cement concrete pavements were built on rural highways. Assuming a pavement width of 20 feet, the cost per mile was approximately $22,500 and the total cost was $225,000,000. The percentage distribution of this total expenditure is shown in figure 4.

The analysis shows that the cost of cement and aggregates delivered to the contractor's plant is 59 percent of the pavement cost, and that 22 percent of this total pavement cost is for the transportation of materials from the source of supply to the batching plant on the project. Transportation charges constitute 37 percent of the cost of these materials.

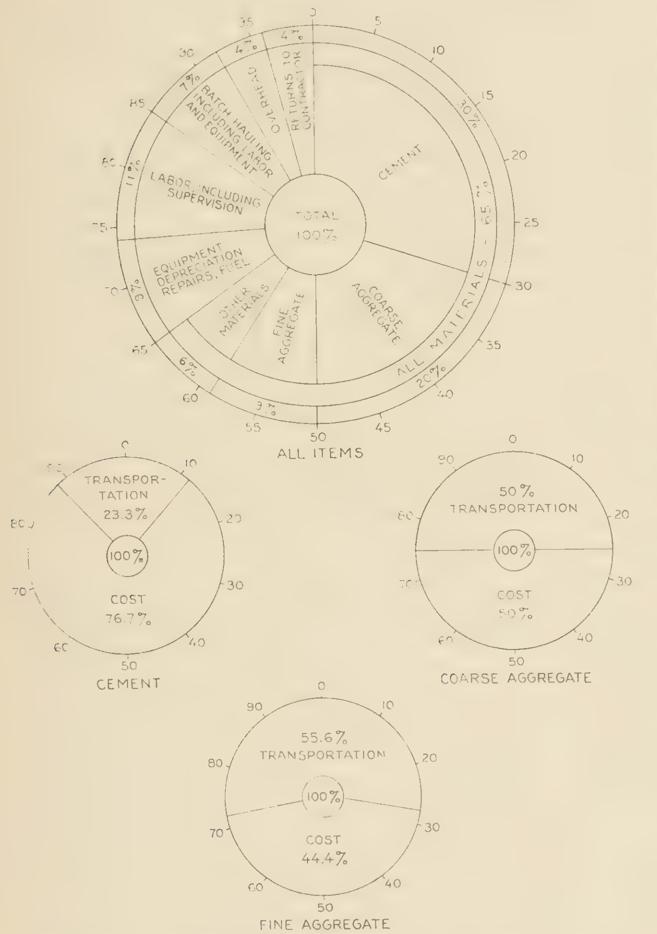


FIGURE 4.—ESTIMATED DISTRIBUTION OF EXPENDITURE ON PORTLAND CEMENT CONCRETE PAVEMENTS DURING 1930.

IF METHODS OF MIXING AND PLACING CAN BE IMPROVED, LESS CEMENT WILL BE REQUIRED

The largest item of expense is for cement the cost of which, delivered to the project, is about 30 percent of the total pavement cost. The cement factors used on the 34 projects studied during 1929 and 1930 varied from 1.23 to 2.10 barrels of cement per cubic yard of concrete. The possibility of reducing the amount of cement used without reducing the quality of the pavement is dependent on several factors, one of which is the uniformity with which the ingredients are distributed throughout the mass of concrete. Available information indicates that the present method of combining ingredients does not produce concrete in which these ingredients are uniformly distributed throughout the mass.

Analyses of samples removed from concrete after it has been spread on the subgrade show that variation in the amount of any one ingredient from one part of a batch to another part is often as high as 20 or 30 percent. One point in the batch may contain 10 or 15 percent more of an ingredient than the average for the batch while another point may be deficient by a similar amount. Percentage differences or "spreads" between points as high as 30 percent are not uncommon. The average spread in the proportion of any 1 of the 4 ingredients is about 10 percent. This lack of uniformity in the distribution of the ingredients no doubt accounts, to a large extent, for the wide variations that are found in the compressive strengths of cores removed from concrete pavements. Figure 5 shows the percentage spreads in materials on two different projects. These are typical examples of the lack of uniformity resulting from the present method of mixing concrete. Could the mixing be improved so that the ingredients would be uniformly distributed in the pavement, the cement content probably could be reduced, resulting both in a reduction in the cost of this material and a probable increase in the quality of the pavement.

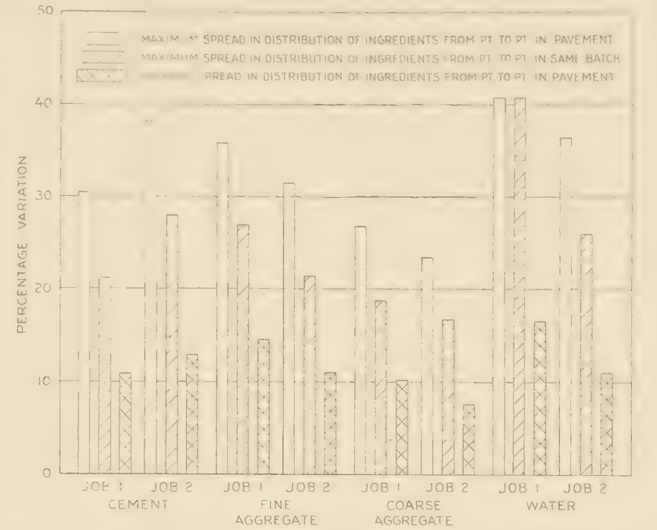


FIGURE 5.—VARIATION IN DISTRIBUTION OF INGREDIENTS OF CONCRETE AS MIXED IN STANDARD PAVERS.

Methods of manipulation must be considered in fixing the water and cement content of concrete. Present methods of placing concrete require rather wet mixes. It is generally accepted that the strength of concrete varies inversely with the ratio of the water to the cement. If methods of manipulation can be improved so that considerably drier concrete can be placed satisfactorily, a reduction in the amount of cement used should result.

The cost of reinforcing steel, material for joints, and other minor materials, averages 6 percent of the pavement cost. The cost varies considerably on different projects. Some States use heavy, double reinforcing while other States use no reinforcing. The spacing of transverse joints likewise varies between wide limits. Some States use no transverse joints while others space joints as close as 20 or 30 feet. For the 34 projects analyzed the transverse joints per square yard of pavement varied from none to 0.45 lineal foot.

EQUIPMENT COSTS ANALYZED

The cost of equipment is about 9 percent of the pavement cost. The most logical way to reduce this cost is to increase the efficiency with which equipment is operated by using a greater percentage of available working time. Annual or monthly expense for equipment is nearly constant except for field repairs, fuel, and lubricants. Costs do not vary materially with production obtained. The unit cost for depreciation, overhauling, major repairs, interest, taxes, storage, and insurance therefore varies almost inversely with the rate of production.

The unit cost for field repairs, fuel, and lubricants can be expected to vary nearly directly with the rate of production. There is no accurate method of determining equipment expense. The care that a piece of equipment receives is important in affecting its life. Equipment obsolescence affects costs. In the absence of a definite method of determining equipment expense, an approximation of the average daily equipment cost for the country as a whole is given in table 17. The figures shown in this table may not be applicable to every paving organization but they are suitable for use in general comparisons.

The figures in table 17 are based on an assumption that the average length of a construction season is 8 months (from Mar. 1 to Nov. 1). There are 245 days in this period of which 35 are Sundays and 3 are holidays. It is reasonable to assume that during an 8-month construction season the average paving contractor will have two projects. This necessitates a move from one project to the other. Allowing 12 working days for this move, 195 days or 24 days per month are available for operation. Table 12 shows that on the 34 projects analyzed the major unavoidable delays were as follows:

UNAVOIDABLE MAJOR DELAYS

Cause of delay:	*Percentage of available working time*
Rain	12. 1
Wet subgrade	9. 4
Cold weather, snow	4. 6
Moving equipment about project	4. 0
Lack of prepared subgrade	2. 3
Lack of materials	1. 4
Paver trouble, mechanical	1. 0
Inadequate water supply	. 4
Miscellaneous	2. 1
Total	37. 3

Thirty-seven percent of the total available working time was lost through delays of 15 minutes or over, delays that the contractor could not have been expected to anticipate and prevent. Delays from adverse weather conditions, wet subgrade, and moving the equipment about the project amount to 30 percent of available working time. Such delays generally last from one-half day to several days. During these periods the outfit usually does not operate, and the personnel, with the exception of straight-time men, is not on the job and does not draw pay.

The remaining delays, which amount to 7 percent of available working time, may or may not be of sufficient duration to shut down the outfit and stop production. In this discussion such delays will be considered as occurring during periods when the entire personnel is on the job and drawing pay. The possible

TABLE 17.—*Estimated equipment costs* [1]

Equipment	Number and capacity	Average annual expense as a percentage of first cost, exclusive of field repairs				Average use per year	Expense per working month	Application of schedule to specific prices		Estimated daily equipment cost for all items except field repairs, fuel, grease, and oil [2]	Estimated daily cost of fuel, oil, grease, and field repair	Total estimated daily equipment cost including all items
		Depreciation	Overhauling, major repairs, painting	Interest, taxes, storage, insurance	Total ownership expense			Price	Expense per working month			
Fine grading:		*Percent*	*Percent*	*Percent*	*Percent*	*Months*	*Percent*					
Blade graders	1, 10 foot	20	20	11	51	8	6. 4	$1, 250	$80	$4. 70	$0. 50	$5. 20
Tractors	1, 60 horsepower	20	15	11	46	8	5. 7	4, 300	245	14. 41	6. 90	21. 31
Scarifiers	1	25	20	11	56	8	7. 0	1, 000	70	4. 12		4. 12
Subgraders (form)	1	25	20	11	56	8	7. 0	1, 075	75	4. 41		4. 41
Subgrade planers	1	25	20	11	56	8	7. 0	500	35	2. 06		2. 06
Rollers	1, 6-ton	14	12	11	37	8	4. 6	2, 900	134	7. 88	3. 00	10. 88
Fresnos	2, 3-foot	33	20	11	64	8	8. 0	50	4	. 29		. 29
Fresno teams	2, 2-horse	10		6	16	12	1. 3	600	8	. 47	[3] 5. 30	5. 77
Handling and setting forms:												
Forms	4,300 feet	25	20	11	56	8	7. 0	3, 440	241	14. 17		14. 17
Teams	1, 2-horse	10		6	16	12	1. 3	300	4	. 24	[3] 2. 65	2. 89
Form trenchers	1	25	20	11	56	8	7. 0	1, 800	126	7. 41	1. 50	8. 91
Handling materials:												
Crane (15 ton)	1, 1 cubic yard	17	10	11	38	8	4. 8	14, 000	672	39. 53	13. 50	53. 03
Batcher plant (complete)	1, 70 cubic yards	20	15	11	46	8	5. 7	2, 785	159	9. 34		9. 34
Cement house	1				75	8	9. 4	500	47	2. 76		2. 76
Pumps (water)	1	25	20	11	56	8	7. 0	1, 700	119	7. 00	3. 00	10. 00
Pipeline, 2½-inch	25,000 feet	25	5	11	41	8	5. 1	6, 425	328	19. 30		19. 30
Hose, 1½-inch	250 feet				50	8	6. 3	150	9	. 53		. 53
Truck (service)	1	36	14	11	61	8	7. 6	1, 150	88	5. 17	2. 50	7. 67
Hauling batches:												
Trucks [4]												
Turntable	1	25	15	11	51	8	6. 4	1, 000	64	3. 76		3. 76
Mixing: Paver, 27-E	1	25	15	11	51	8	6. 4	8, 800	564	33. 18	8. 50	41. 68
Finishing:												
Finishing machine	1	25	15	11	51	8	6. 4	3, 000	192	11. 29	2. 00	13. 29
Flaots	2				100	8	12. 5	50	6	. 35		. 35
Belts	2				100	8	12. 5	20	3	. 18		. 18
Bridges (wood)	4				100	8	12. 5	60	8	. 47		. 47
Curing:												
Burlap	1,300 lineal feet				100	8	12. 5	260	33	1. 94		1. 94
Hose, ¾-inch	400 feet				50	8	6. 3	40	3	. 18		. 18
Miscellaneous:												
Small tools					50	8	6. 2	500	31	1. 82		1. 82
Field machine shop tools					50	8	6. 2	500	31	1. 82		1. 82
Supervision: Automobile [5]	1	33	20	11	64	12	5. 3	1, 500	78	4. 59	3. 50	8. 09
Total								59, 655	3, 457	203. 37	52. 85	256. 22

[1] Cost of all items of expense except field repairs, fuel, oil, and grease based on modified Associated General Contractors' equipment ownership schedule.
[2] Based on 17 working days per month.
[3] Animal feed.
[4] Truck costs are variable depending on length of haul, and have been excluded from this analysis.
[5] Automobile used 26 days per month, but monthly cost charged to 17 productive days.

working time will therefore be 70 percent of 195 days, or 136.5 days. This gives 17 possible working days per month during a construction season.

Monthly equipment expense exclusive of field repairs, fuel, and lubricants is prorated over the 17 working days that equipment can be actually operated under average conditions. Daily costs for field repairs, fuel, and lubricants are based on observations made during the time studies and are estimates only. The total average daily equipment expense as derived by this method of estimating is $256. The portion of this expense regarded as constant regardless of production is $203.

The production studies show that the average contractor operates major equipment with an efficiency of 78 percent. With a 69-second mixing time and a batch of 27 cubic feet this means an average production of 300 cubic yards of concrete per 9-hour day, or a fixed unit cost for equipment of 85 cents per cubic yard. With an efficiency of 90 percent this fixed equipment charge would be 74 cents per cubic yard.

LABOR COSTS DISCUSSED

The cost of labor, including supervision, is 11 percent of the pavement cost. The number of men employed is usually that necessary to handle maximum paver production and remains relatively constant. It does not fluctuate as the hourly or daily rate of production fluctuates because of delays. The daily labor cost can therefore be considered as an almost constant amount. As production decreases, the unit cost for labor increases.

To determine daily labor cost it is first necessary to consider the basis of payment of personnel and that part of the personnel which is on the straight-time pay roll. Although there is some variation in the number of men carried on the straight-time pay roll by different paving organizations, the straight-time men are usually a superintendent, a timekeeper, four foremen, a crane operator, a paver operator, and a mechanic. Some common labor is also employed during periods of nonproduction and appears on the straight-time pay roll. However, such labor is affected by job conditions and therefore is omitted in this discussion. The superintendent is usually paid on a monthly or yearly basis. The other men on the straight-time pay roll are generally kept working on the job during periods of nonproduction and are usually paid on a weekly basis for all time except Sundays and possibly holidays. During an 8-month construction season the superintendent will usually be paid for 245 days. The remaining straight-time workmen will usually be paid for 245 days less 35 Sundays and 3 holidays, or 207 days. It is again assumed that there will be 136 productive days during the construction season on which the remaining personnel will be paid. Table 18 gives the approximate daily cost for labor per day of actual construction, assuming an average working day of 9 hours and wage rates which are averages for the country as a whole. Payments made to straight-time men are distributed among the productive days.

With an over-all efficiency of operation of major equipment of 78 percent and a daily pay-roll cost of $334.23, the unit labor cost is $1.11 per cubic yard. With an over-all efficiency of operation of 90 percent the unit cost would be 96 cents.

TABLE 18.—*Pay-roll costs on an assumed typical project for each productive day. Based on 136 productive days per season*

Position	Number	Daily rate	Days for which pay is received during season	Nonproductive days during season for which pay is received	Total cost of nonproductive time	Prorated cost of nonproductive time to each productive day	Daily cost of productive time	Total cost for each productive day
Superintendent	1	$12.00	245	109	$1,308	$9.62	$12.00	$21.62
Timekeeper	1	5.00	207	71	355	2.61	5.00	7.61
Foremen	4	6.00	207	71	1,704	12.53	24.00	36.53
Crane operator	1	9.00	207	71	639	4.69	9.00	13.69
Paver operator	1	7.00	207	71	497	3.65	7.00	10.65
Mechanic	1	6.00	207	71	426	3.13	6.00	9.13
Other machine operators	7	5.00	136	0	0	0	35.00	35.00
Semiskilled and heavy common labor	18	4.50	136	0	0	0	81.00	81.00
Ordinary common labor	34	3.50	136	0	0	0	119.00	119.00
Total	68				4,929	36.23	297.50	334.23

The cost for labor and equipment on concrete pavement construction during 1930 is estimated to have been $44,600,000. Had the general over-all efficiency of operation of major equipment been 90 percent instead of what it actually was it is reasonable to suppose that the total labor and equipment costs would have been reduced by at least $4,000,000. It is to the advantage of both contractors and engineers that concrete construction be carried on with a high degree of efficiency. Efficiency is advantageous to the contractor in his efforts to meet competition. A competent superintendent, invested with the necessary authority, is invaluable to him. Efficiency works to the advantage of the engineer as it is his duty to see that the general public receives the greatest value in both quality and quantity for expenditure for concrete pavements.

HAULING COSTS AN IMPORTANT ELEMENT

An estimate for the cost of equipment and personnel connected with batch hauling, that is, transporting the batches containing aggregates and cement from the batching plant to the paver, has not been included in the preceding analysis. The cost of batch hauling is estimated to be 7 percent of the pavement cost. This figure is based on average haul and costs on the projects studied. Transporting batches from the batching plant to the paver on the road is an operation separate from that of paving. It is synchronized with the paving operation in that a definite number of trucks is required to furnish the paver with the maximum number of batches that it can mix per hour. The hauling equipment on the average project is usually operated with less efficiency than is the major paving equipment. This is especially true where the hauling is sublet, in which cases the equipment is often owned and operated by several individuals and is not directly supervised.

The daily cost of truck operation is not affected by the amount of work done except in the items of field repairs, fuel, and lubricants. The cost for the truck driver will be the same regardless of the number of batches hauled. The daily cost of operating a hauling unit can be considered as almost a fixed charge. The unit cost of hauling batches will be determined by the number of batches that the truck can deliver per day, and this in turn will be determined by the following items:

1. Haul distance.
2. Condition of hauling road.
3. Efficiency of truck operation.
4. Number of trucks in excess of those required to match maximum paver production.
5. Efficiency of paver operation.
6. Length of time required for loading, turning, backing, passing through plant yard, dumping batch, waiting to dump first batch of multiple batch truck, time interval between the dumping of batches, and necessary delays.

Fluctuating production of the paver increases the unit hauling cost by causing delays to the hauling units. On the other hand an insufficient supply of hauling units or faulty operation causes delays to the paving organization. Table 13 shows that one-half of the minor avoidable delays to major equipment were due to these two causes and amount to 7.6 percent of the time that the major equipment was actually operating. Harmony between the paving operations and the hauling operations requires that the paving organization should operate at a uniform rate; that the hauling equipment be adequate for the rate of paver production; and that the hauling equipment be operated at a steady pace without interruption.

The investment in hauling equipment may be even greater than the combined investments in all the other equipment. Inefficient operation of hauling units may increase costs greatly.

The cost of overhead, interest, bonds, set-up charges, etc., is estimated at 4 percent of the bid price, and the return to the contractor in the form of salary and profit, after all other cost items have been met, is also placed at 4 percent. These items are more or less intangible and the percentages shown are merely estimates made for the purpose of this analysis. The true cost may be a few percent either way from the percentages shown, but the distribution of the remaining cost will not be materially changed from the figures shown in this cost analysis.

TABLE 19.—*Examples of job efficiency between 1923 and 1928*

Project no.	Year	Total available working time during study	Unavoidable delays	Avoidable delays	Time paver operated at full efficiency	Time paver could have operated at full efficiency had avoidable delays been eliminated	Actual efficiency of operation
		Hours	*Hours*	*Hours*	*Hours*	*Hours*	*Percent*
1	1923	740.0	113.0	301.0	326.0	627.0	52.0
2	1924	222.0	63.8	71.2	87.0	158.2	55.0
3	1924	163.0	42.0	56.1	64.9	121.0	53.5
4	1924	146.0	36.5	40.0	69.5	109.5	63.5
5	1925	210.0	73.5	79.9	56.6	136.5	41.5
6	1925	477.5	157.8	120.2	199.5	319.7	62.5
7	1926	1,164.5	429.1	358.9	376.5	735.4	51.2
8	1927	1,143.3	197.3	465.1	480.9	946.0	50.9
9	1927	520.0	82.9	147.6	289.5	437.1	66.2
10	1928	512.0	90.0	182.3	239.7	422.0	56.8
Total		5,298.3	1,285.9	1,822.3	2,190.1	4,012.4	54.6

TABLE 20.—*Summary of weekly time losses on a project operated efficiently*

[Study made in 1931]

Week ending—	Batches produced	Total available working time	Major delays: Class A	Major delays: Class B	Major delays: Total	Minor delays: Class A	Minor delays: Class B	Minor delays: Total	Total of all delays
		Hours	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*
June 27	1,986	65.50	12.50	0.25	12.75	1.84	2.97	4.81	17.56
July 4	1,635	43.00	1.47	.25	1.72	.88	.89	1.77	3.49
July 11	1,447	65.35	29.21		29.21	.04	1.17	1.21	30.42
July 18	1,394	60.75	23.97		23.97	1.48	1.63	3.11	27.08
July 25	1,676	60.50	13.83	[1] 3.50	17.33	1.03	1.64	2.67	20.00
August 1	2,163	60.25	7.01	.25	7.26	.25	.34	.59	7.85
August 8	2,390	60.66	1.30	.75	2.05	.43	.40	.83	2.88
August 15	1,435	60.63	24.62		24.62	.89	.43	1.32	25.94
August 22	2,425	60.30	1.02		1.02	.30	.49	.79	1.81
Total	16,551	536.94	114.93	5.00	119.93	7.14	9.96	17.10	137.03

Week ending—	Time major equipment operated at 100 percent efficiency	Total of all class B delays	Possible operating time eliminating class B delays	Possible batches with class B delays eliminated	Over-all efficiency
	Hours	*Hours*	*Hours*		*Percent*
June 27	47.94	3.22	51.16	2,119	93.5
July 4	39.51	1.14	40.65	1,685	97.0
July 11	34.93	1.17	36.10	1,495	96.6
July 18	33.67	1.63	35.30	1,460	95.4
July 25	40.50	5.14	45.64	1,890	88.7
August 1	52.40	.59	52.99	2,190	98.9
August 8	57.78	1.15	58.93	2,438	98.1
August 15	34.69	.43	35.12	1,451	98.7
August 22	58.49	.49	58.98	2,445	99.2
Total	399.91	14.96	414.87	17,173	96.4

[1] Time required to remove hardened batch of concrete from drum.

TABLE 21.—*Summary of time losses on project reported in table 20 and their effect on production*

[Total available working time, 536.9 hours. Estimated production, 16,551 batches]

TOTAL MAJOR DELAYS OCCURRING DURING AVAILABLE WORKING TIME

Cause of delay	Class A: Hours	Class A: Percent	Class B: Hours	Class B: Percent
Rain	39.69	7.4		
Moving mixer	25.53	4.7		
Wet subgrade	18.74	3.5		
Pouring concrete gutter	12.75	2.4		
Mixer trouble, mechanical	8.56	1.6		
Pouring headwalls	5.89	1.1		
Removing concrete from drum			3.50	0.7
Batcher trouble	1.55	.3		
Preparing subgrade			.75	.1
Skip blocked by traffic	.62	.1		
Water supply trouble	.45	.1		
Truck operation	.40	.1		
Truck shortage	.25	.0		
Wreck	.25	.0		
Miscellaneous	.25	.1	.25	.0
Late start			.50	.1
Total	114.93	21.4	5.00	.9

TOTAL MINOR DELAYS OCCURRING DURING TIME OF ACTUAL OPERATION

Cause of delay	Class A: Hours	Class A: Percent	Class B: Hours	Class B: Percent
Truck operation	2.27	0.5	2.89	0.7
Mixer trouble, mechanical	1.17	.3	2.15	.5
Water supply	1.42	.3	.21	.0
Truck shortage	.30	.1	1.17	.3
Mixer operation			1.21	.3
Handling cement			1.05	.3
Placing reinforcing steel	.17	.0	.65	.2
Wet subgrade	.76	.2		
Rain	.58	.1		
Preparing subgrade			.35	.1
Miscellaneous	.12	.0	.15	.0
Setting expansion joint	.13	.0	.10	.0
Skip blocked by traffic	.11	.0		
Truck trouble, mechanical	.11	.1		
Dumping			.03	.0
Total	7.14	1.6	9.96	2.4

Total major delays 119.9 hours or 22.3 percent of working time.
Total minor delays 17.1 hours or 4 percent of working time.
Possible operating time with all avoidable delays eliminated 414.9 hours.
With all avoidable delays eliminated production would have been 17,170 batches.
Over-all efficiency of operation of major equipment 96.4 percent.

EFFICIENCY IN CONSTRUCTION GREATLY IMPROVED IN RECENT YEARS

When production studies of highway construction were started in 1923 the efficiency with which concrete paving was laid was much less than it is today. Very little attention was given to attaining maximum paver production or to the full use of available working time. In recent years, there has been a gradual increase in the efficient use of working time. Table 19 indicates that trend.

The 10 projects listed in table 19 were studied in the years shown and are representative of supervision better than the average. With few exceptions the projects selected for efficiency studies were each several miles in length and all were constructed with standard paving equipment. The projects were located in five different States. Project no. 2 was in one of the central States. The contractor's organization on project 2 had the reputation of being the most efficient in the State, yet the major equipment was operated with an efficiency of only 55 percent.

In contrast with the rates of efficiency shown in table 19 for years prior to 1929, 10 of the projects studied in recent years (table 11), each using a single paver, were operated with an over-all efficiency of more than 85 percent and 6 projects were operated with an efficiency of 90 percent or more.

An example of the high efficiency that can be maintained in concrete paving is given in table 20. This is a summary of production studies made on a paving project in an eastern State during a period of 9 weeks in the summer of 1931. The drop in efficiency in the fifth week was caused by the paver operator's negligence in allowing a batch of concrete to harden in the mixer while the motor was being repaired. Table 21 contains a summary for the 9 weeks of operation and shows the cause and extent of all delays.

Efficient use of available working time has steadily increased. This increase has had a favorable effect on unit costs. It is generally recognized that this increase in the rate of production has had no adverse effect on the quality of pavements.

The cost of labor and equipment, however, is only a part of the cost of a concrete pavement. Improvements in the methods and equipment used in the production of paving materials as well as in the production of finished surfaces, together with more definite information concerning the design of concrete mixtures as developed through research will increase both the efficiency of concrete pavement construction and the value received by the public per dollar of pavement expenditure.

STATE GASOLINE TAXES, 1933

[Compiled for calendar year from reports and records of State authorities]

State	Gross tax assessed prior to deduction of refund	Exemption refund (deducted from gross tax)	Net tax earning on motor vehicle fuel [1] [2]	Other receipts, under tax law (licenses, etc.)	Grand total earning (tax and other receipts)	Disposition of grand total earning, according to law [2]: Collection and administration cost [3]	Construction and maintenance on rural roads: State highways [4]	Construction and maintenance on rural roads: Local roads [4]	State and county road bond payments [5]	On city streets	Other than highway purposes	Tax rate, 1933: Cents per gallon: Jan. 1	Cents per gallon: Dec. 31	Date of rate change	Gasoline, or other fuel for motor vehicles, taxed: Net gallons taxes	Percent change [6]
Alabama	$8, 033, 141		$8, 033, 141	$1	$8, 033, 142	$17, 671	$2, 508, 119	$4, 001, 673	$1, 505, 679			6	6		133, 885, 679	−1. 86
Arizona	3, 226, 831	$547, 799	2, 679, 032	225	2, 679, 257	(7)	1, 607, 644	924, 060			[8] $147, 553	5	5	[9] Mar. 2	53, 580, 633	−7. 63
Arkansas	6, 543, 025	553, 596	5, 989, 429	8, 861	5, 998, 290	220, 147	1, 376, 222	639, 566	[10] 3, 446, 153		[11] 316, 202	6	[12] 6		114, 791, 930	33. 35
California	38, 774, 555	3, 557, 393	35, 217, 162		35, 217, 162	[13] 82, 134	22, 817, 380	12, 036, 373		$265, 142	[14] 16, 133	3	3		1, 173, 905, 406	−2. 52
Colorado	6, 012, 639	687, 643	5, 324, 996		5, 324, 996	61, 234	3, 684, 633	1, 421, 216		157, 913		4	4		133, 124, 908	−2. 64
Connecticut	4, 962, 513	150, 883	4, 811, 630	45, 394	4, 857, 024	(15)	4, 857, 024					2	2		240, 581, 476	2. 71
Delaware	1, 177, 853	50, 523	1, 127, 330	2, 247	1, 129, 577	(16)	850, 873		[17] 278, 704			3	3		37, 577, 673	3. 41
Florida	14, 249, 308		14, 249, 308	43, 565	14, 292, 873	21, 079	6, 106, 846		[18] 6, 106, 846		[19] 2, 058, 102	7	7		203, 561, 549	−1. 79
Georgia	12, 634, 513		12, 634, 513		12, 634, 513	63, 173	8, 380, 894	2, 095, 223			[20] 2, 095, 223	6	6		210, 575, 216	5. 83
Idaho	2, 535, 966	253, 596	2, 282, 370	796	2, 283, 166	11, 868	2, 055, 048		[21] 216, 250			5	5		45, 647, 396	0. 20
Illinois	29, 129, 584	1, 296, 573	27, 833, 011		27, 833, 011	133, 397	18, 466, 409	5, 468, 109			[22] 3, 765, 096	3	3		927, 767, 039	−3. 20
Indiana	17, 490, 596	1, 207, 394	16, 283, 202	5, 444	16, 288, 646	71, 077	8, 108, 784	6, 487, 028		1, 621, 757		4	4		407, 080, 056	−2. 73
Iowa	10, 667, 048	1, 294, 705	9, 372, 343		9, 372, 343	59, 593	3, 374, 705	3, 838, 045	[23] 2, 100, 000			3	3		312, 411, 442	4. 48
Kansas	10, 258, 397	2, 526, 578	7, 731, 819	39, 550	7, 771, 369	[24] 179, 454	5, 779, 180	1, 800, 000			[25] 12, 735	3	3		257, 727, 287	4. 20
Kentucky	8, 314, 659		8, 314, 659	1, 358	8, 316, 017	48, 246	8, 267, 771					5	5		166, 293, 182	1. 36
Louisiana	8, 155, 482	46	8, 155, 436		8, 155, 436	62, 000	2, 361, 222		4, 100, 825		[26] 1, 631, 389	5	[27] 5		163, 138, 863	−1. 73
Maine	4, 265, 446	185, 075	4, 080, 371	[28] 46, 269	4, 126, 640	16, 074	2, 055, 283	2, 055, 283				4	[29] 4		102, 009, 277	−3. 00
Maryland	7, 588, 176	380, 427	7, 207, 749		7, 207, 749	17, 300	5, 384, 741	7, 423		1, 672, 965	[30] 125, 320	4	4		180, 193, 738	−3. 90
Massachusetts	16, 709, 793	332, 441	16, 377, 352		16, 377, 352	50, 000	6, 517, 673	2, 073, 592	313, 628		[31] 7, 422, 459	3	3		545, 911, 726	−0. 86
Michigan	20, 460, 257	1, 001, 799	19, 458, 458	26, 862	19, 485, 320	109, 502	2, 303, 607	14, 045, 349	3, 000, 000		[32] 26, 862	3	3		648, 615, 259	−4. 76
Minnesota	11, 326, 991	1, 312, 134	10, 014, 857	[33] 198, 779	10, 213, 636	(34)	6, 425, 314	3, 600, 000			[35] 188, 322	3	3		333, 828, 560	0. 14
Mississippi	6, 721, 859	920, 134	5, 801, 725	[36] 299, 223	6, 100, 948	23, 311	2, 874, 459	2, 573, 341	495, 192		[37] 134, 645	6	6		96, 695, 407	−0. 04
Missouri	9, 317, 610	236, 475	9, 081, 135		9, 081, 135	55, 934	9, 025, 201					2	2		454, 056, 751	1. 47
Montana	3, 415, 209	663, 906	2, 751, 303		2, 751, 303	31, 512	2, 650, 591		69, 200			5	5		55, 026, 065	2. 27
Nebraska	7, 792, 812	86, 551	7, 706, 261		7, 706, 261	56, 411	5, 095, 848	2, 298, 602		255, 400		4	4		192, 656, 526	−1. 32
Nevada	825, 176	129, 523	695, 653		695, 653	(38)	695, 653					4	4		17, 391, 339	−4. 33
New Hampshire	2, 418, 103	68, 254	2, 349, 849		2, 349, 849	(39)	1, 762, 387		587, 462			4	4		58, 746, 216	−10. 95
New Jersey	20, 963, 377	4, 565, 991	16, 397, 386	[40] 73, 261	16, 470, 647	52, 450	2, 438, 310	6, 396, 475	2, 296, 000		[41] 5, 287, 412	3	3		546, 579, 541	−1. 32
New Mexico	2, 430, 319	164, 809	2, 265, 510	16, 382	2, 281, 892	33, 935	898, 005		1, 349, 952			5	5		45, 310, 187	3. 34
New York	44, 425, 847	1, 081, 152	43, 344, 695	48, 251	43, 392, 946	[42] 140, 780	21, 646, 458	5, 761, 145		1, 440, 286	[43] 14, 404, 277	3	[44] 3		1, 444, 837, 830	−2. 71
North Carolina	14, 974, 123	204, 521	14, 769, 602	3, 680	14, 773, 282	6, 099	4, 952, 913	2, 931, 286	[45] 6, 540, 385		[46] 342, 599	6	6		246, 160, 036	6. 23
North Dakota	2, 787, 728	863, 777	1, 923, 951	879	1, 924, 830	25, 000	1, 266, 553	633, 277				3	3		64, 131, 714	4. 81
Ohio	35, 740, 548	1, 800, 567	33, 939, 981		33, 939, 981	153, 028	15, 426, 893	7, 640, 678		5, 730, 509	[47] 4, 988, 873	4	4		838, 020, 083	−2. 18
Oklahoma	10, 064, 685		10, 064, 685	13, 960	10, 078, 645	64, 847	4, 994, 942	2, 419, 183			[48] 2, 599, 673	4	4		251, 617, 119	4. 18
Oregon	7, 282, 245	938, 354	6, 343, 891		6, 343, 891	20, 616	4, 604, 599		[17] 1, 718, 676			4	5	June 9	135, 819, 611	−3. 03
Pennsylvania	31, 353, 940	614, 823	30, 739, 117	[49] 320, 261	31, 059, 378	[50] 349, 547	22, 141, 876	5, 110, 747	[17] 3, 457, 208			3	3		1, 024, 637, 243	1. 48
Rhode Island	2, 004, 038	123, 066	1, 880, 972	3, 710	1, 884, 682	(51)	1, 246, 567		302, 000		[52] 336, 115	2	2		94, 048, 613	1. 45
South Carolina	6, 716, 510	37, 184	6, 679, 326		6, 679, 326	(53)	1, 924, 367	1, 113, 221	[54] 3, 641, 738			6	6		111, 322, 101	7. 30
South Dakota	3, 849, 544	[55] 503, 529	[56] 3, 346, 015		3, 346, 015	41, 399	1, 900, 047				[57] 1, 404, 569	4	4		78, 382, 211	5. 80
Tennessee	12, 979, 882		12, 979, 882		12, 979, 882	154, 721	3, 481, 115	[58] 3, 847, 548	[59] 5, 496, 498			7	7		185, 426, 887	6. 52
Texas	31, 430, 379	2, 951, 029	28, 479, 350		28, 479, 350	201, 122	14, 139, 114		[18] 7, 069, 557		[60] 7, 069, 557	4	4		711, 983, 752	5. 23
Utah	2, 189, 065	67	2, 188, 998	716	2, 189, 714	4, 241	2, 185, 473		(61)			4	4		54, 724, 960	0. 79
Vermont	1, 766, 152		1, 766, 152		1, 766, 152		1, 321, 102	230, 000	215, 050			4	4		44, 153, 789	−5. 79
Virginia	11, 679, 511	597, 471	11, 082, 040		11, 082, 040	25, 000	7, 739, 928	3, 317, 112				5	5		221, 640, 804	2. 52
Washington	11, 852, 828	989, 614	10, 863, 214		10, 863, 214	22, 688	7, 971, 469	[62] 2, 000, 000			[63] 869, 057	5	5		217, 264, 282	−1. 66
West Virginia	5, 149, 595	229, 931	4, 919, 664	8, 064	4, 927, 728	11, 506	1, 759, 477		3, 156, 745			4	4		122, 991, 600	−0. 45
Wisconsin	16, 599, 578	1, 430, 152	15, 169, 426		15, 169, 426	29, 705	9, 255, 610	[64] 3, 992, 249	[18] 1, 284, 000	107, 862	[19] 500, 000	4	4		379, 235, 644	1. 48
Wyoming	1, 405, 415		1, 405, 415		1, 405, 415		829, 042	351, 354	[17] 225, 019			4	4		35, 135, 367	−0. 90
District of Columbia	2, 097, 257	14, 911	2, 082, 346		2, 082, 346					2, 082, 346		2	2		104, 117, 297	2. 30
Total			518, 195, 712	1, 207, 738	519, 403, 450	2, 727, 801	277, 517, 371	111, 109, 158	58, 972, 767	13, 334, 180	55, 742, 173	Weighted average rate, 3.65 cents			14, 224, 321, 270	−0. 18

[1] Net gasoline tax earned after deduction of refunds allowed by law.
[2] Legislation enacted in several States authorizes the diversion of gasoline tax revenue to purposes other than for highways after such funds have been transferred by the collecting agency presumably for road purposes. In several such cases the reports of collecting agencies as given here indicate the initial distribution and not the final distribution. The County Commissioners of Florida counties of 4,135 to 4,300 population are authorized to transfer surplus money of road and bridge funds derived from the gasoline tax to courthouse and jail funds. Gilchrist County transferred $6,811. Legislation in Michigan provided possible contingent use of gasoline revenue for payment of calamity or welfare relief bonds. Allocations of gasoline tax funds to counties and cities in Ohio may be expended for poor relief.
[3] Many States pay collection cost from other State funds, and such are noted. Administration cost includes balances allocated to reserve funds for administrative purposes, and amounts are noted.
[4] Since this table covers the calendar year earnings, but not the actual collections during the year, these columns are not comparable with similar columns in tables F–1 and F–4 which cover different periods fixed by State and local agencies; also certain funds are allocated to bond payments shown in next column.
[5] For State highway bonds, except as noted.
[6] Shows percentage increase or decrease compared to net gallons reported in previous year.
[7] Approximately $16,000 paid from State highway budget.
[8] Relief fund, 1/10 of net motor fuel tax after June 30, 1933.
[9] On February 1 tax reverted to 4 cents and on date shown changed back to 5 cents.
[10] Includes $2,692,323 assignable to county bond payments.
[11] Transfer to State Charity fund.
[12] Tax rates of 2, 4, and 5 cents allowed at State borders.
[13] Consists of $61,099 to transportation division of State board of equalization and $21,035 to Controller refund division.
[14] Includes $14,297 for payment of claim and $1,836 for employees retirement fund.
[15] Cost of approximately $16,000 paid from motor vehicle license receipts.
[16] Paid from State general fund.
[17] Bond payments from combined fund of gasoline taxes and motor vehicle fees and pro-rated between them.
[18] Payments on county road bonds.
[19] To State general revenue fund.
[20] To an equalization fund for public schools.
[21] Payments on State highway treasury notes.
[22] Relief fund payments made from fund formerly apportioned to local roads.
[23] Payments on county bonds for State roads; obligations assumed by State.
[24] Law effective May 1, 1933 allowed 3 percent of net gasoline tax receipts for collection costs: $7,500 from State general fund was used during first six months.
[25] To general funds (State, $1,607 and counties, $11,128).
[26] $815,694 for public schools, $815,695 for ports of New Orleans and Lake Charles harbor boards of commissioners.
[27] Rate of 4 cents permitted on 150,717 gallons near border.
[28] Includes receipts from 1 cent tax on gasoline not used in motor vehicles.
[29] Tax refund of 3 cents allowed for use other than in motor vehicles.
[30] $75,000 to conservation department; $48,000 for approaches to ferries, and $2,320 for protest fees.
[31] To unemployment relief fund, and other nonhighway purposes.
[32] For aeronautic fund $22,677 and $4,185 to State general fund.
[33] Includes inspection fees of 2 cents per 50 gallons.
[34] Paid by State appropriation of $13,000.
[35] Includes $172,909 cost of gasoline inspection and $15,413 to State General fund.
[36] Includes $121,342 from special tax in three counties for financing sea wall.
[37] $121,342 for sea wall, $11,600 for police patrol to enforce motor vehicle law, and $1,703 uncollected checks on closed banks.
[38] $7,500 paid from appropriation to State tax commission.
[39] $4,400 paid from motor vehicle license funds.
[40] Includes $4,802 from 2 cent tax on gasoline used by motor boats.
[41] $5,152,412 to State treasury and $135,000 to Department of Commerce and Navigation.
[42] Includes $50,000 paid to refund reserve.
[43] State general emergency fund from 1 cent extra tax.
[44] Tax rate of 2 cents allowed at border of State.
[45] Includes $360,319 for payments on county bonds.
[46] For police patrol and administration of motor vehicle laws.
[47] Consists of $2,000,000 for State emergency poor relief fund and $2,988,873 for public school fund.
[48] Consists of $2,262,625 for redemption of State warrants, $237,127 reserve for taxes paid under protest; $99,921 to State general revenue.
[49] Delinquent tax collections.
[50] Includes part of police patrol expenses; amount not reported.
[51] Paid from Motor vehicle fees, $15,558.
[52] To unemployment relief.
[53] Paid from State tax commission appropriation.
[54] Includes $2,712,661 for payments on county bonds.
[55] New law effective during last nine months allows only 2 cent refunds.
[56] This does not correspond to gallons taxed at 4 cent rate due to refunds being at 2 cent rate.
[57] For payments on rural credit bonds.
[58] Includes $183,217 allocated to roads in Great Smoky Mountain Park.
[59] Includes $1,832,166 payments on county bonds and same amount to sinking fund bonds.
[60] For free school fund.
[61] Payments made from motor vehicle fees.
[62] Estimate based on previous year.
[63] Payments on State emergency relief bonds.
[64] Includes $1,133,848 allotted in lieu of personal property tax.

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS I—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF JUNE 30, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS I PROJECTS ON THE FEDERAL AID HIGHWAY SYSTEM	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS I PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$4,185,067.00	$1,596,441.15	$880,571.63	$715,869.52	61.9	$4,625,778.67	$2,588,735.13	$2,037,043.54	44.5	272.3	$233,948.59	21.5	$481,811.65
Arizona	3,878,555.11	1,776,203.88	1,735,542.70		131.1	2,598,403.90	2,017,309.12		56.3	153.2	96,740.98	10.7	28,962.31
Arkansas	3,374,167.00	299,964.82	200,126.94	99,837.88	9.5	2,721,289.10	2,328,613.72	392,194.13	59.3	137.0	636,509.29	24.0	208,917.05
California	7,803,677.00	3,837,455.68	2,954,376.75		142.5	6,084,486.14	4,648,401.55		39.6	153.1	191,793.40	15.9	9,105.30
Colorado	3,437,265.00	1,514,031.69	1,500,790.30		96.0	2,059,925.09	1,926,296.72	27,435.65	54.1	54.9			10,177.98
Connecticut	1,404,213.00	31,798.76	31,798.76		.1	1,543,762.06	1,367,983.12	175,778.94	35.6	30.7			4,431.12
Delaware	909,544.00	192,063.14	191,170.71		3.0	698,741.30	698,741.30		63.8	14.7	5,770.00	.3	13,861.99
Florida	2,615,917.00	1,281,060.88	814,074.82	466,986.06	43.7	1,940,045.73	1,603,752.50	335,683.13	64.1	72.3	56,281.75	.7	141,807.93
Georgia	5,045,592.00	1,232,521.05	1,232,521.05		73.6	2,400,287.81	2,400,287.81		41.5	177.5	517,218.84	22.4	895,564.30
Idaho	2,166,858.00	824,604.86	809,780.19		81.8	1,281,245.97	1,239,392.09		47.9	93.5	13,782.82		103,902.90
Illinois	4,585,971.00	50,872.54	50,872.54		.9	2,712,498.06	2,712,498.06		43.1	45.1	1,762,692.49	13.3	59,907.91
Indiana	5,018,921.00					4,405,477.21	4,361,358.38		38.5	119.5	657,562.62	13.2	
Iowa	5,027,830.00	1,057,700.42	1,038,800.00		74.5	4,126,332.98	3,828,980.00		75.4	185.6	140,675.50	9.0	19,374.50
Kansas	5,044,802.00	1,330,234.56	1,329,365.58		206.5	3,917,385.48	3,690,045.12		78.4	191.1	25,391.30	.3	
Kentucky	3,608,332.00	554,103.01	549,646.72		59.6	2,599,204.31	2,590,365.88		69.3	177.9	468,319.40	16.5	
Louisiana	2,914,295.00	222,415.49	222,390.49		9.7	2,913,268.66	2,406,617.66		47.1	67.5	42,623.98	1.5	242,662.87
Maine	1,617,560.00					1,515,228.37	1,479,661.42		56.6	44.0	24,085.44	.2	113,813.14
Maryland	1,782,263.00					801,143.78	791,495.03		48.6	14.9	461,850.00	6.4	528,917.97
Massachusetts	1,101,716.00	289,573.84	212,377.94	69,984.24	6.4	1,123,369.76	807,710.12	315,659.64	64.6	31.4			81,627.94
Michigan	6,113,389.00	80,150.00	80,150.00		1.8	5,177,180.00	5,128,180.00	49,000.00	48.2	243.8	602,366.00	21.0	302,693.00
Minnesota	4,561,011.00	2,488,707.73	2,468,224.86	20,482.87	509.5	1,980,571.21	1,949,360.33	27,500.00	31.3	237.7	143,425.81	12.7	
Mississippi	3,489,337.00	288,524.53	164,210.19	124,314.34	12.8	4,586,982.35	2,481,349.56	2,067,000.85	48.0	235.2	276,070.22	29.1	567,707.03
Missouri	5,237,532.00	895,421.61	695,097.86		43.5	4,390,783.57	4,050,641.00	68,548.60	71.3	149.6	252,033.50	9.3	239,759.64
Montana	4,463,849.00	1,426,917.20	1,246,901.20	100,000.00	93.4	3,541,342.66	3,181,685.86	237,025.83	57.8	270.5	31,988.11	36.2	3,273.83
Nebraska	3,914,481.00	2,122,823.42	1,535,019.12	108,538.00	215.8	2,961,612.91	2,342,867.69		62.8	137.1	35,794.58	9.7	799.61
Nevada	2,909,387.00	1,349,395.18	1,349,395.18		173.0	1,401,020.43	1,401,020.43		31.8	87.1	79,129.02		79,842.37
New Hampshire	725,739.00	52,024.43	52,024.43		.3	601,203.04	594,695.63		81.6	10.5			79,018.94
New Jersey	3,099,370.48	66,077.87	66,077.87		6.1	2,756,285.14	2,601,364.13	139,466.42	32.4	36.4	63,503.88	.6	368,424.60
New Mexico	2,896,467.00	1,873,447.55	1,873,447.55		210.5	1,064,442.96	920,513.54	143,929.42	30.1	60.1	41,901.88	3.6	60,604.03
New York	10,271,846.00	510,222.64	410,162.64	43,000.00	8.0	11,280,608.68	9,660,723.68	315,000.00	54.3	230.0	146,997.80	8.4	53,961.88
North Carolina	4,761,147.00	1,037,299.11	714,521.55	322,777.56	103.5	3,310,836.86	2,957,506.09	353,330.77	45.6	465.1	493,815.98	52.9	595,303.38
North Dakota	2,902,224.00	1,050,552.17	1,047,220.19	3,294.32	457.9	1,513,926.68	1,315,248.81	198,677.87	47.0	404.6	473,289.70	138.2	66,465.30
Ohio	7,277,758.00	1,035,375.47	1,030,181.63		27.8	6,437,458.00	6,133,085.00	51,410.00	66.6	159.1	77,878.00	5.0	36,613.37
Oklahoma	4,608,399.00	1,239,211.18	1,237,607.64		101.4	2,931,335.69	2,931,335.69		77.0	196.3	146,968.44	3.1	292,487.23
Oregon	3,053,448.00	1,525,235.01	1,392,618.01	84,317.50	98.9	1,623,500.25	1,484,960.05	128,021.20	45.7	83.2	167,388.02	1.4	8,481.92
Pennsylvania	6,691,194.00	254,788.81	254,421.79		4.4	6,079,556.64	5,895,873.50		44.3	122.0	477,382.67	5.7	63,516.04
Rhode Island	999,354.00	50,178.00	50,178.00		1.1	937,119.34	937,119.34		68.2	19.4	8,732.36		3,324.30
South Carolina	2,729,583.00	263,440.39	263,440.39		24.3	2,039,404.99	2,036,675.37	2,729.62	50.7	186.3	144,097.11	9.0	285,370.13
South Dakota	3,005,739.00	1,086,296.08	1,066,954.69	19,341.39	184.9	1,849,893.45	1,542,099.63	307,793.82	24.1	250.2	143,477.48	41.9	253,207.20
Tennessee	4,246,309.00	1,393,206.06	1,180,143.76	213,062.30	61.5	2,914,317.84	2,553,157.65	361,160.19	54.3	104.0	390,724.63	24.2	122,282.96
Texas	12,122,012.00	4,182,635.90	3,504,691.72		542.4	7,415,941.62	6,877,286.38		44.3	457.5	328,563.97	26.2	1,411,469.93
Utah	2,374,205.00	1,432,093.17	1,429,324.46		146.0	798,151.16	798,151.16		59.5	48.8	68,204.10	.4	78,525.28
Vermont	928,184.00	90,524.22	89,926.93		7.4	847,698.77	818,249.22		59.0	37.4	3,998.46		16,009.39
Virginia	3,708,379.00	1,101,511.50	1,092,037.47	9,474.03	40.2	2,115,368.45	1,992,162.00	119,858.30	54.2	81.4	387,355.78	23.8	236,823.75
Washington	3,057,934.00	884,351.00	879,563.10	3,356.82	44.7	2,095,806.01	2,095,806.01		37.8	60.9	64,640.67	1.4	17,924.22
West Virginia	2,013,405.00	211,470.33	211,470.33		6.7	1,706,233.68	1,700,233.68		73.1	64.9	34,029.42	.7	67,671.57
Wisconsin	4,615,429.00	1,073,457.39	1,063,118.67	1,190.00	50.0	3,553,669.34	3,452,135.29	38,500.00	40.2	174.3	63,174.25	1.4	37,000.79
Wyoming	2,250,663.00	1,005,126.46	882,673.00	80,400.00	177.9	1,423,273.07	1,280,112.23	85,908.57	41.6	272.9	67,031.52	10.2	20,846.25
District of Columbia													
Hawaii	1,683,956.00	122,232.70	109,225.57	12,994.32	6.3	1,626,253.71	1,325,047.89	251,205.82	27.5	26.5	248,693.76	6.8	988.78
TOTALS	186,234,275.59	46,283,442.88	41,194,236.92	2,499,221.15	4,362.8	141,029,652.88	125,926,891.57	8,229,862.31	52.1	6,949.0	10,797,903.52	638.8	8,315,243.58

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS II—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF JUNE 30, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS II PROJECTS IN MUNICIPALITIES	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS II PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$ 2,092,533.00	$ 183,974.41	$ 183,974.41		3.1	$ 1,133,335.74	$ 1,133,335.74		22.5	38.0	$ 703,763.64	18.4	$ 71,459.21
Arizona	807,982.36	179,423.43	177,982.55		4.0	300,059.89	300,059.89		33.0	7.3	284,883.32	2.0	45,056.60
Arkansas	1,889,534.00	267,409.01	239,810.94	$ 27,598.07	7.0	1,112,223.25	1,058,589.04	$ 53,384.21	39.2	28.4	487,403.12	5.8	103,730.90
California	4,213,986.00	1,201,380.99	1,077,458.87		13.8	2,800,607.08	2,505,943.04		23.9	35.6	586,972.69	3.6	43,611.40
Colorado	1,718,633.00	890,911.16	845,103.51		17.2	651,210.04	651,210.04		24.1	13.4	150,989.02	3.6	71,330.43
Connecticut	802,407.00	48,325.68	48,325.68		.5	687,857.65	684,715.77	3,141.88	83.9	9.2	68,293.81	.5	1,071.74
Delaware	454,772.00	82,851.95	75,106.31		.8	203,298.40	203,298.40		49.8	1.9	139,750.00	4.9	36,617.29
Florida	1,307,959.00	238,246.83	178,494.68	59,752.15	3.6	1,307,477.38	1,129,464.32	178,013.06	47.0	13.8			
Georgia	2,724,620.00	270,623.84	270,623.84		12.4	1,047,709.04	1,047,709.04		38.1	35.3	250,709.42	11.9	1,155,577.70
Idaho	1,197,829.00	191,286.86	187,894.42		4.8	965,953.20	943,374.52		26.5	13.5			66,560.06
Illinois	7,718,839.00	213,649.45	213,618.50		3.7	6,298,412.04	6,298,412.04		54.4	64.2	1,033,873.00	3.0	172,935.46
Indiana	4,416,651.00	49,616.53	49,616.53		1.2	2,548,474.57	2,548,474.57		16.7	49.5	1,419,950.27	19.3	398,609.63
Iowa	2,815,585.00	703,618.21	667,865.00		23.6	1,319,843.17	1,247,030.00		56.0	21.6	254,524.50	5.6	646,165.50
Kansas	2,522,401.00	727,167.34	723,495.87		18.5	1,930,602.57	1,785,748.77		75.6	18.7	13,156.36	.1	
Kentucky	2,029,687.00	128,112.17	128,112.17		3.2	731,168.11	724,814.00		40.8	17.3	460,899.41	9.6	715,861.42
Louisiana	1,457,148.00	329,889.35	329,889.35		6.5	617,871.43	617,871.43		24.9	17.8	509,387.22	2.8	
Maine	909,878.00	162,188.29	161,062.72		2.4	646,816.12	645,444.82		48.1	13.9	24,448.68	.4	78,921.78
Maryland	891,132.00					390,738.31	386,588.31		15.5	3.6			504,543.69
Massachusetts	5,007,199.00	96,850.68	73,850.68	23,000.00	1.8	4,475,346.95	4,436,270.79	39,076.16	31.3	13.7	250,293.28	1.0	246,784.25
Michigan	3,438,781.00	195,700.00	195,700.00		2.3	2,722,745.00	2,720,595.00		39.2	35.2	414,075.00	3.5	108,411.00
Minnesota	3,719,143.00	956,049.40	955,888.84		53.6	1,880,914.07	1,869,617.18	2,500.00	20.3	41.9	291,480.62	4.8	602,156.36
Mississippi	1,744,669.00	122,848.45	110,388.95	12,459.50	3.8	638,526.86	638,526.86		27.2	25.4	302,596.74	7.1	693,156.45
Missouri	4,019,501.00	559,179.26	533,233.11		12.7	2,946,033.18	2,542,530.91		44.9	38.8	329,298.82	6.0	614,438.16
Montana	1,115,962.00	345,305.18	345,305.18		9.2	585,139.71	585,139.71		8.2	17.0	178,482.37	9.1	7,034.74
Nebraska	1,957,240.00	269,117.63	268,428.34		11.7	1,569,767.55	1,569,767.55		63.2	20.1	98,955.75	1.5	20,088.36
Nevada	500,051.00	47,203.38	47,203.38		1.2	411,763.76	411,763.76		9.5	7.0			41,083.86
New Hampshire	706,640.00					678,365.95	664,365.95		70.3	15.6	42,274.05	.9	
New Jersey	3,190,118.00	94,073.38	94,073.38		2.1	2,846,861.99	2,792,728.99	30,000.00	43.5	19.9	41,442.01	.5	261,873.62
New Mexico	1,448,234.00	437,759.58	437,759.58		13.1	843,703.69	843,703.69		43.7	16.0	66,812.89	3.2	99,957.84
New York	8,449,487.00	259,723.17	259,341.87		4.0	8,006,217.60	7,489,785.00	39,000.00	47.3	57.7	32,800.00	.6	667,560.13
North Carolina	2,380,573.00	588,701.49	586,560.20	166.10	30.4	962,606.47	961,328.18		23.4	34.4	285,608.05	10.0	547,076.57
North Dakota	1,451,112.00	128,994.64	128,994.64		9.3	454,556.75	427,371.39	27,185.36	50.4	13.7	595,459.44	25.2	299,286.53
Ohio	4,335,686.00	495,616.80	455,579.08		9.4	4,109,684.43	3,625,318.43		60.2	47.2	248,288.37	2.7	6,500.12
Oklahoma	2,304,200.00	220,928.88	220,571.20		7.9	1,664,345.07	1,664,345.07		48.4	32.0	196,978.40	4.5	222,305.33
Oregon	1,526,724.00	422,188.01	406,695.04	14,126.97	9.8	874,529.63	863,369.98		28.2	14.6	145,261.52	3.3	111,397.46
Pennsylvania	4,354,988.00	778,975.47	761,814.18		16.9	2,963,101.24	2,905,023.58		48.0	35.8	598,476.07	6.2	589,674.17
Rhode Island	499,677.00	54,063.40	54,063.40		1.2	338,974.92	338,974.92		54.9	5.2	106,638.68	1.0	
South Carolina	1,364,791.00	147,768.44	147,768.44		4.1	725,672.31	725,267.30	405.01	31.6	30.2	251,062.11	7.8	240,693.15
South Dakota	1,502,870.00	183,149.74	183,149.74		8.1	680,060.88	680,060.88		34.9	21.9	280,530.04	9.0	359,129.34
Tennessee	2,123,155.00	307,829.45	307,829.45		6.7	1,140,039.95	1,140,039.95		44.6	14.3	415,580.88	4.8	259,704.72
Texas	6,061,006.00	1,605,904.15	1,523,073.09		56.4	3,146,496.84	3,079,890.27		22.0	49.4	609,566.77	9.0	848,475.87
Utah	771,826.00	619,858.49	603,798.90		13.9	54,015.64	53,422.98		35.8	2.8			114,604.12
Vermont	500,509.00	41,791.73	41,791.73		1.9	455,811.48	433,717.27	5,838.96	40.6	12.0	25,000.00	.7	
Virginia	2,008,458.00	402,536.67	381,276.18	8,760.49	10.9	1,330,699.04	1,142,139.89		33.5	12.1	338,503.96	5.0	146,537.97
Washington	1,977,260.00	1,187,895.49	1,173,567.02		20.7	786,454.90	786,454.90		22.0	11.7			17,238.08
West Virginia	1,342,270.00	87,291.15	87,291.15		1.9	950,313.53	925,967.79		48.2	16.2	187,844.31	2.2	141,166.75
Wisconsin	2,684,067.00	399,615.60	393,308.77		13.5	1,870,171.39	1,834,767.78	25,898.24	46.4	35.2	259,388.07	3.1	196,602.38
Wyoming	1,125,332.00	82,029.39	81,528.69		1.6	922,428.60	885,471.78		50.8	18.3	45,380.40	3.2	112,951.13
District of Columbia	959,235.00	289,445.89	289,445.89		2.4	680,633.97	663,650.15		64.0	2.3			6,138.96
Hawaii													
TOTALS	115,042,340.36	17,297,070.49	16,707,715.45	145,863.28	468.8	76,409,641.34	73,613,461.62	404,442.88	41.5	1,120.6	13,027,083.06	227.4	11,694,080.23

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS III—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF JUNE 30, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS III PROJECTS ON SECONDARY HIGHWAYS	COMPLETED			UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS III PROJECTS	STATE
		Total cost	Public works funds	Mileage	Estimated total cost	Public works funds allotted	Percentage completed	Mileage	Public works funds allotted	Mileage		
Alabama	$2,092,533.00	$26,236.82	$26,236.82	.1	$857,518.34	$857,518.34	12.8	59.7	$960,759.52	83.0	$248,018.32	Alabama
Arizona	525,422.53	90,857.40	90,857.40	6.3	441,468.95	429,341.96	44.5	36.0			5,223.17	Arizona
Arkansas	1,484,634.00	41,727.43	41,727.43	15.9	948,842.90	948,842.90	34.9	118.9	135,002.66	9.3	359,061.01	Arkansas
California	3,589,691.00	617,476.51	497,034.19	16.0	3,204,357.74	2,721,574.10	33.7	154.9	151,579.17	6.7	219,503.54	California
Colorado	1,718,632.00	617,189.08	616,485.80	82.2	1,025,898.66	994,429.71	73.5	94.0	80,000.00	3.4	27,716.49	Colorado
Connecticut	659,120.00				664,915.58	659,120.00	27.8	14.5				Connecticut
Delaware	454,772.00				181,790.00	181,790.00	41.8	1.8	72,547.50	12.2	200,434.50	Delaware
Florida	1,307,958.00	397,589.58	397,589.58	26.0	850,256.61	850,256.61	65.9	45.6	28,423.34	3.6	31,688.17	Florida
Georgia	2,320,973.00	69,600.63	69,600.63	4.2	920,605.43	920,605.43	49.6	77.3	277,397.03	25.2	1,053,369.91	Georgia
Idaho	1,121,562.00	650,200.91	588,778.59	70.8	546,438.63	532,783.11	55.9	71.1				Idaho
Illinois	5,265,960.00	276,114.65	276,114.65	42.0	4,610,167.64	4,610,167.64	42.2	268.3	379,677.71	10.3		Illinois
Indiana	602,271.00				540,734.86	540,734.86	46.2	69.2			61,536.14	Indiana
Iowa	2,212,245.00	238,660.03	229,800.00	49.2	1,821,511.10	1,640,950.00	54.5	214.0	341,495.00	58.9		Iowa
Kansas	2,522,401.00	345,683.96	345,683.96	17.2	2,152,166.63	2,170,276.56	54.9	146.6	6,440.48	1.7		Kansas
Kentucky	1,879,340.00	448,942.86	448,876.03	69.0	1,391,976.64	1,390,591.40	66.0	146.5	30,000.00	5.4	9,872.57	Kentucky
Louisiana	1,457,148.00	73,405.37	73,405.37	2.4	922,070.51	922,070.51	24.9	42.9	286,879.00	11.5	174,793.12	Louisiana
Maine	842,479.00	577,668.36	571,325.97	54.5	347,893.22	261,598.53	95.0	27.4			9,554.50	Maine
Maryland	891,132.00	22,217.70	22,217.70	1.9	577,528.60	563,602.60	64.5	44.0	262,345.90	17.0	42,965.80	Maryland
Massachusetts	488,185.00				469,741.41	469,741.41	75.1	15.2			18,443.59	Massachusetts
Michigan	3,184,057.00	88,500.00	88,500.00	7.3	2,798,900.00	2,798,900.00	37.7	218.3	182,300.00	2.7	114,357.00	Michigan
Minnesota	2,376,415.00	573,461.23	561,616.55	81.8	1,619,796.48	1,613,476.33	46.4	190.1	5,000.00	1.5	196,322.12	Minnesota
Mississippi	1,744,669.00				801,275.41	801,275.41	42.6	92.4	445,874.39	40.0	497,519.20	Mississippi
Missouri	2,923,273.00	504,000.61	504,000.61	141.8	2,307,941.20	2,307,941.20	77.0	353.6	49,901.33	5.1	61,429.86	Missouri
Montana	1,859,937.00	712,695.05	712,695.05	97.6	1,119,834.58	1,119,834.58	20.5	125.0	26,572.33	3.5	835.04	Montana
Nebraska	1,957,240.00	213,260.07	213,260.07	70.3	1,834,682.07	1,728,953.58	64.8	213.3	12,325.86	.1	2,700.49	Nebraska
Nevada	1,136,479.00	700,561.17	700,561.17	70.6	307,468.71	307,468.71	38.1	28.2			128,449.12	Nevada
New Hampshire	477,460.00	82,647.15	82,647.15	2.5	435,560.52	394,736.67	76.5	23.2			76.18	New Hampshire
New Jersey	56,550.52				56,550.52	56,550.52	80.7	.5				New Jersey
New Mexico	1,448,234.00	351,481.58	351,481.58	62.1	874,633.59	874,633.59	58.3	240.3	20,000.00	3.0	202,118.83	New Mexico
New York	3,608,768.00	333,721.33	333,721.33	11.8	3,702,200.00	3,264,550.00	52.2	87.8			10,496.67	New York
North Carolina	2,380,573.00	690,265.25	689,866.92	51.2	1,119,390.77	1,081,106.83	36.1	126.2	80,200.00	15.1	529,399.25	North Carolina
North Dakota	1,451,112.00	6,021.51	6,021.51	1.4	176,701.59	176,701.59	33.3	22.5	545,234.59	165.0	723,154.31	North Dakota
Ohio	3,871,148.00	610,460.00	610,460.00	159.9	3,316,490.00	3,016,818.00	88.3	142.5	193,150.00	2.5	50,720.00	Ohio
Oklahoma	2,304,199.00	31,741.28	31,741.28	2.9	1,783,376.08	1,677,379.13	24.3	194.4	567,265.51	73.8	27,813.08	Oklahoma
Oregon	1,526,724.00	541,068.81	502,843.61	41.7	1,050,254.52	928,020.15	34.3	55.7	95,860.24	11.1		Oregon
Pennsylvania	7,344,822.00	258,906.83	258,906.83	30.0	6,821,281.19	6,735,617.79	49.7	605.3	252,768.17	20.7	97,529.21	Pennsylvania
Rhode Island	499,677.00				412,465.02	412,465.02	57.0	33.2			87,211.98	Rhode Island
South Carolina	1,364,791.00	54,313.20	54,313.20	1.6	1,247,341.80	1,247,341.80	54.9	144.0	63,136.00	8.7		South Carolina
South Dakota	1,502,870.00	183,741.74	183,741.74	73.2	427,523.09	427,523.09	36.2	140.4	410,634.58	153.1	480,970.59	South Dakota
Tennessee	2,123,155.00	342,701.04	342,701.04	29.3	955,167.96	955,167.96	54.0	74.3	636,341.23	48.8	188,944.77	Tennessee
Texas	6,061,006.00	2,385,381.53	1,835,753.10	408.9	3,984,158.53	3,667,285.48	48.4	366.8	117,416.66	2.5	440,550.76	Texas
Utah	1,048,677.00	523,984.51	504,437.24	107.3	470,666.59	445,300.00	55.7	51.3	68,967.69	5.9	29,372.07	Utah
Vermont	438,880.00				444,002.49	424,132.63	38.0	36.0	14,747.37	.4		Vermont
Virginia	1,699,920.00	518,382.22	498,897.89	96.9	1,054,220.53	993,814.18	54.4	108.5	160,251.99	1.0	46,955.94	Virginia
Washington	1,080,673.00	403,092.71	393,092.71	27.6	653,151.30	653,151.30	31.4	36.1	27,739.30	3.9	6,689.69	Washington
West Virginia	1,118,559.00	21,945.79	21,945.79	.7	897,576.45	897,576.45	42.0	50.0	127,232.93	9.2	71,803.83	West Virginia
Wisconsin	2,425,385.00	894,060.15	858,749.84	58.8	1,333,491.78	1,288,586.71	26.2	95.3	148,404.19	16.6	129,644.26	Wisconsin
Wyoming	1,125,332.00	465,442.38	454,233.00	56.6	626,347.56	611,181.00	45.2	91.6	59,918.00	9.6		Wyoming
District of Columbia	959,234.00	208,113.99	208,113.99	2.6	750,914.71	750,914.71	40.2	5.2			205.30	District of Columbia
Hawaii	187,106.00				177,717.69	177,717.69	32.0	4.9			9,388.31	Hawaii
TOTALS	92,723,384.05	16,193,522.72	15,300,037.92	2,154.1	66,066,966.18	63,502,117.77	49.2	5,604.8	7,323,789.67	852.0	6,597,438.69	TOTALS

PUBLICATIONS of the BUREAU OF PUBLIC ROADS

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D.C. As his office is not connected with the Department and as the Department does not sell publications, please send no remittance to the United States Department of Agriculture.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1927. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1928. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1929. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1932. 10 cents.

DEPARTMENT BULLETINS

No. 136D . . Highway Bonds. 20 cents.

No. 347D . . Methods for the Determination of the Physical Properties of Road-Building Rock. 10 cents.

No. 532D . . The Expansion and Contraction of Concrete and Concrete Roads. 10 cents.

No. 583D . . Reports on Experimental Convict Road Camp, Fulton County, Ga. 25 cents.

No. 660D . . Highway Cost Keeping. 10 cents.

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

TECHNICAL BULLETINS

No. 55T . . Highway Bridge Surveys. 20 cents.

No. 265T . . Electrical Equipment on Movable Bridges. 35 cents.

MISCELLANEOUS CIRCULARS

No. 62MC . . Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects. 5 cents.

No. 93MC . . Direct Production Costs of Broken Stone. 25 cents.

MISCELLANEOUS PUBLICATIONS

No. 76MP . . The results of Physical Tests of Road-Building Rock. 25 cents.

No. ——— . . Federal Legislation and Regulations Relating to Highway Construction. 10 cents.

No. 191 . . . Roadside Improvement. 10 cents.

REPRINT FROM PUBLIC ROADS

Reports on Subgrade Soil Studies. 40 cents.

Single copies of the following publications may be obtained from the Bureau of Public Roads upon request. They cannot be purchased from the Superintendent of Documents.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regiona Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to the U.S. Bureau of Public Roads, Willard Building, Washington, D.C.

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

SUMMARY OF CLASSES I, II, AND III

AS OF JUNE 30, 1934

STATE	TOTAL APPORTIONMENT OF PUBLIC WORKS FUNDS	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR ALL NEW PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$ 8,370,133	$ 1,806,652.38	$ 1,090,782.86	$ 715,869.52	65.1	$ 6,616,632.75	$ 4,579,589.21	$ 2,037,043.54	33.1	370.0	$ 1,898,471.75	122.9	$ 801,289.18
Arizona	5,211,960	2,046,484.71	2,004,382.65		141.4	3,339,932.74	2,746,710.97		51.9	196.5	381,624.30	12.7	79,242.08
Arkansas	6,748,335	609,101.26	481,665.31	127,435.95	32.4	4,782,355.25	4,336,045.66	445,578.34	49.0	284.3	1,258,915.07	39.1	671,708.96
California	15,607,354	5,656,013.18	4,528,869.81		172.3	12,089,450.96	9,875,918.69		34.0	343.6	930,345.26	26.2	272,220.24
Colorado	6,874,530	3,022,131.93	2,962,379.61		195.4	3,737,033.79	3,571,936.47	27,435.65	54.1	162.3	230,989.02	7.0	109,224.90
Connecticut	2,865,740	80,124.44	80,124.44		.6	2,896,535.29	2,711,818.89	178,920.82	45.9	54.4	68,293.81	.5	5,502.86
Delaware	1,819,088	274,915.09	266,277.02		3.8	1,083,829.70	1,083,829.70		57.5	18.4	218,067.50	17.4	250,913.78
Florida	5,231,834	1,916,897.59	1,390,159.38	526,738.21	73.3	4,097,779.72	3,583,473.43	513,696.19	59.1	131.7	84,705.09	4.3	173,496.10
Georgia	10,091,185	1,572,745.52	1,572,745.52		90.2	4,368,602.28	4,368,602.28		42.4	290.1	1,045,325.29	59.5	3,104,511.91
Idaho	4,486,249	1,666,092.63	1,586,453.50		157.4	2,793,637.80	2,715,549.72		42.0	178.1	13,782.82		170,462.96
Illinois	17,570,770	540,636.64	540,605.69		46.6	13,621,077.74	13,621,077.74		48.0	377.6	3,176,243.20	26.6	232,843.37
Indiana	10,037,843	49,616.53	49,616.53		1.2	7,494,686.64	7,450,567.81		31.6	238.2	2,077,512.89	32.5	460,145.77
Iowa	10,055,660	1,999,978.66	1,936,465.00		147.3	7,267,687.25	6,716,960.00		66.7	421.2	736,695.00	73.5	665,540.00
Kansas	10,089,604	2,403,085.86	2,398,545.41		242.2	8,030,154.68	7,646,070.45		71.1	356.4	44,988.14	2.1	
Kentucky	7,517,359	1,131,158.04	1,126,634.92		131.8	4,722,349.06	4,705,771.28		63.9	341.7	959,218.81	31.5	725,733.99
Louisiana	5,828,591	625,710.21	625,685.21		18.6	4,453,210.60	3,946,559.60		38.5	128.2	838,890.20	15.8	417,455.99
Maine	3,369,917	739,856.65	732,388.69		56.9	2,509,937.71	2,386,704.77		58.5	85.3	48,534.12	.6	202,289.42
Maryland	3,564,527	22,217.70	22,217.70		1.9	1,769,410.69	1,741,685.94		46.4	62.5	724,195.90	23.4	1,076,427.46
Massachusetts	6,597,100	386,424.52	286,228.62	92,984.24	8.2	6,068,458.12	5,713,722.32	354,735.80	39.6	60.3	250,293.28	1.0	346,855.78
Michigan	12,736,227	364,350.00	364,350.00		11.4	10,698,825.00	10,647,675.00	49,000.00	43.1	497.3	1,198,741.00	27.2	525,461.00
Minnesota	10,656,569	4,018,218.36	3,985,730.25	20,482.87	644.9	5,481,281.76	5,432,453.84	30,000.00	32.0	469.7	439,906.43	19.0	798,478.48
Mississippi	6,978,675	411,372.98	274,599.14	136,773.84	16.6	6,026,784.62	3,921,151.83	2,067,000.85	43.5	353.0	1,024,541.35	76.2	1,758,382.68
Missouri	12,180,306	1,958,601.48	1,732,331.58		198.0	9,644,757.95	8,901,113.11	68,548.60	65.2	542.0	631,233.65	20.4	915,627.66
Montana	7,439,748	2,484,917.43	2,304,901.43	100,000.00	200.2	5,246,316.95	4,886,660.15	237,025.83	43.3	412.5	237,042.31	48.8	11,143.61
Nebraska	7,828,961	2,605,201.12	2,016,707.53	108,538.00	297.8	6,366,062.53	5,641,588.82		63.5	370.5	147,076.19	11.3	23,588.46
Nevada	4,545,917	2,097,159.73	2,097,159.73		244.8	2,120,252.90	2,120,252.90		28.4	122.3	79,129.02		249,375.35
New Hampshire	1,909,839	134,671.58	134,671.58		2.8	1,715,129.51	1,653,798.25		75.8	49.3	42,274.05	.9	79,095.12
New Jersey	6,346,039	160,151.25	160,151.25		8.2	5,659,697.65	5,450,643.64	169,466.42	38.6	56.8	104,945.89	1.1	630,298.22
New Mexico	5,792,935	2,662,688.71	2,662,688.71		285.7	2,782,780.24	2,638,850.82	143,929.42	43.8	316.4	128,714.77	9.8	362,680.70
New York	22,330,101	1,103,667.14	1,003,225.84	43,000.00	23.8	22,989,026.28	20,415,058.68	354,000.00	51.4	375.5	179,797.80	9.0	732,018.68
North Carolina	9,522,293	2,316,265.85	1,990,948.67	322,943.66	185.1	5,392,834.10	4,999,941.10	353,330.77	39.3	625.7	859,624.03	78.0	1,671,779.20
North Dakota	5,804,448	1,185,568.32	1,182,236.34	3,294.32	468.6	2,145,185.02	1,919,321.79	225,863.23	46.5	440.8	1,613,983.73	328.4	1,088,906.14
Ohio	15,484,592	2,141,452.27	2,096,220.71		197.1	13,863,632.43	12,775,221.43	51,410.00	69.9	348.8	519,316.37	10.2	93,833.49
Oklahoma	9,216,798	1,491,881.34	1,489,920.12		112.2	6,379,056.84	6,273,059.89		55.3	422.7	911,212.35	81.4	542,605.64
Oregon	6,106,896	2,488,491.83	2,302,156.66	98,444.47	150.4	3,548,284.40	3,276,350.18	128,021.20	37.8	153.5	408,509.78	15.8	119,879.38
Pennsylvania	18,891,004	1,292,671.11	1,275,142.80		51.3	15,863,939.07	15,536,514.87		47.3	763.1	1,328,626.91	32.6	750,719.42
Rhode Island	1,998,708	104,241.40	104,241.40		2.3	1,688,559.28	1,688,559.28		62.8	57.8	115,371.04	1.0	90,536.28
South Carolina	5,459,165.	465,522.03	465,522.03		30.0	4,012,419.10	4,009,284.47	3,134.63	48.5	360.5	458,295.22	25.5	526,063.28
South Dakota	6,011,479	1,453,187.56	1,433,846.17	19,341.39	266.2	2,957,477.42	2,649,683.60	307,793.82	28.8	412.5	834,642.10	204.0	1,093,307.13
Tennessee	8,492,619	2,043,736.55	1,830,674.25	213,062.30	97.5	5,009,525.75	4,648,365.56	361,160.19	51.9	192.6	1,442,646.74	77.8	570,932.45
Texas	24,244,024	8,173,921.58	6,863,517.91		1,007.7	14,546,596.99	13,624,462.13		40.3	873.7	1,055,547.40	37.7	2,700,496.56
Utah	4,194,708	2,575,936.17	2,537,560.60		267.2	1,322,833.39	1,296,874.14		57.2	102.9	137,171.79	6.3	223,101.47
Vermont	1,867,573	132,315.95	131,718.66		9.3	1,747,512.74	1,676,099.12	5,838.96	48.9	85.4	43,745.83	1.1	16,009.39
Virginia	7,416,757	2,022,430.39	1,972,211.54	18,234.52	148.0	4,500,288.02	4,128,116.07	119,858.30	48.5	202.0	886,111.73	29.8	430,317.66
Washington	6,115,867	2,475,339.20	2,446,222.83	3,356.82	93.0	3,535,412.21	3,535,412.21		33.1	108.7	92,379.97	5.3	41,851.99
West Virginia	4,474,234	320,707.27	320,707.27		9.3	3,554,123.66	3,523,777.92		58.6	131.1	349,106.66	12.1	280,642.15
Wisconsin	9,724,881	2,367,133.14	2,315,177.28	1,190.00	122.3	6,757,332.51	6,575,489.78	64,398.24	39.2	304.8	470,966.51	21.1	363,247.43
Wyoming	4,501,327	1,552,598.23	1,418,434.69	80,400.00	236.1	2,972,049.23	2,776,765.01	85,908.57	45.3	382.8	172,329.92	23.0	133,797.38
District of Columbia	1,918,469	497,559.88	497,559.88		5.0	1,431,548.68	1,414,564.86		51.4	7.5			6,344.26
Hawaii	1,871,062	122,232.70	109,225.57	12,994.32	6.3	1,803,971.40	1,502,765.58	251,205.82	28.0	31.4	248,693.76	6.8	10,377.09
TOTALS	394,000,000	79,774,036.09	73,201,990.29	2,645,084.43	6,985.7	283,506,260.40	263,042,470.96	8,634,305.19	48.5	13,674.4	31,148,776.25	1,718.2	26,606,762.50

U.S. GOVERNMENT PRINTING OFFICE: 1934

# PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

G. P. St. CLAIR, *Editor*

Volume 15, No. 6 August 1934

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions

In This Issue

THE BUREAU OF PUBLIC ROADS - - - - Willard Building, Washington, D.C.

REGIONAL HEADQUARTERS - - - - - - - - - - Mark Sheldon Building, San Francisco, Calif.

▼

DISTRICT OFFICES

DISTRICT No. 1. Oregon, Washington, and Montana.
Post Office Building, Portland, Oreg.

DISTRICT No. 2. California, Arizona, and Nevada.
Mark Sheldon Building, 461 Market St., San Francisco, Calif.

DISTRICT No. 3. Colorado, New Mexico, and Wyoming.
237 Custom House, Nineteenth and Stout Sts., Denver, Colo.

DISTRICT No. 4. Minnesota, North Dakota, South Dakota, and Wisconsin.
907 Post Office Building, St. Paul, Minn

DISTRICT No. 5. Iowa, Kansas, Missouri, and Nebraska.
Saunders-Kennedy Building, Omaha, Nebr.

DISTRICT No. 6. Arkansas, Louisiana, Oklahoma, and Texas.
Old Post Office Building, Fort Worth, Tex

DISTRICT No. 7. Illinois, Indiana, Kentucky, and Michigan.
South Chicago Post Office Building, Chicago, Ill.

DISTRICT No. 8. Alabama, Georgia, Florida, Mississippi, South Carolina, and Tennessee.
Federal Building, P.O. Box 60, Montgomery, Ala.

DISTRICT No. 9. Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.
Federal Building, Troy, N.Y.

DISTRICT No. 10. Delaware, Maryland, North Carolina, Ohio, Pennsylvania, Virginia, and West Virginia.
Willard Building, Washington, D.C.

DISTRICT No. 11. Alaska.
Room 419, Federal and Territorial Building, Juneau, Alaska.

DISTRICT No. 12. Idaho and Utah.
Federal Building, Ogden, Utah.

Because of the necessarily limited edition of this publication it is impossible to distribute it free to any person or institutions other than State and county officials actually engaged in planning or constructing public highways, instructors in highway engineering, and periodicals upon an exchange basis. At the present time additions to the free mailing list can be made only as vacancies occur. Those desiring to obtain Public Roads can do so by sending $1 per year (foreign subscription $1.50), or 10 cents per single copy, to the Superintendent of Documents, United States Government Printing Office, Washington, D.C.

A STUDY OF OIL-TREATED ROADS IN COLORADO AND WYOMING

BY THE DIVISION OF TESTS, U.S. BUREAU OF PUBLIC ROADS

Reported by C. A. CARPENTER, Assistant Civil Engineer, Bureau of Public Roads

IN JULY 1933 an inspection was made of approximately 150 miles of oil-processed roads in northern Colorado and southeastern Wyoming. Parts of U S 30, 40, 85, and 285, and Colorado 7 and 14 were included in the survey. The locations and mileages of the projects studied and the number of samples taken are given in the following tabulation:

Route	Location	Mileage	Number of samples
Colorado 7	Boulder, Colo.[1]	4	6
Colorado 14	Fort Collins, Colo., to Ault, Colo	18	2
U S 30	Cheyenne, Wyo., east	3	1
U S 40 N	Berthoud Pass, Colo	20	3
U S 85	Ault, Colo., to Cheyenne, Wyo	42	7
U S 285	Fort Collins, Colo., to Laramie, Wyo	63	23
	Total	150	42

[1] Survey covered portions of 2 principal streets surfaced with oil-processed gravel. Population of Boulder is approximately 12,000.

STUDY MADE TO RELATE CHARACTERISTICS OF MIX TO PERFORMANCE IN SERVICE

The study was made to obtain data concerning the range in densities and in percentages of voids in traffic-compacted oil-mix surfaces which had been in service. In was also desired to determine, if possible, whether the percentage of voids in the mixtures in service has any definite bearing on their stability and durability.

All of the surfaces inspected were of the dense-graded mixed-oil-treatment type and were, in most cases, constructed on gravel or crushed-stone base courses.

In conducting the survey, each section of highway selected for study was first traversed by automobile to get a general idea of its condition and to decide upon locations for sampling. Points for sampling were located at failed areas and at adjacent areas in good condition in order that comparative studies might be made of good and bad areas in individual projects. Failed areas varied from a few square yards to occasional sections the full width of the pavement and a few hundred feet in length but were usually comparatively small.

Of the 150 miles of highway inspected there were only three cases where marked failure had occurred over an extended portion of a project. One of these was a section about a mile in length on U S 85 approximately 33 miles south of Cheyenne, where the surface, although having good riding qualities, appeared excessively rich and was very rubbery and unstable. Another was a 1½-mile section on U S 285 in and adjacent to the village of Laporte, Colo., where the surface was constructed on a fill composed largely of clay. The fill crosses a low, wet area where the old gravel road had always been subject to frost heaving in spring. The new fill is wet and a considerable amount of plastic clay was found in a layer between the base and the bituminous surface. This section of surfacing had been scarified and relaid a few days prior to the inspection and was already cracking, rutting, and shoving when the inspection was made.

A SMOOTH RIDING SURFACE BETWEEN FORT COLLINS AND LARAMIE TYPICAL OF MOST OF THE SURFACES INSPECTED.

The third example of extensive failure noted was the oiled portion of the Berthoud Pass Road on the west side of the Pass. This section extends from the town of Frasier, Colo., eastward about 10 miles toward the Pass. About one-third of it is built across mountain meadows which are irrigated by flooding several times each summer. Frequent rains during the summer, heavy snow during the winter, and slush ice in the spring have added to the difficulties of building and maintaining the oil-mixed surface. Virtually the entire length of this 10-mile section was cracked extensively. The condition varied from a network of hair cracks on some portions to extensive "alligator" cracking and shoving on others. Where shoving had occurred the oiled surfacing had separated from the base and the appearance of the underside of the mat indicated that considerable slippage of the mat on the base had occurred. At each of the test holes on this section the base was wet and a layer of plastic clay was found between the base course and the surface mixture.

The west 2.6 miles of this project represented by samples 40, 41, and 42 and the easterly 3 miles had been surfaced about a year at the time of the inspection. The central portion of approximately 4 miles was completed just prior to the inspection. Several short sections of the year-old surface had been scarified and

TABLE 1.—*Results*

Sample no.	Route or local identification	Location	Age, years	Base: Type	Base: Condition	Base: Moisture	Surfacing: Thickness, inches	Surfacing: Seal treatment	Surfacing: Character	Surfacing: Specific gravity by immersion
1	Boulder, Colo., West Pearl St.	150 feet from west end of project.	3	Clay gravel	Well compacted	Damp	2¾	None	Tough, stable, firm	2.311
2	do	500 feet east of no. 1	3	Silty sand gravel	do	Dry	1½	do	Stable and firm	2.361
3	do	1,500 feet from west end of project.	3	Clay gravel	do	Moist	2½	do	Unstable and yielding	2.356
4	do	Same as no. 3 at center	3	Sand gravel	Somewhat loose	Damp	3½	do	Stable and firm	2.342
5	Boulder, Colo., North 12th St.	100 feet south of North St. intersection.	3	Grey clay	Well compacted	do	2¾	do	Unstable, yielding	2.285
6	do	Same as no. 5 but in center of street.	1	Sand gravel	do	do	2½	do	Stable, firm	2.252
7	U S 85, Colorado	14 miles south of Cheyenne.	4	White sand, some clay	do	do	3½	Applied	Firm but crumbles and packs easliy.	2.385
8	do	15 miles south of Cheyenne.	4	do	do	do	2½	do	Stable and firm	2.419
9	do	do	4	do	do	Moist	4½	do	do	2.357
10	do	21 miles south of Cheyenne.	3	Sand clay	do	Dry	3	None	do	2.368
11	do	33 miles south of Cheyenne.	3	Sand gravel	do	Moist	2¼	do	Unstable and plastic	2.316
12	do	32 miles south of Cheyenne.	3	do	do	Damp	3¼	do	Stable, tough, well bonded	2.186
13	do	26 miles south of Cheyenne.	3	do	do	do	4	Applied	Only moderately stable	2.425
14	do	4 miles east of Fort Collins.	1	do	do	do	4	None	Unstable, yielding, crumbles	2.356
15	do	13 miles east of Fort Collins.	1	Silt loam	do	do	3	do	Stable, firm but crumbles easily.	2.328
16	U S 30, Wyoming	3 miles east of Cheyenne.	4	Sand gravel	do	do	3	do	Extremely tough and stable	2.356
17	U S 285, Wyoming	15 miles south of Laramie.	1	Crushed red limestone.	Somewhat loose	do	1¾	Applied	Tough and stable	2.348
18	do	17 miles south of Laramie.	1	do	do	do	1¼	do	do	2.392
19	do	21 miles south of Laramie.	1	Red clay gravel	Well compacted	Dry	1¼	do	Stable and firm but brittle	2.282
20	do	do	1	do	Soft	Wet	1	do	Unstable and yielding	2.330
21	U S 285, Colorado	27 miles south of Laramie.	1	Sand gravel	Medium compaction.	Dry	2¾	None	Fairly stable but not well bonded.	2.190
22	do	34 miles south of Laramie.	1	do	Well compacted	do	3¾	do	Stable but not well bonded	2.279
23	do	38 miles south of Laramie.	1	do	do	do	3½	do	Stable and tough	2.254
24	do	39 miles south of Laramie.	1	do	Well compacted, hard.	do	4	Applied	Unstable and rubbery	2.352
25	do	41 miles South of Laramie.	3	Clay gravel, chunks of clay.	Well compacted	Moist	2¼	None	Unstable and spongy over clay spots.	2.318
26	do	do	3	Sand gravel	do	Damp	2	do	Stable and firm	2.352
27	do	43 miles south of Laramie.	3	Sand clay	do	Moist	3¾	do	Stable, tough, firm	2.331
28	do	46 miles south of Laramie.	4	Clay gravel	Loosely compacted.	Wet	2½	do	Soft and plastic	2.307
29	do	do	4	do	Well compacted	Dry	2¼	do	Stable and firm	2.412
30	do	49 miles south of Laramie.	4	do	do	do	3	do	Stable, firm, well bonded	2.311
31	do	do	4	do	do	do	3	do	Stable, hard, tough	2.419
32	do	do	4	do	do	Damp	2½	do	Slightly unstable and rubbery.	2.405
33	do	do	4	do	do	Dry	2	do	Stable, firm, tough	2.395
34	do	50 miles south of Laramie.	4	Sand gravel	do	Damp	2	do	Unstable, poorly bonded	2.375
35	do	58 miles south of Laramie.	2	Silty gravel	do	Dry	3½	do	Stable in place but has no bond.	2.149
36	do	do	2	do	do	Damp	3	do	Stable, firm, well bonded	2.224
37	do	64 miles south of Laramie.	2	Silt, sand, some gravel	do	Dry	3½	do	do	2.345
38	do	do	2	Silt, sand, clay, gypsum.	do	Damp	3¼	do	Unstable, plastic	2.328
39	do	do	2	do	do	Moist	3¼	do	do	2.305
40	U S 40 N., Colorado	½ mile east of Frasier	1	Sand gravel, decomposed granite.	do	Wet	2½	do	Unstable, spongy	2.404
41	do	1 mile east of Frasier	1	Clay	Plastic	do	2½	do	do	
42	do	2½ miles east of Frasier	1	Decomposed granite	Well compacted	do	2½	do	Unstable, plastic	2.366

relaid a few days prior to the inspection. These reworked portions showed a general tendency to develop cracks as soon as traffic had recompacted them. In general, the mixture on the entire project was rubbery and unstable and appeared to be excessively rich.

LIQUID CONTENT, TYPE OF FILLER AND DRAINAGE CONDITIONS APPEAR TO AFFECT SERVICE QUALITY

In addition to the three cases of extensive failure, which totaled approximately 12½ of the 150 miles of surfacing observed, there were numerous instances of local failure due to clay spots in the base, seepage of water, and local areas deficient in oil binder. Many of these small local failures were not detrimental to the riding qualities of the road.

The bulk specific gravity or density of the compacted surface was determined in the field at all locations where samples were taken. For this purpose a special portable balance, sampling equipment, and a tank of water for immersing specimens were carried in the car. The balance was designed especially for the purpose. It was constructed with a demountable beam and was accurate to one-tenth gram. Besides the unbroken samples taken for gravity determinations, samples were taken from each test hole, sealed in metal buckets and shipped to the Arlington laboratory for further *of field observations*

Surface			
Riding quality	Evidence of failure	Texture	Remarks
Excellent	None	Fine grained, closed	No reworking or patching.
do	do	Flat mosaic	Was rich and unstable first year, gravel added.
Good	Alligator cracks, laminations	Fine grained, closed	Not reworked. Sample from strip 3 feet wide 20 feet long, near edge of road shows slip on base.
Excellent	None	do	No repairs. Sample from center of street opposite no. 3.
Poor	Fine cracks, laminations, badly shoved.	Rich, black, glossy	Reworked first year. Test hole in traffic lane.
Good	Slightly raveled	Rough mosaic	(Replaces cartracks.) Has a dry, lean appearance.
do	Seal has picked up. Pitted	Some alligator cracks, alternate seal and mosaic.	Pitting due to picking up of seal, has not impaired riding qualities
do	None	Flat mosaic	Seal has penetrated well and is well bonded to surface.
Poor	Seal mostly gone, raveling extensive	Rough pitted	
Excellent	None	Flat mosaic	Appears dry on surface but amply rich when opened.
Fair	Alligator cracks, corrugations	do	Requires frequent maintenance to prevent complete failure.
Excellent	Slightly pitted	Fine gritty, some mosaic	Typical of about ½ of the entire job.
Good	Slightly corrugated and laminated	Black, glossy, slightly mosaic	Although slightly corrugated is not noticeably rough.
Excellent	Slight cracks in wheel lanes	Black, glossy, gritty	Has an excellent appearance but durability doubtful.
do	None	Flat mosaic	Appears dry on surface.
do	do	Rough mosaic	No repairs or reworking. Excellent surface.
Fair	Seal picked up in places	Mosaic, nonskid	Base primed with S.C.-1. Seal was chipped with 1 inch maximum size limestone.
Excellent	None	do	Seal was chipped with 1 inch maximum size limestone. Base primed with S.C.-1.
Good	do	Fine, rough mosaic	East ½ sealed with cut-back asphalt. Seal was covered with gravel.
Fair	Seal peeling, surface pitted and tending to corrugate.	Rough stucco appearance	West ½ sealed with 94+ road oil. Seal covered with gravel.
Excellent	None	Slightly mosaic	Not thoroughly compacted. Crumbles when opened.
do	do	Fine grain, closed	Do.
do	Slight raveling	Rough stucco appearance	Slight raveling due to loaded trucks turning onto pavement from stock pile.
do	Marks badly and is cracked	Fine grained, closed	Base shows extensive oil penetration (½ inch or more). No corrugation.
Fair	Alligator cracks, laminated	Flat mosaic	This road is kept in good riding condition by careful maintenance.
do	None	do	This sample taken about 18 inches from no. 25 in good area.
Excellent	do	do	
Poor	Badly shoved, laminated, slippage, plane on base.	Rich, glossy, closed	This represents a spot about 10 feet by 30 feet near crest of hill.
Excellent	None	Flat mosaic	This sample taken about 100 feet down hill from no. 28.
do	do	do	This section scarified and relaid within past year.
do	do	Slightly mosaic, fine grained, closed	Not reworked since laid (200 feet south of no. 30).
Good	Laminated, shows some slippage on base.	do	Taken 200 feet south of no. 31.
Excellent	None	Slightly mosaic	Taken 100 feet south of no. 32
Poor	Corrugated, rutted	Flat mosaic	Scarified and relaid 1 year ago.
do	Raveled badly	Harsh mosaic	Has raveled to a depth of ½ inch in wheel lanes.
Excellent	None	do	This sample from a point 300 feet south of no. 35.
Good	do	Rough mosaic	This is from a 50-foot good section out of about 1½ miles built on clay soil. The rest of the 1½ miles failed.
do	Alligator cracks and slippage on base	Flat mosaic	From 1½-mile stretch on clay soil fill. 30 feet south of sample no. 37.
Poor	Corrugated, rutted, alligator cracked, laminated, slipped.	Rich, glossy, some mosaic	This place requires constant maintenance. Sampled 5 days after scarified and remixed.
Fair	Extensive fine cracking	Some mosaic, fine grained, closed	Built over wet meadows. Rain nearly every day.
Poor	Material badly shoved, laminated	Fine grained, closed	Do.
Good	Extensive cracks, slippage	do	Primed portion of base attached to surface. (All slips on unpenetrated base.)

tests. Notes were kept on the type and condition of the base, drainage, and any visible peculiarities of the subgrade and appearance and condition of the surfacing mixture. As much information as could be obtained in the limited time available as to construction details and date of construction was included in the field notes. Table 1 is a summary of the field data on the surfaces represented by the 42 samples collected.

In the laboratory the samples were tested for specific gravity of the constituents of the mixture, water and oil contents, grading and type of aggregate, and type of filler. Portions of the samples passing the no. 8 sieve were tested for Hubbard-Field stability with the water content as received and also with the water removed by drying for 3 hours at 212° F. Two Hubbard-Field specimens of the water-free mortar from each sample were tested for swell in water over a period of 9 days.

The percentages of air and water voids in the compacted road surfaces were computed from the specific gravities as determined in the field and the specific gravities of the constituents as determined in the laboratory. Table 2 gives the results of laboratory tests on the 42 samples.

TABLE 2.—*Results of laboratory tests of samples*

Laboratory no.	Percentage by weight		Voids in mixture, percentage by volume		Absorption percentage by weight		Percentage of swell of Hubbard-Field specimens immersed 9 days	Mechanical analysis of aggregate, percentage by weight passing and retained on—								Percentage clay in material passing no. 40 sieve	Hubbard-Field stability of mortar		Type of mineral predominating in coarse aggregate	Apparent cause of failure
	Water	Oil	Air filled	Air and water filled	Aggregate retained on ¼-inch screen	Swell test specimens immersed 9 days		1¼ inch–1 inch	1 inch–¾ inch	¾ inch–½ inch	½ inch–¼ inch	¼ inch–no. 10	No. 10–no. 40	No. 40–no. 200	Passing no. 200		With original water content	Water free		
1	1.34	3.10	7.0	10.1	0.5	8.6	1.6	4.2	4.3	3.7	6.3	15.4	31.8	23.9	10.4	11	2,050	2,225	Granite, sandstone	
2	.95	3.90	2.4	4.6	.7	7.5	1.3			4.8	6.9	14.6	33.0	28.1	12.6	13	2,525	2,425	do	
3	.91	4.44	1.6	3.7	1.1	6.3	1.4			4.4	11.4	17.8	31.9	23.7	10.8	17	1,925	2,275	Sandstone, granite	Voids extremely low, richer than average.
4	.63	4.42	3.4	4.9	1.7	7.1	1.3			4.6	10.2	17.5	34.5	23.4	9.8	12	2,100	2,050	do	
5	2.46	3.54	3.4	9.0	.9	7.2	2.1			7.3	16.1	18.6	27.6	19.7	10.7	17	1,725	2,600	do	Clay base, high combined water and oil content.
6	.30	3.86	8.5	9.2	.5	8.1	1.4			2.7	15.0	18.7	29.2	23.2	11.2	13	2,650	2,675	do	Insufficient oil
7	1.19	2.76	3.2	6.0	.2	9.3	2.0		7.0	15.2	13.1	10.9	23.5	20.2	10.1	12	1,175	1,500	do	Do.
8	1.85	2.00	2.0	6.5	.3	11.6	4.6		5.4	10.0	16.1	12.8	23.3	23.8	8.6	12	2,325	2,475	Granite, schist, quartzite	
9	.76	2.58	5.3	7.2	.3	13.7	5.6		6.7	16.8	11.6	12.2	21.6	20.7	10.4	14	2,425	2,300	Altered granite, quartzite	Do.
10	1.12	4.42	.5	3.3	.4	8.9	3.7			9.5	10.9	14.4	26.6	25.9	12.7	14	2,450	3,100	Altered granite	
11	1.08	5.52	1.0	3.5	.2	4.9	2.2		4.0	2.9	20.7	24.0	19.4	14.0	15.0	14	1,900	2,275	Biotite granite	Voids extremely low, high oil and water content.
12	.75	3.74	9.2	10.8	.5	8.5	3.2			2.8	15.7	26.3	23.8	19.8	11.6	16	3,000	3,400	Feldspathic granite	
13	2.05	3.06	0	4.8	.4	14.1	7.5			12.4	19.9	18.4	22.9	17.7	8.7	15	2,400	2,150	do	Inferior filler has absorbed water.
14	.51	3.56	3.5	4.7	.4	5.5	2.0		9.5	7.3	13.9	21.3	28.3	12.4	7.3	16	1,150	1,200	do	Oil and water slightly high for grading.
15	.54	3.26	4.9	6.2	.2	6.1	1.6			1.9	17.5	28.7	26.2	13.2	12.5	13	925	1,500	Granite, mica schist, nonuniform.	
16	1.12	2.16	4.3	6.9	.4	13.7	6.6	4.9	5.0	6.6	17.6	19.8	20.3	17.1	8.7	15	1,900	1,675	Feldspathic granite	
17	1.41	2.96	3.0	6.3	1.3	6.6	1.6			23.8	27.8	14.2	8.9	11.2	14.1	14	1,300	1,475	Limestone (silicious)	Insufficient oil.
18	.65	3.70	1.8	3.4	.8	3.9	.8		8.6	18.3	21.5	14.7	14.0	14.0	8.9	16	1,875	1,925	Limestone (argillacious)	
19	1.00	3.96	5.5	7.8	.5	16.9	7.6		1.6	.9	12.1	25.3	33.0	13.0	14.1	14	2,850	3,000	Syenite (feldspar)	
20	4.00	3.38	0	9.3	.4	19.6	10.2			1.7	10.8	23.6	30.9	21.1	11.9	16	1,225	2,625	do	Inferior filler has absorbed water.
21	.73	4.26	8.9	10.5	.9	7.0	2.9			3.6	15.3	26.1	27.0	19.3	8.7	14	2,250	2,300	Biotite granite	
22	.76	3.36	7.2	8.9	.4	5.1	2.2			7.3	22.6	29.0	21.9	9.6	9.6	14	1,975	2,050	Feldspathic granite	
23	.76	3.02	8.3	10.0	.5	7.8	3.2		1.6	7.3	19.6	23.9	21.9	13.6	12.1	15	2,475	2,725	Biotite granite	Heavy trucks turning.
24	1.01	4.62	2.0	4.4	.3	2.9	1.2			16.4	6.1	28.5	24.1	12.5	12.4	13	975	1,050	do	Oil and water excessive.
25	2.88	4.38	.04	6.7	.3	5.0	2.3			4.0	16.5	25.4	29.5	16.4	8.2	20	2,150	1,150	Syenite	Oil and water extremely high, clay in base.
26	1.46	3.98	2.1	5.5	.5	5.3	2.1		2.2	4.2	19.8	25.1	24.5	13.9	10.3	17	1,725	2,375	Feldspathic granite	
27	1.06	2.96	5.1	7.6	.4	8.5	3.0		3.9	7.8	17.3	28.0	22.4	11.3	9.3	15	2,575	2,675		
28	3.22	2.68	.1	7.5	.6	8.7	4.6			6.9	28.3	25.9	21.5	8.0	9.4	23	475	2,950	Syenite	Questionable filler, wet clay in base.
29	1.61	2.58	1.0	4.9	.5	8.0	3.3		3.3	6.1	20.3	27.8	20.9	12.5	9.1	15	1,575	3,000	do	
30	.85	3.24	5.4	7.5	.4	7.9	2.7		1.3	7.5	20.2	23.2	24.0	13.0	10.8	15	3,025	3,450	Feldspathic granite	
31	1.23	2.50	1.2	4.2	.8	9.1	4.0		3.3	7.8	23.2	24.4	21.5	10.9	8.9	14	2,700	3,275	Syenite	
32	2.11	2.38	1.1	6.2	.3	6.1	2.8	3.7	4.8	6.2	20.4	25.9	19.3	9.6	10.1	18	925	2,850	do	Water and oil about equal, damp clay in base.
33	1.22	2.28	3.6	6.5	.6	8.3	3.1			1.9	22.8	31.0	22.8	10.6	10.9	13	2,475	3,100	Feldspathic granite	
34	1.35	2.82	2.3	5.5	.5	6.1	2.4		3.4	.9	18.2	26.6	24.5	14.6	11.8	21	2,125	3,275	Syenite	Not evident.
35	.57	3.04	11.2	12.4	1.3	9.0	3.1	7.0	7.5	2.5	14.4	26.3	22.2	8.1	12.0	21	3,125	4,300	Granite sandstone	Insufficient oil for grading.
36	1.43	3.48	6.8	10.0	1.2	9.2	3.1		1.2	2.4	12.4	28.4	30.0	16.8	8.8	19	3,625	4,850	do	
37	1.09	3.40	2.3	5.9	1.1	5.7	2.0		2.5	3.5	20.4	26.4	22.7	13.2	11.3	14	2,575	3,275	do	
38	2.44	3.00	1.9	7.6	1.0	5.2	2.2			1.4	13.6	28.0	29.4	19.2	8.4	20	1,600	3,225	do	Oil and water excessive for grading, wet clay in base.
39	2.19	3.78	1.9	7.0	1.0	5.3	3.5			1.7	15.4	27.3	28.6	16.5	10.5	19	1,575	3,250	do	Do.
40	.70	4.98	.8	2.5	.5	1.4	.6		4.7	19.1	17.7	13.0	18.8	16.0	10.7	13	2,350	3,525	Gneiss and schist	Do.
41	2.19	4.52			.7	1.1	.4		10.4	14.4	14.9	12.9	19.2	17.9	10.3	13	1,325	3,750	Gneiss	Do.
42	.91	5.26	1.1	3.3	.5	1.1	.3		5.2	13.3	15.0	13.7	19.8	18.1	14.9	15	2,525	3,650	do	Wet clay in base.

The percentages of bituminous material required for the various gradings were calculated by the Stanton (Calif.) formula,[1] the California surface area method,[2] the Wyoming formula,[3] and the McKesson-Frickstad formula.[4] The results of these calculations are compared with the oil contents of the mixtures as determined by extraction in table 3. Some of the data from tables 1 and 2 are repeated in table 3 for convenience in making comparisons.

It will be noted that the percentages of oil calculated by the Stanton formula are in close agreement with the mean percentages given by the surface area method. The Wyoming formula indicates considerably higher percentages, agreeing closely with the maximum percentages given by the surface area method. The McKesson-Frickstad formula indicates lower percentages and agrees closely with the minimum percentages given by the surface area method. The average spread between the maximum and minimum as given by the surface area method is 1.4 percent.

Analysis of the data presented in table 3 indicates that the void content of a compacted mixture has relatively little bearing on its behavior and that such factors as oil and water content, type of filler, type and condition of the base and subgrade drainage are of primary importance.

General View and Detail of a Surface of Group 1 Which Was Highly Unstable Due to a High Combined Oil and Water Content. Age Approximately One Year at Time of Inspection. Note Tire Marks and Foot Tracks on This Surface.

EVIDENCE OF FAILURE NOTED IN MOST SURFACES HAVING HIGH LIQUID CONTENT

The sections of surfacing represented by the first 15 samples listed in table 3 and designated as group 1 showed evidence of failure of the type usually found in unstable mixtures containing excessive quantities of liquid binder, namely, shoving, corrugating, and rutting. Ten of them also showed extensive "alligator" cracking. The combined percentage of water and oil in these was, in all but one case (sample no. 14), considerably greater than the percentage of oil required by the Stanton formula, and all but three contained more total liquid than the percentage of oil required by the Wyoming formula. Considering oil alone, all but three of these mixtures contained less oil than is required by the Stanton formula. Nine of the 15 samples contained more than 2 percent water, the average water content for the 15 samples being 1.9 percent. These facts seem definitely to associate high liquid content with lack of stability. There are indications that high liquid content causes instability regardless of whether the liquid is principally oil or oil and water in various proportions.

The next 20 samples listed in table 3 and designated as group 2 are from sections which showed no visible evidence of failure. All but six of these contained less total liquid (oil and water) than the percentage of oil

---

[1] $P=0.02a+0.045b+0.18c$.

Where P = percentage of oil in mix by weight.

a = percentage of aggregate retained on no. 10 sieve.

b = percentage of aggregate passing no. 10 and retained on no. 200 sieve.

c = percentage of aggregate passing no. 200 sieve.

For coarse mixtures (50 percent or less passing ¼-inch screen) increase coefficient of c to 0.20. For fine mixtures (100 percent passing ¼-inch screen) reduce coefficient of c to 0.15.

[2] Amount of oil determined from surface area constants of the different fractions of aggregate. Method of application described in Pacific Constructor for June 1, 1932.

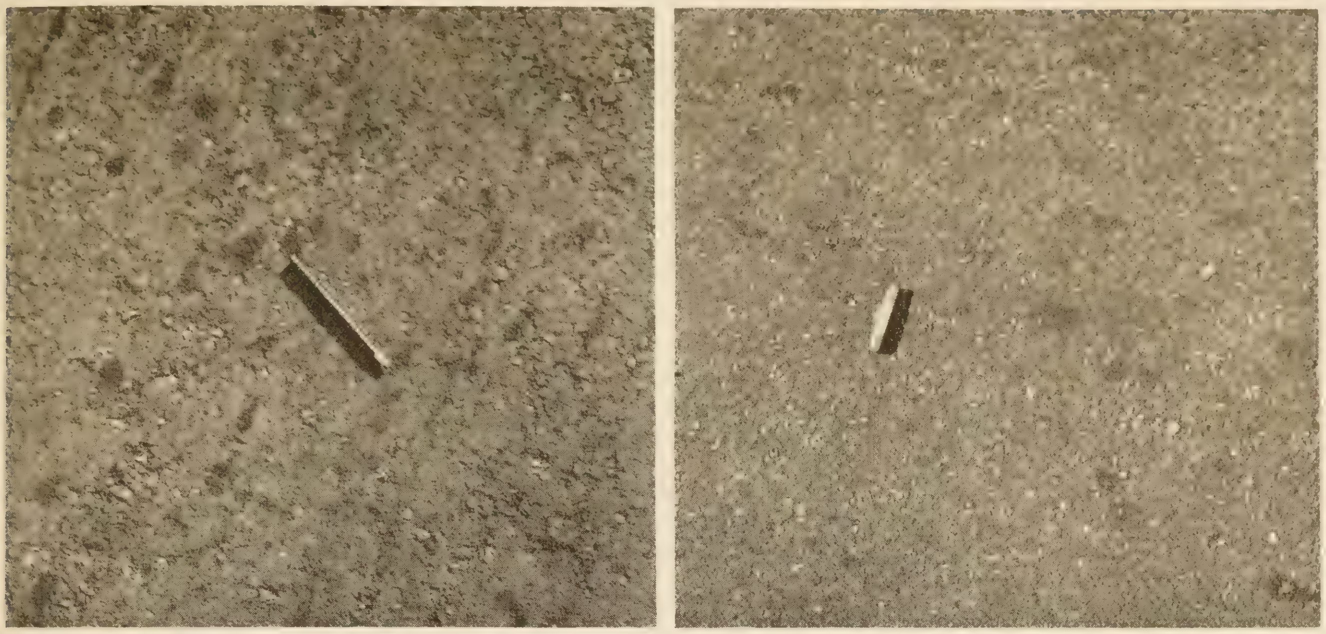
[3] $P=1.4(0.015a+0.03b+0.17c)$. Symbols the same as in note 1.

[4] $P=0.015a+0.03b+0.17c$. Symbols the same as in note 1.

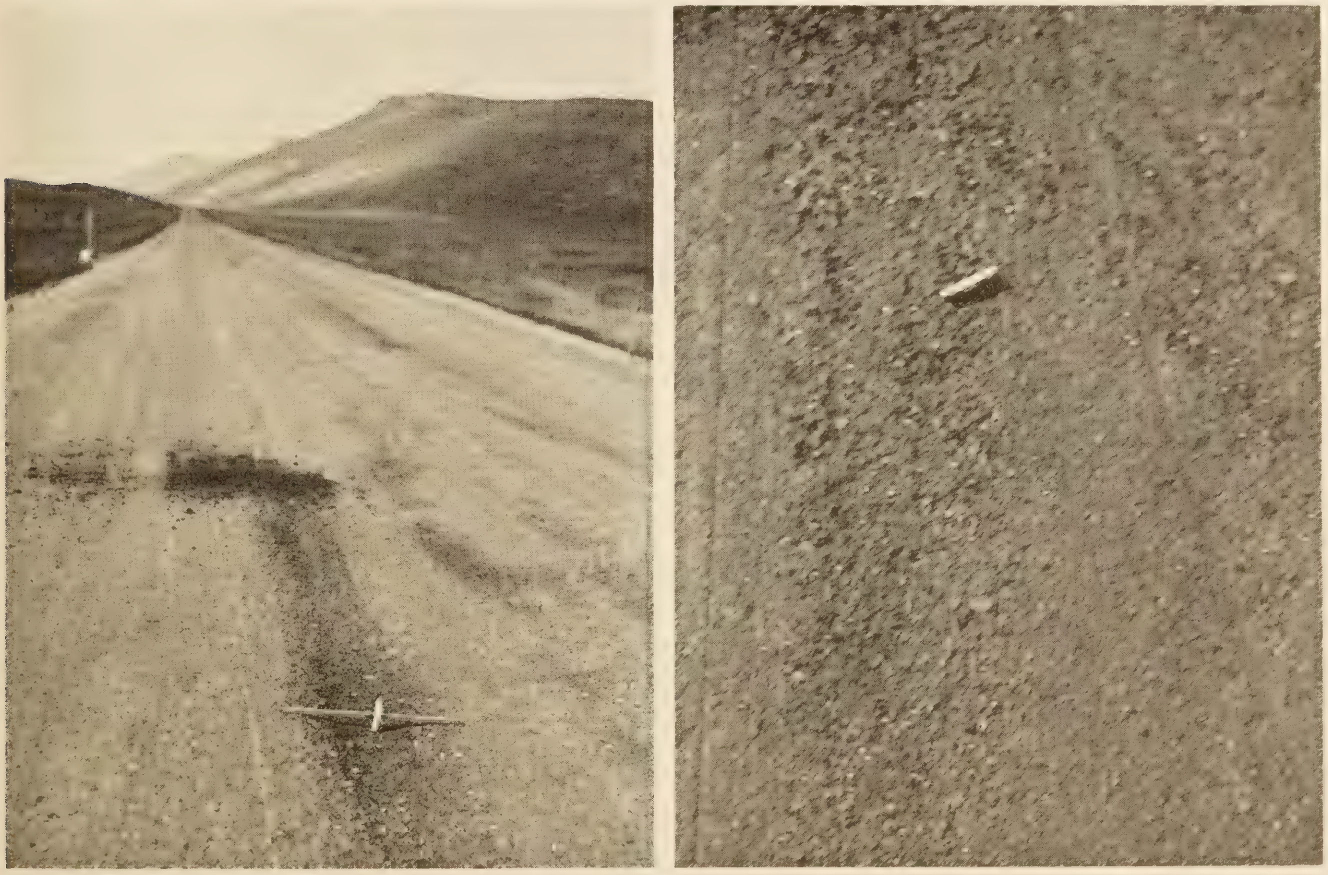
TABLE 3.—*Correlation of field and laboratory test data*

Sample no.	Type of failure in service	Voids by volume: Air filled	Voids by volume: Air and water filled	Composition of mixture by weight: Water	Composition of mixture by weight: Oil by ext.	Composition of mixture by weight: Total oil and water	Oil calculated by Stanton formula	Variation from Stanton formula, entire mix taken as 100 percent: Difference in oil	Variation from Stanton formula, entire mix taken as 100 percent: Difference in oil and water	Variation from Stanton formula, oil content taken as 100 percent: Variation in oil	Variation from Stanton formula, oil content taken as 100 percent: Variation in oil and water	Oil (proportion by weight) required by— California surface area method: Minimum	Oil required by— California surface area method: Mean	Oil required by— California surface area method: Maximum	Oil required by— McKesson-Frickstad formula	Oil required by— Wyoming 1.4 McKesson-Frickstad	Grading of aggregate by weight: Retained on no. 10	Grading of aggregate by weight: Passed no. 10 retained no. 200	Grading of aggregate by weight: Passing no. 200	Clay (smaller than 0.005 mm) in aggregate passing no. 40 sieve	Tests on mortar (oiled material passing no. 8 sieve): Hubbard-Field stability: With original water content	Tests on mortar: Hubbard-Field stability: Water removed by drying	Tests on mortar: Swell of Hubbard-Field specimens immersed 9 days	Condition of base[1]
	GROUP 1	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*			*Per-cent*	
20	Peeled, corrugated	0	9.3	4.0	3.4	7.4	5.2	−1.8	+2.2	−35	+42	4.2	5.0	5.7	4.0	5.6	36.1	52.0	11.9	16	1,225	2,625	10.2	Wet.
25	Spongy, cracked	0	6.7	2.9	4.4	7.3	4.5	−.1	+2.8	−2	+62	3.7	4.4	5.1	3.5	4.8	45.9	45.9	8.2	20	975	1,050	2.3	Moist.
13	Corrugated	0	4.8	2.1	3.1	5.2	4.4	−1.3	+.8	−30	+18	3.7	4.5	5.2	3.5	4.8	50.7	40.6	8.7	15	2,400	2,150	7.5	Damp.
28	Plastic, shoved	.1	7.5	3.2	2.7	5.9	4.2	−1.5	+1.7	−36	+41	3.4	4.2	4.9	3.4	4.8	61.1	29.5	9.4	23	475	2,950	4.6	Wet.
40	Spongy, fine cracks	.8	2.5	.7	5.0	5.7	4.6	+.4	+1.1	+9	+24	3.9	4.6	5.4	3.7	5.2	54.5	34.8	10.7	13	2,350	3,525	.6	Do.
11	Cracked, corrugated	1.0	3.5	1.1	5.5	6.6	5.2	+.3	+1.4	+6	+27	4.3	5.0	5.8	4.3	6.0	51.6	33.4	15.0	14	1,900	2,275	2.2	Moist.
32	Slightly, cracked and shoved	1.1	6.2	2.1	2.4	4.5	4.3	−1.9	+.2	−44	+5	3.7	4.4	5.2	3.5	4.9	61.0	28.9	10.1	18	925	2,850	2.8	Damp.
42	Cracked, shoved	1.1	3.3	.9	5.3	6.2	5.3	0	+.9	0	+17	4.3	5.1	5.9	4.4	6.1	47.2	37.9	14.9	15	2,525	3,650	.3	Wet.
3	Cracked	1.6	3.7	.9	4.4	5.3	5.1	−.7	+.2	−14	+4	4.2	4.9	5.7	4.0	5.6	33.6	55.6	10.8	17	1,925	2,275	1.4	Moist.
38	Cracked, shoved	1.9	7.6	2.4	3.0	5.4	4.6	−1.6	+.8	−35	+17	3.8	4.5	5.2	3.5	5.0	43.0	48.6	8.4	20	1,600	3,225	2.2	Damp.
39	Corrugated, rutted, shoved	1.9	7.0	2.2	3.8	6.0	4.8	−1.0	+1.2	−21	+25	3.9	4.7	5.4	3.8	5.3	44.4	45.1	10.5	19	1,575	3,250	3.5	Moist.
24	Cracked, marked badly	2.0	4.4	1.0	4.6	5.6	4.9	−.3	+.7	−6	+14	4.0	4.7	5.5	4.0	5.6	51.0	36.6	12.4	13	975	1,050	1.2	Damp.
5	Cracked, shoved	3.4	9.0	2.5	3.5	6.0	4.9	−1.4	+1.1	−29	+22	4.1	4.8	5.5	3.9	5.4	42.0	47.3	10.7	17	1,725	2,600	2.1	Do.
14	Slightly cracked, rubbery	3.5	4.7	.5	3.6	4.1	4.2	−.6	−.1	−14	−2	3.4	4.1	4.8	3.2	4.5	52.0	40.7	7.3	16	1,150	1,200	2.0	Do.
41	Badly shoved, cracked	------	------	2.2	4.5	6.7	4.6	−.1	+2.1	−2	+46	3.9	4.7	5.4	3.7	5.1	52.6	37.1	10.3	13	1,325	3,750	.4	Wet.
	GROUP 2																							
10	No evidence of failure	.5	3.3	1.1	4.4	5.5	5.4	−1.0	+.1	−19	+2	4.4	5.2	5.9	4.3	6.0	34.8	52.5	12.7	14	2,450	3,100	3.7	Dry.
29	do	1.0	4.9	1.6	2.6	4.2	4.3	−1.7	−.1	−40	−2	3.6	4.3	5.0	3.4	4.8	57.5	33.4	9.1	15	1,575	3,000	3.3	Do.
31	do	1.2	4.2	1.2	2.5	3.7	4.2	−1.7	−.5	−40	−12	3.5	4.2	4.9	3.4	4.7	57.8	32.4	8.9	14	2,700	3,275	4.0	Do.
18	do	1.8	3.4	.6	3.7	4.3	4.1	−.4	+.2	−10	+5	3.6	4.3	5.0	3.3	4.6	63.1	28.0	8.9	16	1,875	1,925	.8	Damp.
8	do	2.0	6.5	1.9	2.0	3.9	4.6	−2.6	−.7	−57	−15	3.9	4.7	5.4	3.5	4.9	44.3	47.1	8.6	12	2,325	2,475	4.6	Do.
26	do	2.1	5.5	1.5	4.0	5.5	4.6	−.6	+.9	−13	+20	3.9	4.6	5.3	3.7	5.1	51.3	38.4	10.3	17	1,150	2,150	2.1	Do.
37	do	2.3	5.9	1.1	3.4	4.5	4.7	−1.3	−.2	−28	−4	3.9	4.6	5.3	3.8	5.3	52.8	35.9	11.3	14	2,575	3,275	2.0	Dry.
2	do	2.4	4.6	1.0	3.9	4.9	5.6	−1.7	−.7	−30	−12	4.5	5.3	6.0	4.4	6.1	26.3	61.1	12.6	13	2,525	2,425	1.3	Do.
4	do	3.4	4.9	.6	4.4	5.0	5.0	−.6	0	−12	0	4.1	4.8	5.6	3.9	5.4	32.3	57.9	9.8	12	2,100	2,050	1.3	Damp.
33	do	3.6	6.5	1.2	2.3	3.5	4.6	−2.3	−1.1	−50	−24	3.8	4.5	5.2	3.7	5.2	55.7	33.4	10.9	13	2,475	3,100	3.1	Dry.
16	do	4.3	6.9	1.1	2.2	3.3	4.3	−2.1	−1.0	−49	−23	3.7	4.5	5.2	3.4	4.8	53.9	37.4	8.7	15	1,900	1,675	6.6	Damp.
15	do	4.9	6.2	.5	3.3	3.8	5.0	−1.7	−1.2	−34	−24	3.9	4.6	5.3	4.0	5.6	48.1	39.4	12.5	13	925	1,500	1.6	Do.
27	do	5.1	7.6	1.1	3.0	4.1	4.3	−1.3	−.2	−30	−5	3.6	4.3	5.0	3.5	4.8	57.0	33.7	9.3	15	2,575	2,675	3.0	Moist.
30	do	5.4	7.5	.9	3.2	4.1	4.7	−1.5	−.6	−32	−13	3.9	4.6	5.3	3.7	5.2	52.2	37.0	10.8	15	3,025	3,450	2.7	Dry.
19	do	5.5	7.8	1.0	4.0	5.0	5.4	−1.4	−.4	−26	−7	4.2	4.9	5.7	4.4	6.1	39.9	46.0	14.1	14	2,850	3,000	7.6	Do.
36	do	6.8	10.0	1.4	3.5	4.9	4.6	−1.1	+.3	−24	+7	3.6	4.4	5.1	3.6	5.0	44.4	46.8	8.8	19	3,625	4,850	3.1	Damp.
1	do	7.0	10.1	1.3	3.1	4.4	5.1	−2.0	−.7	−39	−14	4.2	4.9	5.6	4.0	5.5	33.9	55.7	10.4	11	2,050	2,225	1.6	Do.
22	do	7.2	8.9	.8	3.4	4.2	4.3	−.9	−.1	−21	−2	3.5	4.3	5.0	3.5	4.8	58.9	31.5	9.6	14	1,975	2,050	2.2	Dry.
21	do	8.9	10.5	.7	4.3	5.0	4.6	−.3	+.4	−7	+9	3.8	4.5	5.3	3.6	5.0	45.0	46.3	8.7	14	2,250	2,300	2.9	Do.
12	do	9.2	10.8	.8	3.7	4.5	5.0	−1.3	−.5	−26	−10	4.1	4.9	5.6	4.0	5.5	44.8	43.6	11.6	16	3,000	3,400	3.2	Damp.
	GROUP 3																							
34	Corrugated, raveled, poorly bonded	2.3	5.5	1.4	2.8	4.2	4.9	−2.1	−.7	−43	−14	3.9	4.7	5.4	3.9	5.5	49.1	39.1	11.8	21	2,125	3,275	2.4	Do.
17	Seal picked up, pitted	3.0	6.3	1.4	3.0	4.4	4.8	−1.8	−.4	−37	−8	3.8	4.5	5.2	4.0	5.6	65.8	20.1	14.1	14	1,300	1,475	1.6	Do.
7	do	3.2	6.0	1.2	2.8	4.0	4.7	−1.9	−.7	−40	−15	4.0	4.8	5.5	3.7	5.2	46.2	43.7	10.1	12	1,175	1,500	2.0	Do.
9	Seal mostly gone, raveled	5.3	7.2	.8	2.6	3.4	4.7	−2.1	−1.3	−45	−28	4.0	4.8	5.5	3.8	5.3	47.3	42.3	10.4	14	2,425	2,300	5.6	Moist.
23	Raveled slightly from turning	8.3	10.0	.8	3.0	3.8	4.8	−1.8	−1.0	−37	−21	4.0	4.7	5.5	3.9	5.5	52.4	35.5	12.1	15	2,475	2,725	3.2	Dry.
6	Raveled slightly	8.5	9.2	.3	3.9	4.2	5.1	−1.2	−.9	−24	−18	4.2	5.0	5.8	4.0	5.6	36.4	52.4	11.2	13	2,650	2,675	1.4	Damp.
35	Raveled badly	11.2	12.4	.6	3.0	3.6	4.7	−1.7	−1.1	−36	−23	3.7	4.4	5.1	3.8	5.3	57.7	30.3	12.0	21	3,125	4,300	3.1	Dry
	Average	3.5	6.7	1.4	3.5	4.9	4.7	------	------	------	------	3.9	4.6	5.4	3.8	5.3	48.5	40.8	10.7	15.4	------	------	------	------
	Maximum	11.2	12.4	4.0	5.5	7.4	5.6	------	------	------	------	4.5	5.3	6.0	4.4	6.1	65.8	57.9	15.0	23	------	------	------	------
	Minimum	0	2.5	.3	2.0	3.3	4.1	------	------	------	------	3.4	4.1	4.8	3.2	4.5	26.3	20.1	7.3	11	------	------	------	------

[1] Bases were described as "dry" when they would powder or dust; "damp" when only sufficient moisture was present to be discernable to the eye; "moist" when containing sufficient water to permit the formation of a ball by pressing in the hands and "wet" when sticky or wet to the touch.



Typical Oil-Mix Surfaces Which Have Given Excellent Service. The Mix Shown on the Left Was Rich and Unstable the First Year and Was Remixed with Additional Gravel. It Was Three Years Old at the Time of Inspection. The One on the Right Had Received No Maintenance of Any Kind Since Its Construction Four Years Prior to the Inspection.



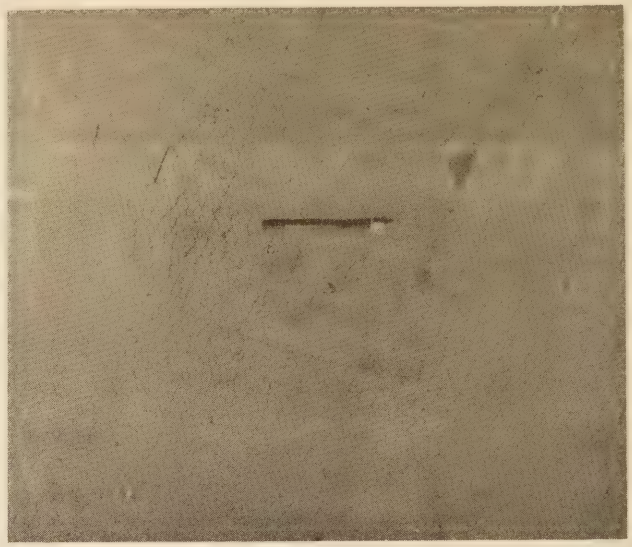
Typical Examples of Raveling of Group 3 Surfaces Having a Low Oil Content and No Seal Coat or Surface Treatment to Prevent Loss of Aggregate.

Group 3 Surface Represented by Sample 9. Mixture Was Low in Oil Content and Had Been Sealed to Prevent Raveling. Picture Shows Local Area Where Seal Had Peeled and Raveling Followed. Sealed Portion Represented by Sample 8 Was in Excellent Condition.

required by the Stanton formula. Only two contained as much total liquid as the percentage of oil required by the Wyoming formula. Considering oil content alone all but six samples were fairly close to the minimum content required by the surface area method, the six exceptions having from 1 to 1.9 percent less oil than would be required by this minimum. Sample no. 8, which had 1.9 percent less oil than the minimum by the surface area method, contained only 2 percent oil but the section represented by it had been given a seal treatment. This surface was in good condition except for a few small areas such as that represented by sample 9 and illustrated above, where the seal coat had peeled off allowing the mixture to ravel. None of the 20 mixtures contained as much as 2 percent water. The average water content was 1.1 percent.

These data indicate that stability and durability of the surface under traffic are definitely associated with comparatively low oil content and water content below 2 percent. Considering all the mixtures sampled, evidence of failure was noted in all but five instances where the total liquid content (oil and water) was greater than the oil requirement as calculated by the Stanton formula. In four of these exceptional cases the liquid content was only slightly greater than the percentage given by the formula. Not a single example of satisfactory service behavior was noted where the water content in the surface was as high as 2 percent.

The last seven samples listed in table 3 as group 3 are from sections of pavement which, although having adequate stability, showed raveling because of poor bond. These mixtures, without exception, contained less total liquid than the percentage of oil required by the Stanton formula. Their total liquid contents are in very close agreement with the oil requirements of the McKesson-Frickstad formula and also with the minimum percentages required by the surface area formula but, considering oil alone, they are all deficient in oil content as indicated by the formulas. The deficiency ranges from 0.3 to 1.4 percent and averages 0.9 percent on the basis of the minimum requirement by the surface area formula. Their water contents varied from 0.3 to 1.4 percent. The average water content was 0.9 percent.



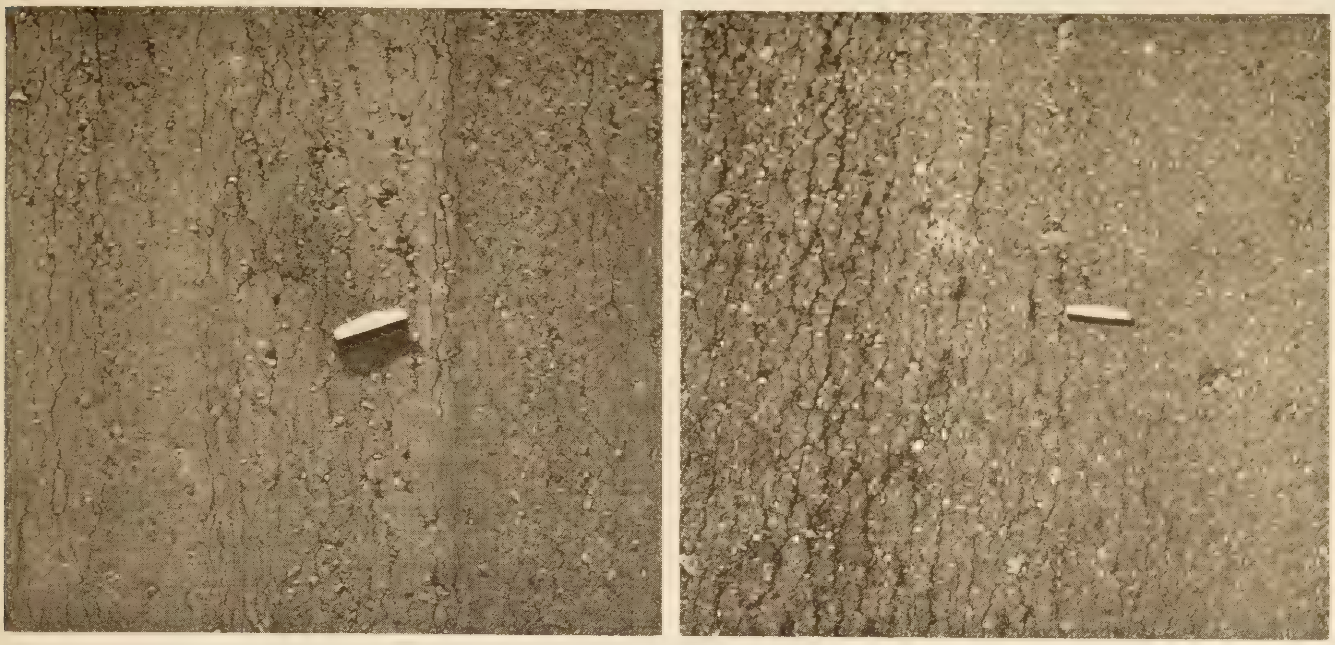
Group 1 Surface Represented by Sample 5. The Base Was Moist Clay-Gravel. Surface Smooth and Firm but Badly Cracked.

LABORATORY STABILITY TESTS ON MORTAR SPECIMENS APPEAR TO INDICATE STABILITY OF MIXTURES IN SERVICE

Raveling and loss of surfacing material caused by poor bond are shown to be associated with lack of oil. The average water content of the seven lean mixtures was distinctly lower than that of the first group and slightly below that for the second group.

Although the unstable group has a slightly lower average void content than had the two stable groups, study of the data obtained on these surfaces indicates that there is little definite relation between the percentage of voids in the compacted mixtures and the service behavior of the pavement. In the case of the sections showing failure because of lack of stability the percentage of air-filled voids ranges from 0 to 3.5, with an average of 1.3. For the mixtures showing no evidence of failure the air-filled voids range from 0.5 to 9.2 percent with an average of 4.2. The mixtures showing failure caused by raveling had air-filled voids ranging from 2.3 to 11.2 percent and averaged 6 percent. These figures are all based on the percentage of air-filled voids in a given mixture. Any water present is considered as a part of the mixture.

Assuming all water to be evaporated from samples leaving additional air voids, the percentages of voids would be appreciably higher but there would still be no significant differences between groups. Considering group averages only, the voids increase by increments of approximately 1 percent from group to group but the range of voids is so great within each group that each group overlaps the others. The 15 mixtures failing on account of instability have voids (air and water filled) ranging from 2.5 to 9.3 percent with an average of 5.7. Those showing no failure have voids ranging from 3.3 to 10.8 percent and average 6.8. Those showing failure caused by raveling have voids



Typical Examples of Failure Caused by High Moisture Contents in the Mixtures. These Group 1 Surfaces Are Two and Three Years Old.

between 5.5 and 12.4 percent with an average of 8.2 percent. These percentages are given in table 3 under the heading "Air and water-filled voids."

The Hubbard-Field stabilities of the mortars (oil coated material passing the no. 8 sieve) appear to have a general relation to the service stabilities of the mixtures. Although there is considerable variation in mortar stabilities within each group, the group averages show a tendency toward low mortar stabilities for the mixtures which failed because of excess oil or oil and water combined. Although the stability of mortar from the unstable mixtures with field water content is low, when the test is made on water-free specimens the stabilities are almost as high as the average for the other two groups. There is no appreciable difference in the average stabilities of either wet or water-free mortars representing the sound surfaces and the raveled surfaces. The average increase in mortar stability caused by the drying of the mortar is much less for groups 2 and 3 than for the unstable group 1.

The average stabilities by groups and the maximum and minimum stabilities by groups are summarized below.

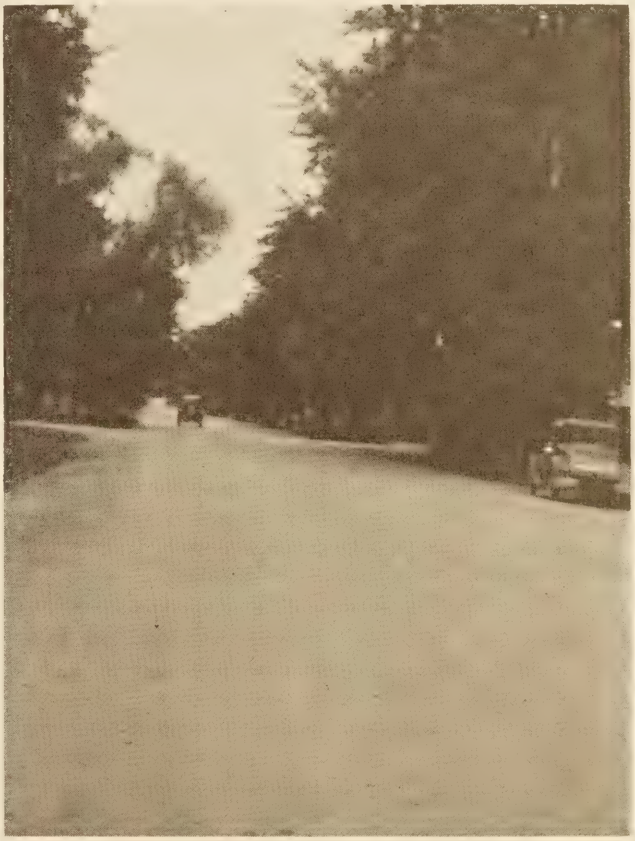
Hubbard-Field stabilities of the mortar

[Passing no. 8 sieve]

	With water content as received			With water removed by drying		
	Minimum	Average	Maximum	Minimum	Average	Maximum
Group 1 (failed because of instability)	475	1,535	2,525	1,050	2,560	3,750
Group 2 (satisfactory service)	925	2,295	3,625	1,500	2,695	4,850
Group 3 (failed through raveling)	1,175	2,180	3,125	1,500	2,605	4,300

The relations shown above indicate that the stability of the mortar is appreciably reduced by the presence of water in the amounts found in these samples. It seems reasonable to conclude, from the behavior of the sections studied, that the stability of the surface is to some extent influenced by the stability of the mortar.

76178—34——2



An Oil-Mix Surface in Boulder, Colo. Surface Has Carried Through Traffic for Three Years and Is in Excellent Condition Except for Occasional Small Cracked Areas.

The soil analyses of the mineral aggregates extracted from these samples indicate that all the filler materials used were comparatively low in clay content. The maximum percentage of clay in any of the samples, based on the material passing the no. 40 sieve, was 23 percent (table 3) and the average for all samples was 15.4 percent.

FILLERS HAVING HIGH VOLUME CHANGE UNDESIRABLE

It was not possible to obtain sufficient filler from the samples to make other soil tests. However, swell measurements were made on molded specimens of the portion of the original mixtures passing the no. 8 sieve. After sieving, the mortar was oven-dried at 100° C. to remove any water present, then molded into Hubbard-Field specimens and immersed in water for 9 days. Vertical swell was measured with an Ames dial gage at 1, 3, and 6 hours and at 1, 2, 3, 7, and 9 days. The percentages of swell of these specimens are given in table 3.

Swell of such specimens in excess of about 2½ percent at 9 days may be considered to indicate inferior or questionable filler material. At 3 days, 2 percent swell may be considered the critical value. The figures given in table 3 are based on the results at 9 days.

Results of the swell tests do not indicate that inferior filler contributed to the failure of the mixtures in group 1, with the possible exception of those represented by samples 13, 20, 28, 32, and 39. In addition to having high percentages of swell, the mortar specimens from these five samples developed more or less cracking and disintegration during immersion. It is interesting to note that of the 15 mixtures in this unstable group, those containing fillers with high volume change and a tendency to disintegrate during immersion had, in general, the highest water contents regardless of whether the base course was wet, moist, or merely damp. The same relation is also noticeable to some degree in the other two groups and leads to the conclusion that fillers which have high volume change and show disintegration or slaking tend to retain moisture in the mix, once it has entered the surfacing. In the case of mixtures which are susceptible to loss of stability when wet, this tendency apparently prolongs the period of surface instability for some time after the base has dried.

In the swell test on the mortars of group 2, about half the materials showed considerable swell, and six developed cracking and disintegration during immersion. With only one exception, however, the surfaces from which these samples were taken were on dry or only slighlty damp bases, and the mixtures, without exception, contained only small amounts of moisture. This probably accounts for the fact that the surfaces represented were not affected by the questionable quality of the filler material.

Three of the mortars from the group 3 samples showed considerable volume change and two of them developed cracking and disintegration during immersion. Two of these were from surfaces which had dry bases and the other was from a surface having a moist base. All three mixtures had very low water contents and for this reason the raveling of these surfaces in service is not believed to have any connection with the type of filler used.

CONCLUSIONS

The results of the observations and tests are briefly summarized as follows:

1. Instability of the oil-processed surfaces was caused by high liquid content. In some cases this high liquid content was made up principally of bituminous material with 1 percent or less of water but in 9 of the 15 cases of failure caused by instability, the mixtures contained water in excess of 2 percent. No mixtures in which the water content was 2 percent or more were found to give satisfactory service.

2. The mixtures which, after a year or more of service, contained percentages of bituminous material agreeing roughly with the minimum requirements of the California surface area formula, were sufficiently rich to prevent loss of aggregate by raveling. In order to account for normal losses during early service, it is assumed that the mixtures were somewhat richer when laid and for this reason it is believed that either the Stanton formula or the mean surface area formula is approximately correct for designing mixtures containing close-graded aggregate.

3. The mixtures which showed evidence of failure caused by raveling contained less oil than would be required by any formula now in use. These mixtures, however, were in no case lacking in stability and it is believed that surface treatment would give them satisfactory wearing qualities.

4. Clay spots and areas in the bases containing excessive proportions of clay were found to be the cause of numerous small local failures.

5. In several cases where a high moisture content was found in a mixture on a comparatively dry base, the filler material was found to have a tendency to swell and disintegrate in the swell test, thus indicating a relatively high colloidal content. Colloidal contents are believed to have been responsible for the retention of water in mixtures containing them.

6. Hubbard-Field stabilities of the mortars from the unstable mixtures were noticeably low when the mortars were tested with water contents as received. The stabilities were raised to very nearly the same values as those for the stable mixtures after the water had been dried out. This is interpreted to indicate that water destroyed the stability of these mixtures by reducing the stability of their mortars.

7. The relation between the percentage of voids in a mix and the service behavior of the surface is so indefinite for any one group of samples and the variation in voids between groups is so slight as to supply no basis for conclusions as to the effect of voids, or for designing oil-aggregate mixtures on the basis of void contents.

POWER-SHOVEL OPERATION IN HIGHWAY GRADING

BY THE DIVISION OF MANAGEMENT, BUREAU OF PUBLIC ROADS

Reported by T. WARREN ALLEN, Chief, Division of Management, and ANDREW P. ANDERSON, Highway Engineer

PART 1.—THE OPERATING CYCLE AND FACTORS AFFECTING THE RATE OF PRODUCTION

THE DAILY COST of operating a power-shovel grading outfit is very nearly fixed for any given set of conditions, regardless of whether the output is high or low. The most effective way, therefore, for a contractor to reduce his unit costs is to increase his rate of production. Some of the more important factors controlling rates of production and attainment of efficient and economical operation will be discussed in these articles.

When working in ordinary "common excavation" where the material dumps freely from the bucket and is 4 or more feet in depth, a good power shovel can be operated so as to load vehicles at the rate of four dipper loads per minute, provided the vehicles are so placed that the average boom swing does not exceed 90°. A highly skilled operator can attain this rate for intermittent periods throughout the day. To do so, it is necessary to load the dipper in about 5 1/4 seconds, to swing and spot the dipper in about 4 seconds, to dump it in 1 1/4 seconds, and then return the dipper to the loading point in about 4 1/2 seconds.

Many jobs have been found on which this rate has been maintained during intermittent periods of varying lengths under the conditions given above, and this may be taken, therefore, as about the maximum rate attainable with present-day power shovels under ordinarily favorable field conditions. Numerous jobs have been found on which the average rate of all-day shovel operation, in good common excavation, was at the rate of three or more dipper loads per minute; and this may be accepted as a criterion of good operation under normally favorable field conditions.

HIGH DEGREE OF EFFICIENCY ATTAINABLE IN SHOVEL OPERATION

Efficient use of the power shovel in highway grading generally involves the proper coordination of at least three distinct operations: (1) Digging and loading, (2) hauling and dumping, (3) spreading and compacting. The material, except where it can be cast, must be dug and loaded into the hauling units at or near the maximum rate of production which can be attained by the shovel in that particular material. The hauling units must be sufficient to carry the output of the shovel and must be operated with almost clocklike precision, so that the loads may be received, transported to the place of disposal and dumped, and the hauling units returned to the shovel without delay to individual units or interruption to the steady operation of the shovel. At the fill or dump the material brought by the hauling units must be spread and compacted or otherwise cared for as may be required by specifications without interfering with the steady operation of hauling units.

If the material is too hard to be dug effectively with the shovel, drilling and blasting are necessary. These operations also must be carried on efficiently and without interfering with other work.

Aside from the management, efficiency in power-shovel operation is largely dependent on the operator and on the shovel itself. A first-class operator may be able to obtain fair production with a poor shovel, but a poor operator is a heavy handicap, even with the best equipment. It is hoped that the data assembled in these papers will help contractors to increase their present rates of shovel production and power-shovel manufacturers to perfect their shovels so as to meet still better those conditions which are prerequisite to high rates of production.

The shovel is the primary producer and all production is dependent on it. The shovel should be sturdy, powerful, dependable, fast, and easily operated. But no matter how good the shovel, a high grade of skill, intelligence, and endurance is required of the operator for a consistent high rate of production.

Efficient power-shovel operation, in the sense intended here, demands high production with a minimum use of labor and auxiliary equipment. This requires the synchronization and coordination of all operations so that the entire organization functions as a unit. Absolute perfection in all details is probably impossible. Nevertheless, extensive studies on a large number of projects operated under a great variety of conditions show conclusively that (1) a high degree of efficiency is possible of attainment, and (2) that, in general, the low production found on many projects is due to conditions over which the management has some control and which are therefore to some extent remediable.

CHARACTER OF MATERIAL AFFECTS SIZE OF DIPPER LOAD

Under conditions to which each shovel size is adapted, shovels of all the sizes usually found in highway work can be operated at approximately the same cycle speed. In general, data for one size can be applied to any other size—at least within the range of shovels with capacities of from 5/8 to 2 cubic yards. In making such comparisons we must remember, however, to extend data only to similar working conditions for each of the respective shovel sizes. Rock which would class as well blasted for a 2-yard shovel might readily grade as poorly blasted for a smaller shovel. Well-blasted material should have very few pieces with any dimension much greater than about half the smallest inside dimension of the bucket. A large shovel may work readily in material which a small shovel could handle only with difficulty.

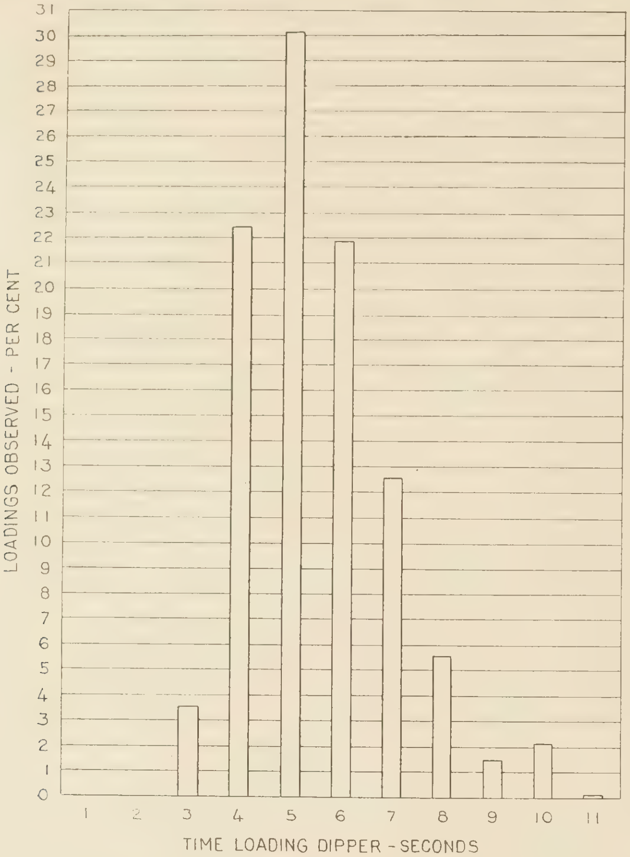


FIGURE 1.—ANALYSIS OF TIME STUDY OF 1,518 DIPPER LOADINGS. AVERAGE LOADING TIME, 5.5 SECONDS.

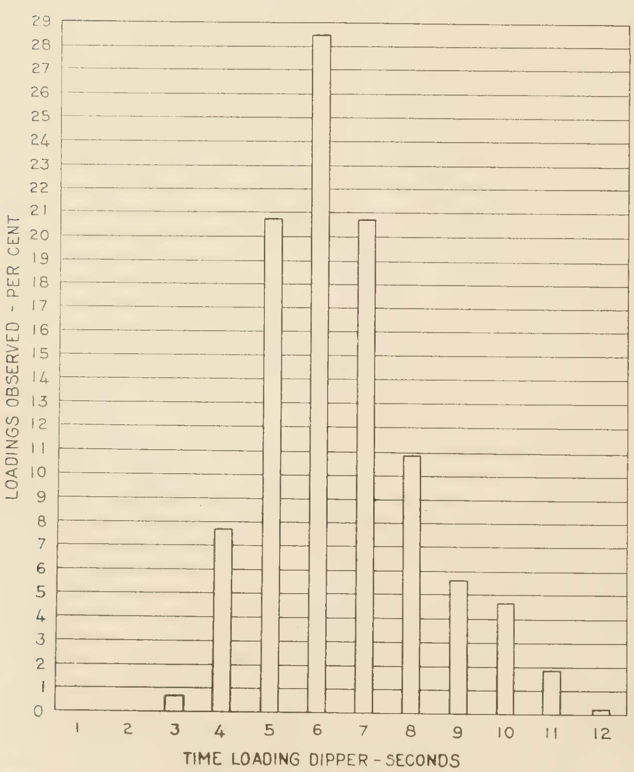


FIGURE 2.—ANALYSIS OF TIME STUDY OF 1,667 DIPPER LOADINGS. AVERAGE LOADING TIME, 6.4 SECONDS.

FIGURE 3.—DIAGRAM SHOWING PERCENTAGE OF LOADING OPERATIONS PERFORMED IN VARIOUS TIME INTERVALS. BASED ON 734 LOADINGS OF $1\frac{1}{8}$-YARD SHOVEL WORKING IN $2\frac{1}{2}$ TO 7 FEET OF CLAY WITH A FEW BOULDERS.

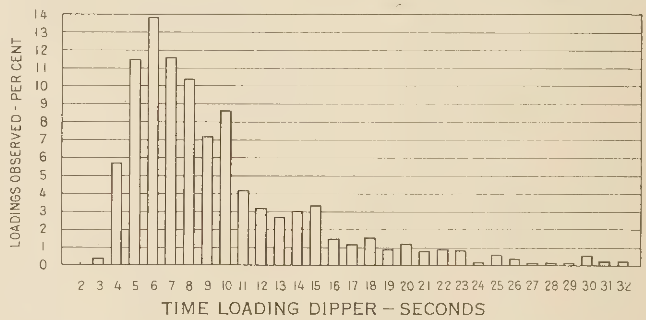


FIGURE 4.—DIAGRAM SHOWING PERCENTAGE OF LOADING OPERATIONS PERFORMED IN VARIOUS TIME INTERVALS. BASED ON 1,058 LOADINGS (18 WERE OVER 32 SECONDS) OF A $\frac{3}{4}$-YARD DIPPER WORKING IN 1 TO 5 FEET OF STICKY CLAY. AVERAGE TIME 10.29 SECONDS.

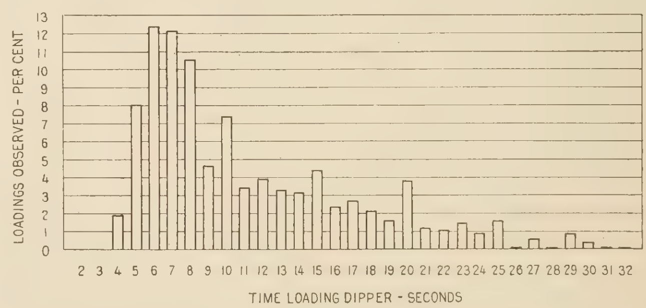


FIGURE 5.—DIAGRAM SHOWING PERCENTAGE OF LOADING OPERATIONS PERFORMED IN VARIOUS TIME INTERVALS. BASED ON 658 LOADINGS (16 WERE OVER 32 SECONDS) OF A $\frac{3}{4}$-YARD SHOVEL WORKING IN 2 TO 6 FEET OF STICKY CLAY. AVERAGE TIME, 12.2 SECONDS.

Output is the product of dipper loads and the average yardage per load. A good operator can combine speed and high average quantity of material per dipper load. In ordinary common excavation three or more feet in depth, the average dipper load in terms of cubic yards of material, as measured in place, may be expected to average about as shown in table 1.

In some materials which heap up in the dipper and do not spill on the swing, the average load will sometimes equal the rated capacity. In poorly blasted rock or shale or in materials full of roots and stumps, the aver-

TABLE 1.—*Average yardage per dipper load for different dipper sizes*

Size of dipper (rated capacity)	Material per dipper load
Cubic yards	*Cubic yards*
¾	0.50
1	.68
1¼	.88
1½	1.10

age dipper load may be 40 percent less than the average for ordinary common excavation or about 0.3 cubic yard for a ¾-yard dipper and 0.65 cubic yard for a 1½-yard dipper. Figures 1 to 5 and tables 7, 9, 10 and 11 are illustrative of the studies made, and show the rates at which dipper loads can be deposited in the hauling units with fast operation, and how a few operations increase the average time per cycle for the entire period. As the material changes from good common to other classifications, the digging and loading become slower and there is greater difficulty in obtaining a full dipper.

During the studies on which these articles are based many determinations were made as to the number of dipper loads and the quantity of material moved under various conditions. Quantities were usually determined by careful cross-sectioning and are believed to include sufficient volume and variety to represent a fair average of the more usual conditions met with in highway grading work. Table 2 gives the results obtained on a considerable number of jobs and illustrates how the size of the dipper load may vary from time to time and from job to job. The average dipper load of a so-called "¾-yard dipper", having a capacity of approximately three-fourths of a cubic yard when struck in line with the top of the teeth and the top of the rear edge, may vary from 0.3 to 0.8 cubic yard, depending on the material and the skill of the operator. In fair to good common excavation with few roots and boulders, a good operator working under favorable conditions should move an average of 0.5 to 0.6 cubic yard per dipper load. In poorly blasted rock or shale, very rooty and stumpy soils, and in certain tough, moist clays, the average load may be only 0.3 to 0.35 cubic yard or even less in exceptional cases. The average dipper load is also likely to be low in shallow cuts. The same is true of materials which bulk considerably when broken up or which lack cohesion and will not heap up in the dipper.

TIME OF LOADING GREATLY INCREASED IN DIFFICULT MATERIAL

The material itself is responsible for much slow digging. Cuts usually classed as common excavation but which contain many medium-sized or large rocks embedded in stiff clay are particularly troublesome. The shovel operator cannot see such rocks until they are exposed, and when the dipper strikes one it may be necessary to draw back and try again. Often two or three passes, sometimes more, are made before either a load of loose material is obtained or the position of the rock defined so that it can be picked up.

Tables 3, 4, and 5 show the effect of the character of the material on the time required for filling the dipper. The tables do not all show the quantities moved per dipper load; but, in general, fast operation in good material is accompanied by large dipper loads. The size of the dipper load decreases with an increase in the difficulty of loading, and this decrease is at a somewhat faster rate than is indicated by the time factor.

MATERIAL TOO HARD TO DIG READILY WITHOUT BLASTING.

TABLE 2.—*Average size of dipper load under various conditions*

Type of shovel	Rated capacity of dipper	Character of material	Dipper loads handled	Average load per dipper
	Cubic yards		*Number*	*Cubic yard*
Steam	¾	Light moist clay, free from roots and stones	147	0.39
Do	¾	do	223	.51
Do	¾	do	170	.50
Do	¾	Light moist clay, with some shale	148	.44
Do	¾	Loamy clay, with 25 percent loose rock	50	.48
Do	¾	do	156	.40
Do	¾	Sand-clay	82	.60
Do	¾	do	150	.62
Do	¾	Loamy to hard clay	85	.58
Do	¾	Loamy to sandy clay	141	.35
Do	¾	Loamy to clay	157	.38
Do	¾	do	72	.53
Do	¾	Gneiss-granite, poorly blasted	2,960	.33
Do	¾	Wet, sticky clay, with a few stumps	1,745	.67
Do	¾	Moist to wet sand-clay	1,825	.80
Do	¾	Sandstone, well blasted	632	.35
Do	¾	do	2,599	.43
Do	¾	Moist clay, with a few small surface boulders	794	.65
Do	¾	Very wet clay	990	.59
Do	¾	Wet clay, with small stumps	210	.48
Do	¾	Sandy gravel, with some hard chunks of shale	4,099	.41
Do	¾	Dry loamy clay	309	.53
Do	¾	do	71	.41
Do	⅞	Granite-gneiss, poorly blasted	3,340	.40
Gas	¾	Loamy clay, moist, with a few roots	583	.61
Do	1⅛	Sandstone, blasted	3,448	.53
Do	1⅛	Dry clay, with a few boulders	2,892	.53
Do	1½	Dry clay, with surface boulders	996	.64
Do	1⅛	70 percent large boulders and 30 percent dry clay	667	.57
Do	1⅛	10 percent dry clay, 20 percent loose rock, 70 percent solid rock, blasted.	4,384	.63
Do	1⅛	Wet sticky clay, with a few surface boulders	2,396	.57
Do	1⅛	20 percent dry clay, with 80 percent sandstone, well blasted.	784	.60
Steam	¾	Sandy clay and clay loam, with some stone	3,504	.44
Gas	¾	80 percent sandstone, poorly blasted, with 20 percent clay.	788	.46
Do	¾	do	6,646	.46
Do	1¼	Mostly earth, with about 25 percent fair to poorly blasted granite.	10,254	.88
Do	1¼	About 75 percent in poorly blasted granite	4,485	.61
Do	1¼	Mostly shallow earth cuts with many boulders, some poorly blasted rock	8,778	.68
Do	1¼	Mostly poorly blasted rock and shale	39,600	.62
Do	1½	do	29,860	.70
Do	1½	Fairly well blasted rock and shale	53,740	.85
Do	1¼	do	88,600	.74
Do	1¼	Deep cuts of well blasted shale and sandstone	78,300	.80
Do	1¼	do	58,000	.87
Do	1¼	Good common	9,110	.88
Do	1¼	Good common, fairly deep cuts	14,800	.99
Do	1¼	do	18,060	1.00

Large Boulders Are Hard on Equipment and Decrease the Rate of Production. They Should Be Reduced by Blasting.

Figures 1 to 7 show graphically the number of dipper loadings performed in different time intervals on different jobs.

Table 3.—*Effect of character of material on time required to load and dump dipper*

Character of material	Observations	Time to dump dipper	Time to load dipper
	Number	*Seconds*	*Seconds*
Loam and light clay	722	1.0	4.2
Do	351	1.5	5.4
Loamy clay and soft shale	254	1.9	5.4
Soft shale	399	4.2	6.5
Sandy clay	249	3.0	7.4
Moist clay	96	2.4	8.0
Light clay, wet and gummy	173	4.6	8.1
Clay and surface loam	692	1.9	8.4
Sandy clay, moist to wet	349	4.8	8.8
Well blasted sandstone with 20 percent light clay	229	1.8	9.3
Clay with a few boulders	448	2.1	10.0
Heavy clay, wet and gummy	271	5.3	10.4
Clay with some surface boulders	2,892	1.8	10.5
Loam with loose rock and loose shale	369	2.8	10.5
Do	288	2.4	11.8
Clay-gravel	506	1.7	11.8
Heavy clay, wet and sticky	83	6.0	12.0
Seventy-five percent loose shale with 25 percent clay	579	3.2	12.4
Heavy clay with a few boulders	101	2.0	12.5
Wet clay with some stumps	105	3.2	12.8
Loam with 30 percent loose rock	148	2.1	13.5
Rock, well blasted	183	3.4	13.9
Do	560	4.2	15.1
Hard shale, well blasted	1,434	2.6	16.4
Gneiss, poorly blasted	550	10.7	18.5
Fifty percent loose rock with 50 percent unblasted shale rock	338		28.0

CONDITIONS JUSTIFYING MORE THAN ONE PASS OF DIPPER ANALYZED

In general, operating speed should not be obtained at the sacrifice of size of dipper load. To sacrifice, say, 10 percent of the dipper load to increase the number of dippers by 10 percent results in a loss of amount of material dug and it frequently results, also, in smaller loads for the hauling units. The value of making additional passes to obtain a larger dipper load is dependent on the amount of material which such passes will add to the dipper load and the speed at which the shovel is operating. If a ¾-yard shovel is operating in fairly good common excavation in which the average dipper load is 0.5 cubic yard of material as measured in place, and the average operating cycle is 20 seconds, then production is at an average rate of 0.025 cubic yard per second. If a second pass to fill an occasional dipper is to be profitable, it must increase the dipper load at least at this rate, during time required to make the extra pass. If 6 seconds are required to make an

Table 4.—*Effect of material on time required to load a ¾-yard dipper as indicated by one-hour stop-watch studies with same operator throughout on each shovel*

SHOVEL NO. 1

Kind and character of material	Time to load dipper	Height of face
	Seconds	*Feet*
Light sandy loam, free from roots and stones	3.3	10.0
Do	3.3	7.0
Loamy clay, free from roots and stones	4.5	6.5
Do	4.7	6.0
Do	4.8	10.0
Light clay and loam top soil, no roots or stones	4.9	2.0
Light clay with small amount of soft shale	5.0	5.0
Loam	5.3	5.0
Light clay, free from roots and stones	5.6	10.0
Light clay with small amount of shale	5.7	10.0
Do	5.8	4.0
Light clay with increasing amount of shale	5.9	7.0
Loamy clay, with some roots	6.0	6.5
Ordinary clay, free from roots and stones	6.2	4.5
Loamy clay	6.5	0.3–1.5
Light clay and soft shale	6.6	8.0
Loamy clay with loose rock in old roadbed	8.2	2.0
Clay with 50 percent loose shale	10.7	6.5
Hard clay with loose rock in old roadbed	15.9	0.25–2.5
Hard clay with loose rock	16.3	2.0

SHOVEL NO. 2

Kind and character of material	Time to load dipper	Height of face
Light, loamy clay, no stones or roots	5.2	5.5
Do	5.3	4.0
Light clay, free from stones or roots	5.7	4.0
Light clay, practically free from roots and stones	6.0	3.5
Light clay with old hard roadbed on one side	6.7	6.0
Do	6.9	4.0
Light to medium clay	7.5	4.5
Clay and soft shale	8.2	2.0
Light clay with small amount of rock, side hill cut	9.2	0–4.0
Clay and soft shale	9.4	7.0
Sandstone, soft enough to crumble in hand	11.0	11.0

Table 5.—*Effect of material on average time required to load dipper. Number of 1-hour studies during which the dipper was loaded from the class of material indicated in the time shown in the first column*

Average time to load dipper (seconds)	Loam, loamy, sandy, gravelly or friable materials, practically free from roots, boulders, etc.	Ordinary clays and ordinary soils, with few roots or rocks, etc.	Fairly hard or tough clays, ordinary clay with some loose rock, shale, etc.	Mixtures of clay and loose rock, soft shale, and hard and tough clays, etc.	Well-blasted rock, shale, etc.	Poorly blasted rock, large rock and boulders, hard or tough clay with many rocks, etc.	Clay-gravel in 6- to 9-foot cuts, with 2 feet of hard frost on surface	Very poorly blasted rock or shale
3 to 4	1							
4 to 5	7							
5 to 6	20	5						
6 to 7	10	20			6			
7 to 8		12	30		23			
8 to 9		5	11	12	27			
9 to 10			13	16	6			
10 to 11			26	16	2			
11 to 12				21	4			
12 to 13				11	9	7		
13 to 14				7	5	14	3	
14 to 15					9	11	2	
15 to 16					3	4	1	
16 to 17					2	7	1	
17 to 18						10		1
18 to 19						7	4	
19 to 20						6		3
20 to 22						1	2	9
22 to 24								3
24 to 26							1	7
26 to 28								4
28 to 30								1
30 to 35								
35 to 40								2
Average time of loading in seconds	5.5	6.7	8.9	10.9	9.9	15.8	17.4	23.9

extra pass it is not warranted unless 0.15 cubic yard can be added to the load.

The less the time of loading the dipper as compared with the time of the entire cycle, the greater is the importance of obtaining a full dipper. Consequently, it is more important to try for a full dipper when the swing is long than when it is short.

The relation between size of dipper load, length of shovel cycle, and time required to make an additional pass with the dipper may be shown as follows:

Let

C = shovel cycle, in seconds, when only one pass is made with dipper.

W = dipper load, in cubic yards, when only one pass is made with dipper.

Q = percentage by which dipper load is increased by each additional pass of the dipper.

P = time, in seconds, required for making each additional pass with dipper.

Then

$\frac{W}{C}$ = rate of production when using only one pass of the dipper.

and $\frac{W+XQW}{C+XP}$ = rate of production when using X passes.

$\frac{W+XQW}{C+XP}-\frac{W}{C}$ = increase in the rate of operation over that of using only one pass.

So long as CQ is greater than P, additional passes of the dipper will result in increased production.

For example, an operator working on a 20-second cycle occasionally finds that the 1¼-yard dipper, with which he usually obtains 0.9 cubic yard per dipper load, is only about two-thirds filled by the first pass. He has found that it requires 6 seconds to make each additional pass. Would it pay to make one or more additional passes to obtain the usual dipper load of 0.9 cubic yard? The solution is as follows:

The load in the dipper from one pass is 0.6 cubic yard. To obtain 0.9 cubic yard an increase of 50 percent is necessary, and $20\times0.50=10$ seconds. Since each pass can be made in 6 seconds, a distinct gain will be registered if the dipper can be filled to normal in one additional pass, but a loss will result if two passes are used to obtain the normal load. Since the cycle is 20 seconds, and the time required to make the additional pass is 6 seconds, the additional pass will be justified if a partial load can be increased by 6/20, or 30 percent.

If the normal cycle were 25 seconds, then even two additional passes at 6 seconds each to obtain the normal load would register a definite gain. Additional passes would be advantageous so long as each pass increased the part-load by 24 percent. This discussion also demonstrates the greater importance of securing a full dipper load when the swing is long, as the longer the swing the longer the operating cycle. Table 6 shows readings of the time required to make additional passes and the extent to which such extra passes may be expected to increase the average loading time for the dipper.

Several instances have been observed in which contractors in an effort to increase the yardage per dipper load have replaced regular ¾-yard dippers with 1¼-yard dippers. This proved a decided handicap to production, except in extremely soft and easy digging, as the power of the shovel was insufficient to force the large dipper through the material at normal loading speed. In addition to decreased normal production, time losses due to breakage and repairs were high. A dipper larger than that for which the shovel was designed is not recommended.

Table 6.—*Effect of multiple passes on time of loading dipper*

TIME REQUIRED IN MAKING MULTIPLE PASSES IN LOADING A MOIST TO WET GRAVELLY CLAY

Number of passes	Number of observations	Average time per dipper load
		Seconds
1	1,332	7.2
2	298	14.1
3	82	21.2
4	32	27.6
Total and average	1,744	9.4

NUMBER OF PASSES REQUIRED WHEN WORKING IN FAIR TO GOOD COMMON EXCAVATION. MOSTLY SHALLOW CUTS. ⅞-YARD SHOVEL IN GOOD CONDITION

Number of passes	Time required to load dipper	Percentage of dipper loads secured in this way
	Seconds	*Percent*
1	6.4	61.4
2	13.0	20.0
3	18.9	13.7
4	25.4	3.8
5	31.2	1.0
6	38.0	0.1

It has been pointed out that the time required to load the dipper often varies considerably from the average. The manner of this variation and its extent are shown in figures 1 to 7 and in various tables. Each of the graphs shown covers a considerable number of observations and shows the number of times the dipper was loaded in any given number of seconds. It is clear that a few of the loading times took very much longer than the others and that the effect was to increase the average loading time materially.

Figure 1 is based on a job in earth and well-blasted shale where the shovel performance was excellent. A comparatively large number of dipper loads required only 4 seconds each. The average loading time was 5.5 seconds, and there were only a few dipper loads which required much time, none over 11 seconds—an indication that a good, consistent operator was handling the shovel.

Figures 1 and 6 show results obtained on jobs with good, consistent operation. Figure 5 shows time of loading dipper in tough and somewhat sticky clay in which it was hard to pick up a full load. In about 50 percent of the observations on this job, one pass of the dipper was made in an average of less than 7 seconds. In the remaining cases, 2 or 3, or even 4, passes were made to fill the dipper to the satisfaction of the shovel runner. Occasionally the time of filling the dipper was as much as a full minute. The average time of filling the dipper on this job was 12.2 seconds.

Figure 7 illustrates the loading time of a rather indifferent operator. Although working in light loam soil, his average loading time was 16.5 seconds, more than double what it should have been.

INSUFFICIENT BLASTING FOUND ON MANY PROJECTS

There is a rather general tendency among grading contractors to do too little blasting, as well as to slight the clearing and grubbing. Poor blasting usually

Improper Spacing and Loading of Drill Holes Resulted in Material Hard to Load.

Same Rock Ledge as Above, Well Broken by Proper Blasting.

Appearance of Ground After a Satisfactory Blast. Material Well Broken but Not Scattered.

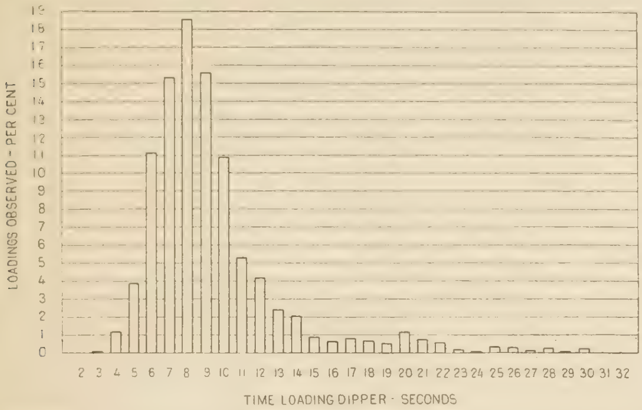


Figure 6.—Diagram Showing Percentage of Loading Operations Performed in Various Time Intervals. Based on 1,322 Loadings (15 Were Over 32 Seconds) of a 1⅛-Yard Dipper Working in 1½ to 5 Feet of Clay and Loam with a Few Boulders. Average Time, 9.67 Seconds.

Figure 7.—Diagram Showing Percentage of Loading Operations Performed in Various Time Intervals. Based on 763 Loadings (21 Were Over 32 Seconds) of a ¾-Yard Dipper Working in 1 to 4½ Feet of Light Loam. Average Time, 16.5 Seconds.

means the presence of large rocks and also very frequently some tight or even unbroken ground. Large rocks, tight ground, large roots and stumps can be handled only with difficulty and at a slow rate. Further delays are often imposed on the shovel while large rocks are being "bulldozed" or while unbroken ground is being reblasted.

When blasting has been so thorough that the largest dimensions of the larger pieces do not exceed one-half of the smallest inside dimension of the dipper, the rate of operation can be practically the same as in good to fair common earth. The increase in the amount of material moved per dipper load with improved blasting is striking, especially with the smaller shovels. In poorly blasted rock, the average dipper load for a ¾-yard shovel is not likely to exceed 0.3 cubic yard and may readily be as low as 0.25 cubic yard, while in well-blasted rock the same shovel will generally average about 0.45 cubic yard per dipper load, or about 50 percent more material than in poorly blasted materials.

In poorly blasted material there is not only a large reduction in the amount of material handled by each dipper load but there is also a decided decrease in the rate at which the shovel can be operated. Poor blasting, consequently, is a serious handicap to production. Table 12 illustrates the increase in production which can sometimes be obtained by comparatively light blasting. In this case the material was hard caliche which the 1-yard shovel could move at the rate of only 64 cubic yards per hour before it was blasted. After blasting, the same shovel moved the material at the rate of 151 cubic yards an hour. The net gain to the contractor after paying the cost of drilling and blasting was about 7½ cents per cubic yard in addition to the saving in wear and tear on his shovel.

It will generally pay to blast material which is too hard to dig readily with the shovel. In hard rock thorough blasting is a prerequisite to efficient shovel operation. Examples of the effect of poor blasting on production rates are given in tables 5, 11, and 12.[1]

BEST POSITION FOR SHOVEL DEPENDS ON HEIGHT OF CUT

The position of the shovel with reference to the face of cut is often responsible for the repeated passes some shovel operators make to fill the dipper. Aside from the swing, the dipper is actuated by two separate and distinct motions: One, known as the "hoist", tends to raise the dipper in a vertical circle about the point of intersection of the boom and the dipper stick, while the other, known as the "crowd", controls the radius of the arc in which the "hoist" moves the dipper. The "crowd" is used to force the dipper against the face of the cut, and on the swing to spot the dipper correctly over the hauling unit. When the dipper stick is vertical, the combined motion of the "crowd" and the "hoist" can drive the cutting edge of the dipper almost straight forward several feet. When the dipper stick is horizontal, the "crowd" holds the cutting edge of the dipper hard into the bank.

When loading a dipper in a bank less than 2 feet high, a direct forward thrust of the cutting edge into the bank is required. While on a bank 6 or more feet high the loading is generally best done by a longer swinging motion in which a slice is cut from the bank. For some reason it appears to be difficult to find operators who work equally well in both shallow and deep cuts. The shovel should stand close to a low bank with the boom somewhat lower than normal and must be moved forward frequently. This is because the forward thrust of the dipper resulting from the proper combination of "hoist" and the "crowd" only reaches a relatively short distance. Most of the cutting from a high bank is best done after the dipper has begun to turn upward in its swing. This requires the shovel to stand somewhat back from the bank with the boom relatively high. The superintendent who will drill his shovel operators in the proper placing of the shovel for effective dipper-loading should find the results gratifying.

If there is any considerable amount of shallow cutting, the contractor may well consider the advisability of using some other method than operation of a power shovel to move that portion of the work. Various kinds of scrapers, and in very rough country even bulldozers, are frequently used to good advantage in conjunction with the shovel, first, to move short-haul material and make shallow cuts, and, second, to help the blade grader trim the cuts to exact grade after the shovel has passed through.

MOVING SHOVEL CONSUMES MUCH TIME

The time spent in moving the shovel forward within a cut varies somewhat inversely as the depth of the cut. In shallow cuts careful attention must be given to the time required to make each forward move of the shovel. Table 7 gives a few observations of the time required for individual moves of two 1¼-yard shovels working in earth and in well-blasted shale and schist. It will be noted that the time required for each move varies considerably under different conditions. The average time required to move the shovel which was in good condition was only half of that required to move the shovel in poor condition.

[1] For more definite data on this question the reader is referred to Some Studies of Drilling and Blasting in Highway Grading, published in Public Roads, February 1932.

TABLE 7.—*Length of time, in seconds, required to move shovel forward in cut*

1¼-YARD SHOVEL, IN GOOD CONDITION, WORKING IN COMMON EXCAVATION

Seconds	Seconds	Seconds	Seconds	Seconds	Seconds	Seconds	Seconds
21	22	10	13	11	12	14	12
12	10	11	10	14	33	13	12
11	11	15	31	11	10	12	14
12	12	16	24	15	10	10	13
12	10	20	13	10	22	35	14
15	11	11	12	11	11	25	14
17	12	18	9	11	14	11	16
9	10	10	11	27	28	10	11
12	17	13	12	41	15	12	14

Average time per move, 14.8 seconds.

1¼-YARD SHOVEL, IN POOR CONDITION, WORKING IN WELL BLASTED SHALE AND EARTH

Seconds	Seconds	Seconds	Seconds	Seconds	Seconds	Seconds	Seconds	Seconds	Seconds
35	27	28	28	15	34	35	40	26	32
46	28	22	10	21	41	48	26	33	26
33	28	39	38	37	41	44	21	26	30
50	22	23	35	14	30	45	40	20	27
37	23	35	51	16	34	31	45	34	31
41	32	26	54	17	26	31	82	45	16
42	20	30	31	40	13	23	54	31	23
36	25	29	28	58	34	61	81	25	28

Average time per move, 33.3 seconds.

TABLE 8.—*Time consumed in moving 1¼-yard shovels forward in cuts of different depths and on different jobs*

[Each entry is result of 1 or more hours of stop-watch study]

Job no. 1		Job no. 2		Job no. 1		Job no. 2	
Depth of cut	Working time consumed in moving forward	Depth of cut	Working time consumed in moving forward	Depth of cut	Working time consumed in moving forward	Depth of cut	Working time consumed in moving forward
Feet	*Percent*	*Feet*	*Percent*	*Feet*	*Percent*	*Feet*	*Percent*
14	2.5	12	1.7	6	3.9	6	[1] 5.9
12	4.0	10	1.2	5	3.4	6	[1] 6.2
11	1.3	10	1.7	3	[2] 12.8	4	4.0
10	1.3	8	3.1	2½	6.8	2	8.3
9	3.8	7	3.1	2	5.3	--------	--------
8	2.0	6	2.4	1	10.3		
7	2.7	6	4.0				

[Each entry is average time consumed throughout job]

On jobs mainly involving deep cuts	On jobs mainly involving shallow cuts	On jobs mainly involving deep cuts	On jobs mainly involving shallow cuts
Percent	*Percent*	*Percent*	*Percent*
[3] 6.0	10.0	3.3	7.0
[3] 5.2	9.9	3.4	6.1
[3] 5.4	8.4	2.1	4.3
4.8	8.4	1.7	3.9
3.9	7.2		

[1] Shovel operating in a cut composed mostly of fine, dry sand.
[2] Slippery clay, difficult moving.
[3] Mostly rock work and many steep grades.

The moving time is affected by grade, soft or rough ground, condition of the moving mechanism, and ability of the operator. This is brought out more fully in tables 8 and 9. In general, the modern crawler-type shovel in good condition can be moved forward in about 15 seconds. If, under ordinary operating conditions, the average time required per move is more than 30 seconds, either the operator is unduly slow or the mechanism is in need of attention. The larger the shovel and the higher the rate of production, the more time will be required to move the shovel forward.

TABLE 9.—*Working time lost by shovel in moving within cuts, because of shortage of hauling equipment, and total from all causes*

[Each line represents a different job]

Moving within cuts	Shortage of hauling equipment	Total minor time losses from all causes	Moving within cuts	Shortage of hauling equipment	Total minor time losses from all causes
Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
9.9	9.8	54.6	5.7	3.2	33.1
9.2	12.3	50.8	5.5	5.3	30.9
5.8	2.4	45.8	4.9	0.6	27.8
7.3	18.3	43.0	5.0	6.3	25.0
4.1	17.1	42.5	2.9	1.5	22.8
4.6	8.5	42.2	3.1	11.4	22.7
6.6	10.4	39.0	7.3	3.9	22.7
3.4	4.7	35.0	0.9	3.4	19.0
2.7	16.7	34.6	1.8	3.8	18.8
5.0	6.3	33.9	3.1	3.1	17.4
3.5	2.0	33.7			

The movement of the shovel within the cut to keep within easy reach of the face is a check on production which cannot be removed entirely. The best that can be done is to train the operator to make the moves as expeditiously as possible. In deep cuts the time required is small—sometimes little more than 1 percent (table 8). In shallow cuts the proportion mounts rapidly and cases where from 8 to 10 percent of the total time is used in moving the shovel are not uncommon, especially where the operator is slow or the mechanism in poor condition.

Because of generally insufficient hauling equipment, it has become a more or less accepted practice to consider the time required for moving the shovel as of no importance, since it can usually be done while waiting for wagons or trucks. This may seem like a good way of neutralizing an inherent shortcoming of the shovel, but it is one which absorbs profits which might otherwise be had from the job.

Moving shovel within the cuts consumes about 5 percent of the actual working time (table 9) and forms about 15 percent of the total minor time loss. Table 9 shows that the statement that moving the shovel is generally done while waiting for hauling equipment is not well founded. The 7 jobs with the highest waiting time for hauling units lost 6.1 percent of their working time in moving the shovel, while the 7 jobs with the lowest time loss from waiting for hauling units required 3.8 percent of the working time for moving the shovel. The 7 jobs having the highest moving time used 6.8 percent of the time, while the 7 lowest used 3.4 percent.

ANGLE OF SWING GREATLY AFFECTS RATE OF PRODUCTION

When the dipper is loaded, the operator swings the shovel through the angle necessary to bring the dipper over the hauling unit, at the same time adjusting the height and reach of the dipper, dumps the load and returns the dipper for another load. Figures 8 to 11 show the time required to swing and return the dipper through various angles on four jobs. The time required to complete a swing and return movement does not depend entirely upon the angle through which the movement is made. Time is required for the operator to react and start the mechanism. The mechanism requires time to function, while still more time is required to accelerate, and at the end of the swing to decelerate, the large mass of the load and shovel. The time actually required to get a swing under way and later stopped varies with the operator, the load, type of shovel, and its mechanical condition. With some operators and under some conditions this

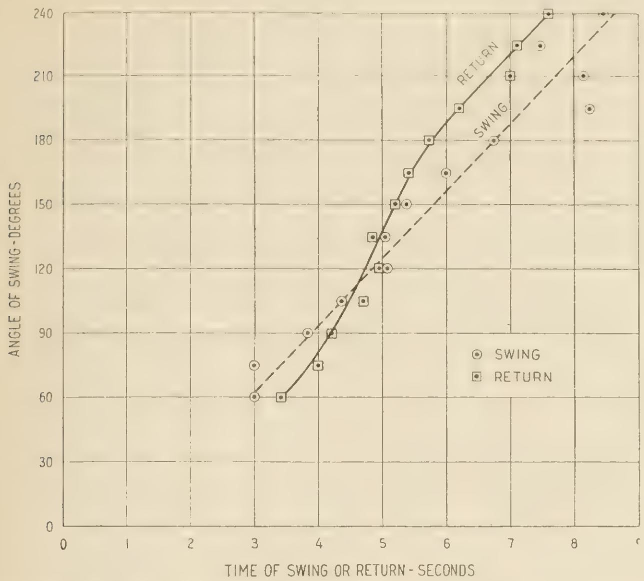


FIGURE 8.—INFLUENCE OF ANGLE OF SWING ON TIME OF SWING AND RETURN BASED ON 506 OPERATIONS OF A ¾-YARD SHOVEL HANDLING POORLY BLASTED ROCK. NOTE THAT THE POINTS LOCATED FOR TIME OF SWING ARE MUCH MORE IRREGULAR THAN THOSE FOR TIME OF RETURN. THIS IS EXPLAINED IN PART BY THE EXTRA CARE REQUIRED IN HANDLING BOULDERS. AVERAGE RATE OF SWING, 32° PER SECOND. AVERAGE RATE OF RETURN, 46° PER SECOND.

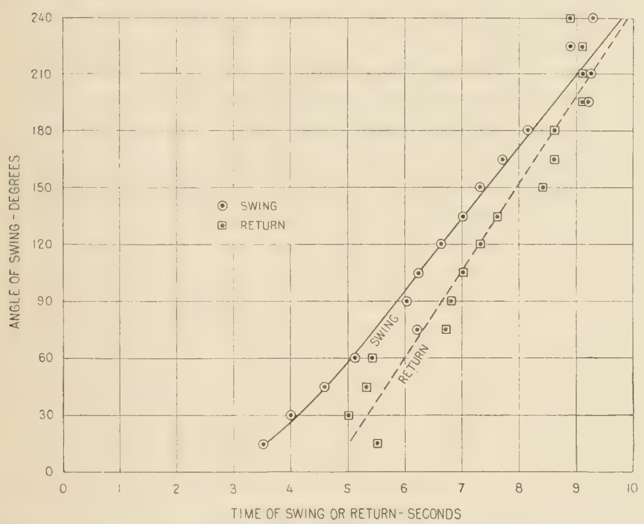


FIGURE 9.—INFLUENCE OF ANGLE OF SWING ON TIME OF SWING AND RETURN BASED ON 2,069 OPERATIONS OF A ¾-YARD SHOVEL WORKING IN CLAYEY GRAVEL. AVERAGE RATE OF SWING, 37.5° PER SECOND. AVERAGE RATE OF RETURN, 46° PER SECOND.

time may be as much as 3 or 4 seconds and is rarely less than 1 second.

The return swing involves much the same process as the loaded swing, except that the dipper, instead of simply being stopped at the completion of the swing, must also be lowered into position for beginning a new cycle. It appears that some shovels with slow swing speed have quick starting and stopping, so that the time required for the swing and return, as shown in table 10, is often as short as, or shorter than, for the slow-speed types so long as the angle of swing is small. On longer swings, the higher speed types are considerably faster.

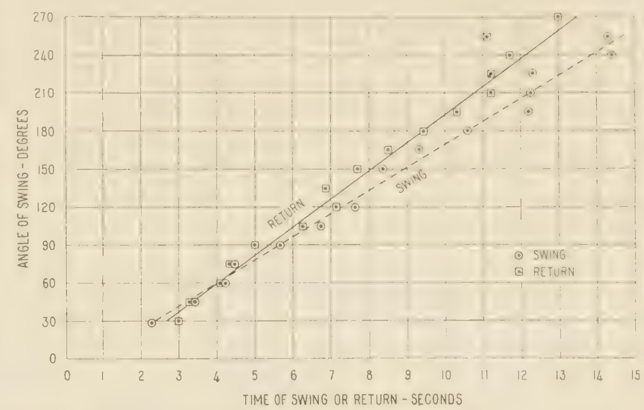


FIGURE 10.—INFLUENCE OF ANGLE OF SWING ON TIME OF SWING AND RETURN BASED ON 1,788 OPERATIONS OF A ¾-YARD SHOVEL WORKING IN GRAVEL AND LOOSE AND BLASTED SHALE. AVERAGE RATE OF SWING, 18° PER SECOND. AVERAGE RATE OF RETURN, 22° PER SECOND.

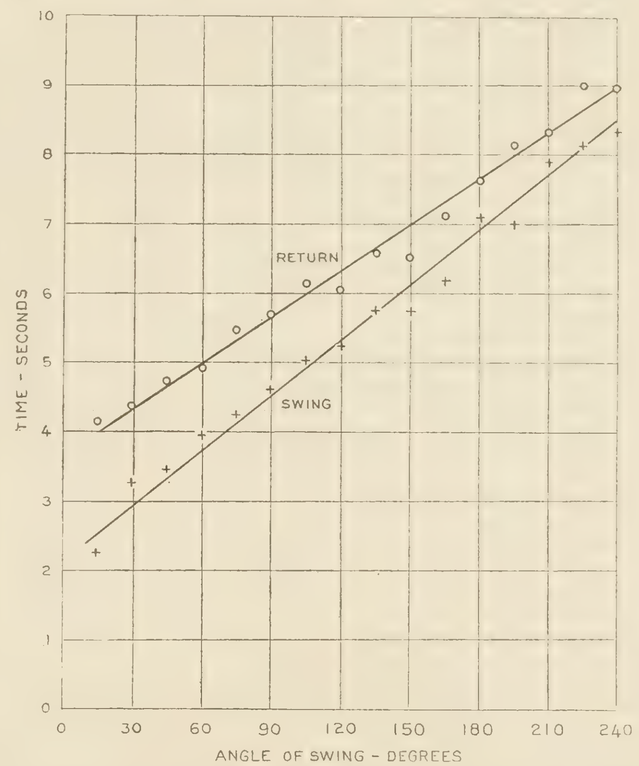
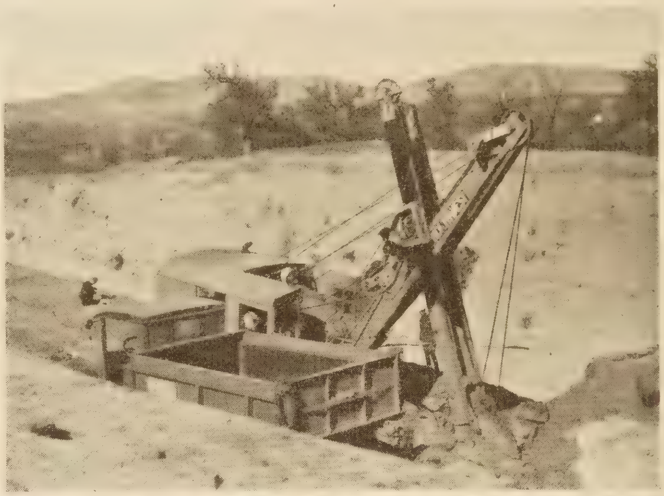


FIGURE 11.—RELATION BETWEEN ANGLE OF SWING AND TIME OF SWING AND RETURN. ⅞-YARD SHOVEL IN GOOD CONDITION.

TABLE 10.—*Comparison of combined swing and return time for various types of power shovels*

[Values are averages from a large number of field studies under actual operating conditions]

Angle of swing	Shovels			
	No. 1	No. 2	No. 3	No. 4
	Seconds	*Seconds*	*Seconds*	*Seconds*
30°	8.2	8.0	8.2	5.7
60°	10.4	9.0	9.9	8.4
90°	12.5	10.0	11.5	11.2
120°	14.6	11.0	13.2	13.9
180°	19.0	12.9	16.5	19.3
240°	23.4	14.9	19.8	24.8
270°	25.5	15.9	21.5	27.5

Examples of Correct "Spotting" of Trucks for Loading with Short Swing of Shovel.

The portion of the swing and return time required for the operator to actuate the controls and for the machine to accelerate and decelerate is designated as "lag." It is difficult to separate the "lag" into personal and mechanical components but the studies show that the personal time element is sufficiently large to warrant careful consideration because of its effect on the rate of production. For a good operator the reaction lags are small—generally not more than 1 second. For a slow operator they may run 2 seconds or even more. The difference of 1 or 2 seconds seems a trifling matter, but an operator who takes 18 seconds where only 15 are necessary, reduces the rate of production almost 17 percent. To change an operator making a load every 18 seconds for a man who takes 20 seconds reduces the rate of output about 10 percent. With efficient operation otherwise, this can easily reduce the value of the output from $20 to $25 a day—about twice the ordinary wage of a first-class operator. It never pays to hire cheap, poorly trained operators on any work requiring fast, uniform, consistent operation, and nowhere in highway work is this more true than on power shovels.

In good common excavation and under favorable conditions, a 90° swing (loading at the side of the shovel) can be performed in 15 seconds. An extension of the swing to 180° (loading back of the shovel) ordinarily increases the cycle by from 4 to 8 seconds, depending on the type of shovel used and the skill of the operator. As a general average it may be said that loading behind the shovel instead of at the side extends a 15-second cycle to at least 20 seconds and thereby reduces the attainable rate of output 25 percent. There is, of course, much work where loading at the side of the shovel is impossible. However, there are many more situations where side loading is practicable but is not employed.

Extending the average swing to 270° is the worst possible practice, especially with a slow-swing shovel. This extends a normal 15-second cycle to 25 seconds or more and correspondingly reduces the rate of output. Such operation may be caused by a cab arrangement that makes it hard for the operator to see out of one side. To avoid swinging the dipper over objects he cannot see clearly and thus running the risk of accidents, the longer swing is sometimes used. Poor vision also interferes with spotting the dipper exactly before dropping the load. Hauling units are usually placed for swings over the side or rear of the vehicles. This is important if rock is being handled. A good operator seldom drops any material, but a relatively small rock may seriously injure a man or an animal. Every effort should be made to keep the average swing from exceeding 90°, and, in general, a swing of over 180° is the result of improper equipment or of faulty operating methods.

Figures 12 and 13 show the average time used in loading, swinging, dumping, and returning the dipper on jobs where the swings ranged from 45° to 90°.

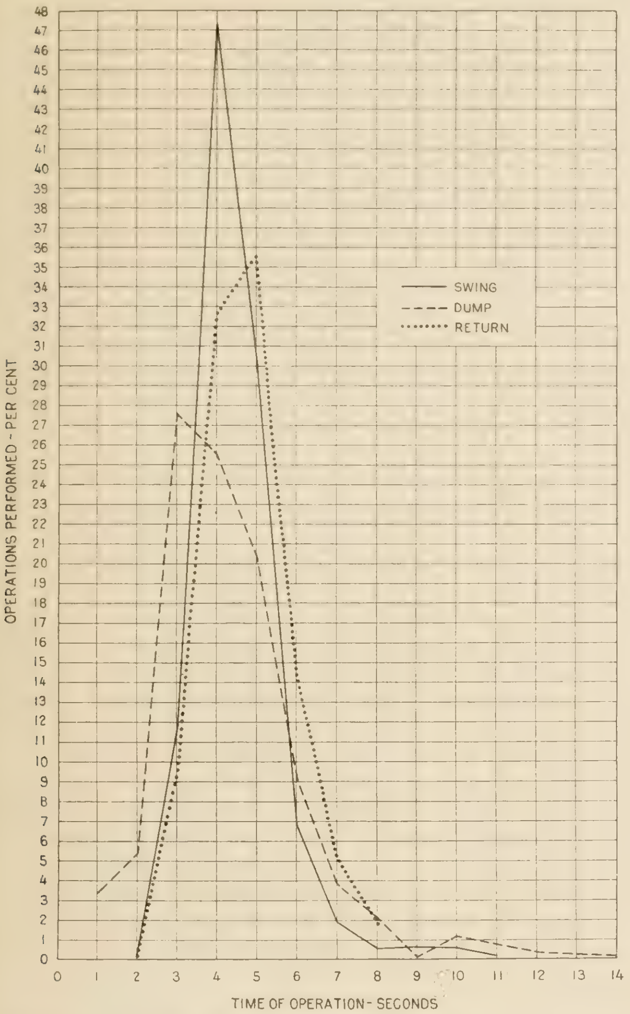


FIGURE 12.—PERCENTAGE OF OPERATIONS OF SWINGING, DUMPING, AND RETURNING PERFORMED IN VARIOUS TIME INTERVALS. BASED ON 1,058 CYCLES OF A ¾-YARD SHOVEL WORKING IN STICKY CLAY WITH AN ANGLE OF SWING OF FROM 45° TO 90°. AVERAGE TIME OF SWING 4.42 SECONDS. AVERAGE TIME OF DUMPING, 4.31 SECONDS. AVERAGE TIME OF RETURN, 4.86 SECONDS.

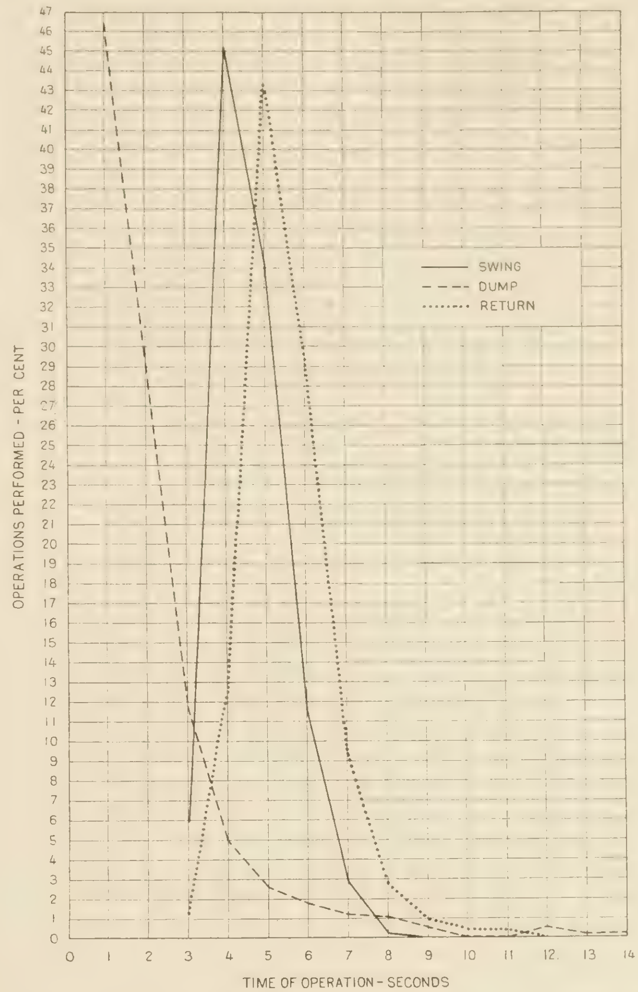


FIGURE 13.—PERCENTAGE OF OPERATIONS OF SWINGING, DUMPING, AND RETURNING PERFORMED IN VARIOUS TIME INTERVALS. BASED ON 1,322 CYCLES OF A 1⅛-YARD SHOVEL WORKING IN CLAY WITH SOME BOULDERS WITH AN ANGLE OF SWING VARYING FROM 45° TO 90°. AVERAGE TIME OF SWING, 4.62 SECONDS. AVERAGE TIME OF DUMPING, 2.23 SECONDS. AVERAGE TIME OF RETURN 5.49 SECONDS.

Figure 14 shows similar averages for swings of 150° to 180°. When the point of loading and the point of dumping are within the operator's vision at the same time, he can keep his mind far enough ahead of his work to react quickly and plan his operations with confidence. As he digs his load he decides where he will dump and plans the manipulations necessary in the process. As he drops his load, he determines where he will get the next bite, and so on. The saving in time is small per load, but it is enough to make considerable difference in a day's run.

DUMPING THE DIPPER LOAD

Dumping or discharging the dipper load requires great skill if done rapidly. The load must not be dropped from too great a height or the truck or wagon may be damaged. It must not be dropped too soon or too late or much of it will fall outside of the vehicle. If the load is composed of materials which dump freely, an experienced shovel operator will drop it just as the swing ends and be ready to start the return as soon as the dipper comes to a stop. In such material the fast operator really takes no time to drop the load, the time consumed being only that needed to stop the dipper and then start it on the return swing. Ordinarily, this can be done in 1 second. Wet, sticky clay and other adhesive materials often require considerable shaking or jarring to force them out of the dipper. With such materials, the time required depends on the skill of the operator and the amount of shaking and jarring necessary to empty the dipper.

For materials which clear the dipper freely, dumping time should not exceed an average of about 1 second. Sticky, adhesive materials and large rocks require much skill if average dumping time is to be held below 2 or 3 seconds, especially when small-capacity hauling units are used. A slow, inexperienced operator may readily consume 2 or 3 times the normal average time per dipper load. Because of the time required to empty the dipper, daily production in very sticky or adhesive materials may be as low as that in poorly blasted rock.

It is not unusual to find the dumping time in sticky materials running as high as 5 or 6 seconds regularly. In handling large rocks considerable care must be taken by the operator to prevent injury to the wagons or trucks. This naturally slows down the rate of operation. Large chunks often hang to or wedge in the dipper and require manipulation before they are released. Roots and stumps are often troublesome in this respect.

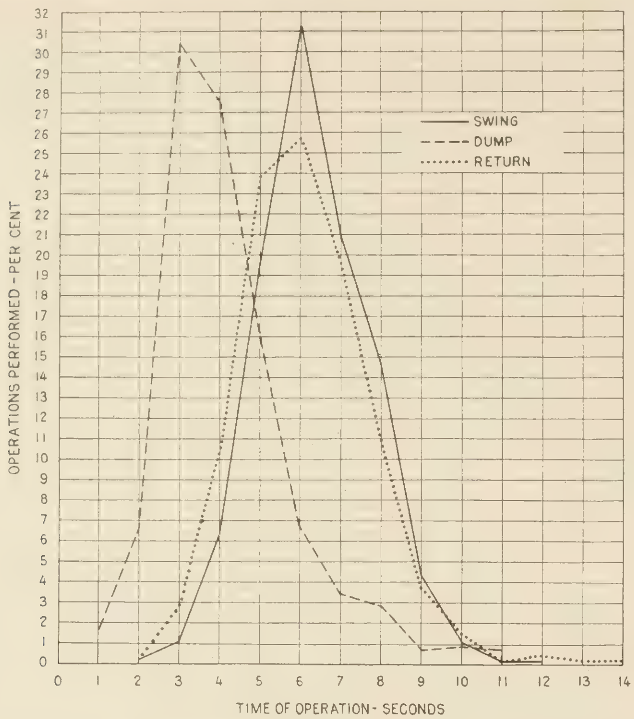


FIGURE 14.—PERCENTAGE OF OPERATIONS OF SWINGING, DUMPING, AND RETURNING PERFORMED IN VARIOUS TIME INTERVALS. BASED ON 658 CYCLES OF A ¾-YARD SHOVEL WORKING IN STICKY CLAY WITH AN ANGLE OF SWING OF FROM 150° TO 180°. AVERAGE TIME OF SWING, 6.23 SECONDS. AVERAGE TIME OF DUMPING, 4.33 SECONDS. AVERAGE TIME OF RETURN, 6.10 SECONDS.

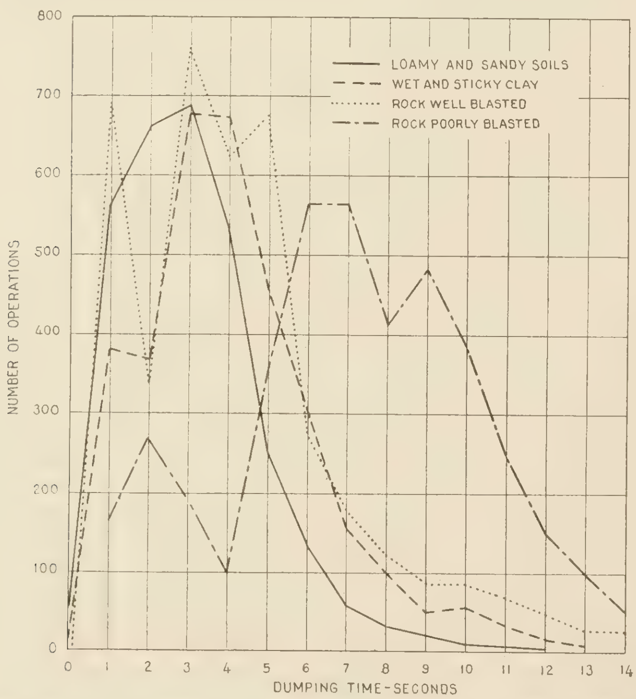


FIGURE 15.—NUMBER OF DUMPING OPERATIONS PERFORMED IN VARIOUS TIME INTERVALS IN DIFFERENT KINDS OF MATERIAL. BASED ON 10,200 OBSERVATIONS ON 13 DIFFERENT JOBS.

Tables 3, 11, and 12 show how average dumping time is affected by the kind and character of the materials. Figures 12, 13, and 14 also show the time used in emptying material from the dipper into the wagons or trucks under typical conditions. Figure 15 shows the average dumping time for a number of classes of material as

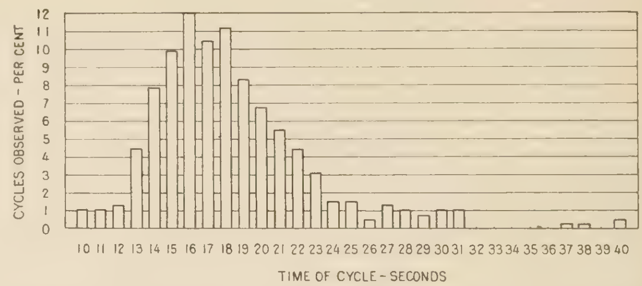


FIGURE 16.—DIAGRAM SHOWING PERCENTAGE OF SHOVEL CYCLES PERFORMED IN VARIOUS TIME INTERVALS. BASED ON 383 COMPLETE CYCLES (4 GREATER THAN 40 SECONDS) OF A ¾-YARD SHOVEL WORKING IN AN 8½-FOOT CUT OF BLASTED SHALE AND LOADING TRUCKS AT SIDE. AVERAGE TIME PER CYCLE, 18.9 SECONDS.

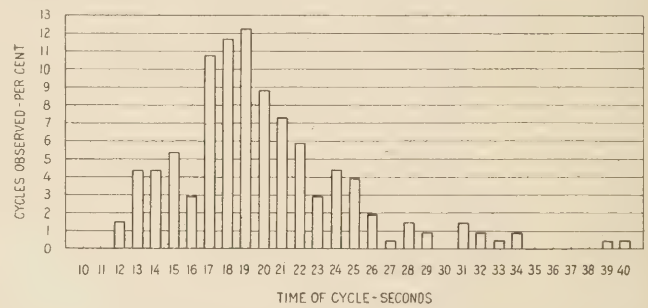


FIGURE 17.—DIAGRAM SHOWING PERCENTAGE OF SHOVEL CYCLES PERFORMED IN VARIOUS TIME INTERVALS. BASED ON 204 COMPLETE CYCLES (5 WERE OVER 40 SECONDS AND NOT SHOWN) OF A ¾-YARD SHOVEL WORKING IN FROM 8 INCHES TO 2 FEET OF LOAMY CLAY WITH AN ANGLE OF SWING OF FROM 45° TO 90°. AVERAGE TIME PER CYCLE, 20 SECONDS.

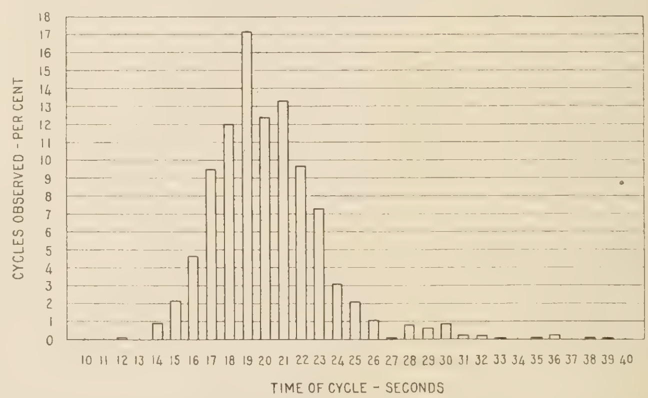


FIGURE 18.—DIAGRAM SHOWING PERCENTAGE OF SHOVEL CYCLES PERFORMED IN VARIOUS TIME INTERVALS. BASED ON 734 COMPLETE CYCLES (3 WERE OVER 40 SECONDS AND NOT SHOWN) OF A 1⅛-YARD SHOVEL WORKING IN 2 TO 6 FEET OF CLAY WITH A FEW BOULDERS. LENGTH OF SWING, 45° TO 90°. AVERAGE TIME PER CYCLE, 20.3 SECONDS.

found from the analysis of 10,200 readings on 13 different jobs with various grades of operators and 6 different makes of shovels. It will be noted that many of the operations were performed very rapidly in all but the most difficult materials.

LOW PRODUCTION FREQUENTLY CAUSED BY INSUFFICIENT HAULING EQUIPMENT

On the jobs studied an inadequate supply or poor operation of the hauling equipment, or both, caused the largest and most frequent time losses.

If the highest possible production is to be obtained the hauling vehicles must be exchanged within the time required to handle 1 dipper load, or in about 15 to 18

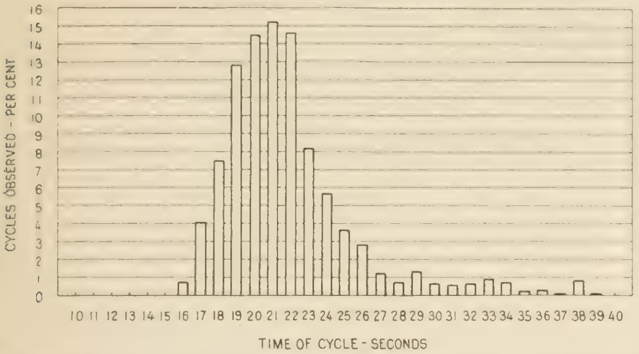


FIGURE 19.—DIAGRAM SHOWING PERCENTAGE OF SHOVEL CYCLES PERFORMED IN VARIOUS TIME INTERVALS. BASED ON 1,322 COMPLETE CYCLES (20 WERE OVER 40 SECONDS AND NOT SHOWN) OF A 1⅛-YARD SHOVEL WORKING IN FROM 1 TO 6 FEET OF CLAY WITH A FEW BOULDERS WITH A SWING OF FROM 45° TO 90°. AVERAGE TIME PER CYCLE, 22 SECONDS.

seconds in good common excavation. Operation of hauling equipment to meet this requirement is practical under ordinary field conditions, provided each vehicle can carry two or more dipper loads. Except under very unusual conditions, it has not been found possible to synchronize the operation of the hauling equipment for consistent maximum shovel production if only one dipperful is carried per load.

The adequacy of the hauling equipment has a decided effect on production. The number of hauling units of any given kind required to maintain full shovel production varies more or less directly as the length of haul which generally fluctuates between rather wide limits and often at frequent but irregular intervals. The characteristics which affect the rate at which material can be dug by the shovel sometimes change also with unexpected frequency.

In practice, it is usually found inadvisable to attempt to maintain an exact balance between hauling equipment and the maximum possible rate of shovel production. In many instances a definite number of hauling units is maintained on the job until grading is completed. On short hauls some of the equipment is idle or working at a slow rate, while on long hauls not enough equipment is available to keep the shovel working at full production. The question is one of determining what hauling equipment should be maintained on the job in order to complete the grading at the lowest possible cost. This question will be discussed more fully in a following article.

USE OF SHOVEL FOR FINE GRADING GENERALLY UNPROFITABLE

Trimming to grade and dressing slopes were prolific causes of extending the time per dipper load. While more accurate trimming of slopes has been required in many States during recent years, the loss in shovel time from this cause does not seem to have changed greatly. This is probably due to greater use of special mechanical equipment or hand labor for these operations.

Using the shovel for fine trimming of slopes and grade usually means practically stopping yardage production while these operations are being performed. From time to time during the day equipment worth $20,000 to $30,000, and especially adapted to function as a unit in the production of pay yardage, is diverted to performing a task for which it is but poorly adapted and to which only the shovel can contribute useful work.

On the average job the hauling units and the equipment on the dump are entirely unproductive when the shovel is dressing or trimming slopes. Some contractors condone a certain amount of shortage in hauling equipment because the resulting delays impressed on the shovel are used in trimming or dressing slopes. This may be good in theory but in practice it is found that slopes must be trimmed about as often when hauling units are on hand as when the shovel is waiting for hauling units.

COMPLETE SHOVEL CYCLE DISCUSSED

Under ordinary field conditions the fastest operation possible in good, common excavation with present shovels is in the neighborhood of 15 seconds per dipper load when the swing is 90°. The importance of approaching this limit as closely as possible can hardly be overstated. A 15-second cycle, consistently maintained, will yield the large output of 240 dipper loads an hour. To attain a 15-second cycle it is necessary to load the dipper regularly in about 5 seconds, to swing it over the wagon in about 4 seconds, to dump it in 1 to 1½ seconds, and return it again to loading position in 4 to 5 seconds. Lengthening the cycle time to 20 seconds drops the output to 180 dipper loads an hour—a reduction of 25 percent. If the cycle is lengthened to 25 seconds, the best the shovel can turn out is 144 dipper loads an hour, while if a 30-second cycle obtains the output cannot exceed 120 dipper loads.

The difference between operation on a 15-second cycle and on a 20-second cycle is often a matter of a second or so in loading, a slight hesitation during the swing, with perhaps a bit of delay in spotting over the wagon—delays which may not be noticed except with the aid of extended stop-watch readings. It is not surprising to find that slow operators are sometimes rated as fast because there is nothing definite with which to compare their work, and to find that fast operators are sometimes being discredited because job conditions or methods of job management over which they have no control hold down the output. Examples of the full operating-cycle time where loading was at the side of the shovel are shown in figures 16 to 19.

Tables 11 and 12 show in detail the average operating characteristics found under normal working conditions on 14 rather large, well-managed jobs. The effect of the character of the material on production is very marked. The production of similar shovels varies from an average of 38 cubic yards an hour in poorly blasted granite to 168 cubic yards in good earth. Not all but most of this difference in production was due to a difference in the material. Table 12 shows that the production in hard caliche was only 64 cubic yards per hour. When the caliche had been blasted, the same shovel produced 151 cubic yards an hour.

MAJOR TIME LOSSES ANALYZED

As the successive shovel operations are repeated over and over again throughout the day, it is clear that if a few seconds, or even fractions of a second, are regularly lost on any one operation, the total loss during the course of the day will be large. If an operator working consistently on a 20-second cycle slows up only just enough regularly to add 1 second to each of the major operations, the output will be cut from 3 to 2½ dippers per minute. If the regular unhampered output is 50 loads per hour, and the drivers of the hauling units in getting into place to be

TABLE 11.—*Average rates of power-shovel operation as observed on typical jobs*

	Job no. 1, earth and poorly blasted rock	Job no. 2, poorly blasted granite	Job no. 3, earth with many boulders	Job no. 4, fairly well-blasted rock	Job no. 5, well-blasted rock and earth	Job no. 6, fairly well-blasted rock	Job no. 7, soft rock, blasted	Job no. 8, well-blasted sandstone and shale	Job no. 9, well-blasted shale and sandstone	Job no. 10, well-blasted shale and sandstone	Job no. 11, fair to hard earth	Job no. 12, good earth	Job no. 13, earth with 12 to 18 inches of frost
Size of shovel, cubic yards	1¼	1¼	1¼	1¼	1½	1½	1¼	1¼	1¼	1¼	1¼	1¼	1¼
Condition of shovel	New	Very good	New	Fair	Very good	Very good	New	Good	Very good	Good	Good	Good	Good
Shovel cycle:													
Load, seconds	11.5	16.7	11.0	9.6	7.1	8.5	7.9	7.5	7.0	7.4	8.3	5.6	9.0
Swing, seconds	6.0	8.6	6.8	7.6	5.9	8.0	4.9	4.1	3.5	4.9	5.1	4.7	4.7
Dump, seconds	2.0	3.5	1.6	1.7	1.6	1.6	1.0	1.5	1.3	1.1	1.3	1.0	1.8
Return, seconds	6.6	9.1	7.3	8.2	6.2	7.9	4.7	4.5	4.3	5.2	5.1	4.6	5.7
Average shovel cycle, seconds	26.1	37.9	26.7	27.1	20.8	26.0	18.5	17.6	16.1	18.6	19.8	15.9	21.2
Average angle of swing, degrees	85	130	129	138	103	136	111	96	83	47	76	50	63
Average load per dipper, cubic yards	0.88	0.61	0.68	0.62	0.70	0.85	0.74	0.80	0.87	0.88	1.00	0.96	0.99
Average rate of production, cubic yards per working hour	71.4	38.0	42.8	69.0	97.0	98.0	128	128	150	130	133	168	110
Time lost in moving shovel, percentage of working time	7.2	5.2	7.0	1.7	3.3	4.8	2.1	3.4	5.4	3.9	6.1	9.9	5.5
Total minor time losses, including all stops of less than 15 minutes in duration, percentage of working time	41.2	35.5	54.0	14.8	20.1	17.6	13.4	22.1	23.3	25.0	25.2	23.1	24.4
Total major time losses, including all stops of 15 minutes or more in duration, percentage of available time	21.0	15.5	33.9	12.9	13.8	16.1	11.0	5.7	10.9	8.4	6.1	11.0	11.0
Total yardage moved during study, cubic yards	8,900	2,800	5,950	24,560	20,900	45,680	65,420	62,650	50,400	8,036	18,060	104,680	14,700

TABLE 12.—*Effect of material on length of shovel cycle*

[1-yard shovel in good condition. Hauling done with light trucks. Management good. Materials, very dry]

	Good common excavation	Hard caliche	Blasted caliche	Blasted rock
Percentage total excavation on job	26	38	15	21
Load dipper, seconds	6.5	10.3	5.8	8.5
Swing, do	5.2	6.1	5.5	6.4
Dump, do	0.8	0.9	0.9	1.1
Return, do	5.1	6.0	5.4	6.1
Average angle of swing, degrees	152	148	157	156
Average cycle, seconds	17.6	23.3	17.6	22.1
Average dipper load, cubic yards	0.84	0.65	0.90	0.65
Average production per hour, do	137	64	151	97

PERCENTAGE OF WORKING TIME LOST

	Percent
Minor time losses	
Hauling equipment, insufficient supply	7.8
Hauling equipment, faulty operation	.1
Moving shovel within cut	6.7
Shovel operator	1.3
Mechanical trouble with shovel	4.2
Sloping	2.6
Checking grade	2.3
Miscellaneous	2.6
Major mechanical repairs, shovel and cable	7.4
Light trucks, operation characteristics:	
Average speed, loaded, in reverse, 448 feet per minute.	
Average speed, return, forward, 690 feet per minute.	
Average loading time, 40.6 seconds.	

loaded delay the shovel only 18 seconds on each load, the output will be cut to 40 loads per hour.

Definite stops are obvious time losses and every contractor makes efforts to eliminate or reduce them. But a shovel outfit may operate all day without a definite stop and yet produce less than half the yardage it is capable of producing, simply because the management is not aware of the effect on production of the constant loss of seconds, or even fractions of seconds, in the repetitive operations.

TABLE 13.—*Major time losses (delays of 15 minutes or more) on power-shovel grading jobs. Average values for more than 100 jobs*

Cause	Percentage of available time lost
Rain and wet ground	9.4
Repairs to shovel and other equipment	10.5
Moving shovel from cut to cut	2.8
Waiting for drilling or blasting	2.1
Hauling equipment trouble or shortage	1.4
Taking on or lack of fuel or water	0.9
Miscellaneous causes	3.0
Total	30.1

LARGE DIPPER LOADS ARE NECESSARY FOR HIGH PRODUCTION RATES.

Field studies on more than a hundred jobs have shown that no contractor succeeds in maintaining capacity production all the time. Many were able to keep the shovel at work less than half of the available working hours. Table 13 gives the average percentage of the normally available working hours lost from various causes.

MINOR TIME DELAYS CONSIDERABLE IN EXTENT

These definite stops, each of 15 minutes or more in duration, do not comprise the entire time loss. Stopwatch studies on the same jobs showed that an average of 38.8 percent of the remaining time during which the crew was on the job was lost in minor stops and interruptions, each less than 15 minutes in duration. Many of the delays were only a second or so in duration but were repeated at more or less regular intervals, so that their accumulated totals often assumed surprising proportions. The average percentages of the normal working time consumed by these minor delays or interruptions to continuous operation and the causes to which they were due are given in table 14.

No matter how excellent the shovel and its supporting equipment, a high degree of efficiency can be obtained only through the proper coordination of all elements in the moving of material from cut to fill. Aside from management, the first and most important element in this combination is the operator. The ideal operator is gifted with quick reaction, a true eye, good judgment, great endurance, and a high degree of

TABLE 14.—*Minor time losses (less than 15 minutes duration) on power-shovel grading jobs. Average values for more than 100 jobs*

Cause	Percentage of actual working time[1] lost
Insufficient hauling equipment	11.7
Improper operation of hauling equipment	7.7
Moving shovel within cuts	4.7
Handling large rocks, boulders, stumps, etc	3.6
Minor shovel repairs, adjustments, etc	3.3
Shovel operator	1.6
Taking on fuel or water	1.0
Blasting boulders, rocks, etc	.6
Checking grade	.4
Miscellaneous causes	4.2
Total	38.8

[1] Actual working time is available working time less major delays.

skill and experience. He should know the possiblities and limitations of the shovel and be able to maintain it in first-class condition.

Except in casting, the operator can dig no more material than can be hauled away, and he can dig only when hauling units are in place for loading. If the supply of wagons or trucks is inadequate for full production, or if their operation is such as to interfere with the steady operation of the shovel, the fault lies with the management.

The management is frequently at fault in failing to maintain and replace equipment. High rates of production cannot be obtained from equipment in poor mechanical condition; yet the field studies give abundant evidence that proper maintenance of both the shovel and the hauling equipment is frequently neglected.

CARE OF EQUIPMENT IMPORTANT

Operating conditions in highway grading work are severe on equipment, and neglect soon proves costly. Many contractors using two or more shovels have found it economical to provide a shop and a good mechanic and helper. A particularly satisfactory arrangement was one in which the mechanic was made responsible for the regular inspection and maintenance of all equipment. Frequently he was also made responsible for the proper oiling and greasing of the hauling units, tractors, compressors, and similar equipment. In making repairs on the shovel the shovel operator usually acted as helper.

If no mechanic is employed the contractor must be certain that the shovel operator is competent to make all ordinary adjustments and repairs to the shovel. Unless a good mechanic is on the job or especially high-grade drivers are employed, the contractor should assign some one, such as the shovel foreman, to be personally responsible for seeing that the hauling units, tractors, and other pieces of equipment are inspected at frequent intervals and greased, oiled, adjusted, and repaired as may be found necessary.

Equipment should be given a general overhauling at the time of storing. All parts should be thoroughly inspected, repaired if necessary, and then greased, oiled, or painted as may be proper. Effective protection from the elements should be provided. If the storage is on the job or in an isolated location, all indicators, valves, brasses, and other small parts should be removed, labeled, boxed, and placed in safe custody. The contractor can then be sure his equipment will be ready when work is resumed.

In too many cases, equipment is left in such shape that deterioration during so-called storage is as great as, or at times even greater than, if it had been in use for the same period. Deterioration of the equipment is a big drain on the profits of any going power-shovel grading job. To permit this drain to continue after the job has been closed down or completed seems inexcusable. The duty of the management does not end with the movement of the last dipper load of excavation. Management is not fully efficient until it extends to every source through which profits may be lost as well as to every source through which profits may be made. The storage and protection of the equipment during idle periods is one of the most important of the sources of profits.

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS I—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM
OUTSIDE OF MUNICIPALITIES

AS OF JULY 31,1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS I PROJECTS ON THE FEDERAL AID HIGHWAY SYSTEM	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS I PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$ 4,123,000.00	$ 1,780,465.93	$ 985,168.06	$ 795,297.87	69.5	$ 4,411,922.33	$ 2,470,719.78	$ 1,941,202.55	54.5	264.2	$ 379,393.98	42.0	$ 287,718.18
Arizona	3,878,555.11	2,170,625.64	2,127,472.41		162.1	2,191,576.91	1,623,475.36	70,684.50	46.0	122.2	96,740.98	10.7	30,866.36
Arkansas	3,374,167.00	468,018.43	368,180.55	99,837.88	14.2	3,010,804.62	2,575,575.14	429,074.13	58.6	140.0	264,552.08	18.3	165,859.23
California	7,803,677.00	4,192,457.71	3,199,789.44		152.4	6,667,446.28	4,586,944.46		48.4	153.6	6,000.00	9.6	10,943.10
Colorado	3,437 265.00	1,884,447.57	1,873,867.22		104.1	1,687,951.88	1,554,323.51	27,435.65	58.9	46.8			9,074.27
Connecticut	1,404,213.00	35,284.96	35,284.96		.1	1,539,691.56	1,363,912.62	175,778.94	47.7	30.7	584.30		4,431.12
Delaware	909,544.00	314,726.65	313,834.22		7.2	574,806.60	574,806.60		72.0	10.4	5,770.00	.3	15,133.18
Florida	2,519,010.59	2,137,060.84	1,523,905.02	612,545.72	73.3	1,105,848.94	915,349.17	190,499.77	45.0	42.7	37,685.10	.6	42,071.30
Georgia	5,045,592.00	1,707,619.51	1,707,619.51		106.7	2,077,371.15	2,077,371.15		39.6	150.1	455,162.44	30.0	805,438.90
Idaho	2,166,858.00	905,193.28	885,279.79		91.7	1,210,030.45	1,173,178.16		61.0	83.6	5,180.27		103,219.78
Illinois	4,585,971.00	168,731.15	168,065.26		5.3	2,646,754.55	2,646,754.55		55.7	41.0	1,759,950.13	13.4	11,201.06
Indiana	5,018,921.00	156,803.28	156,803.28		7.1	4,107,828.73	4,107,828.73		50.3	118.5	518,254.16	9.4	236,034.83
Iowa	5,027,830.00	1,359,588.87	1,326,600.00		90.0	3,822,172.29	3,541,180.00		86.2	170.1	148,525.50	9.0	11,524.50
Kansas	5,044,802.00	2,085,233.29	2,083,742.37		260.9	3,183,028.72	2,922,592.89	113,490.85	90.8	136.9	20,169.51		18,297.23
Kentucky	3,608,332.00	956,126.56	946,555.71		98.0	2,296,066.98	2,278,615.36		79.1	145.2	383,160.93	10.0	
Louisiana	2,914,295.00	482,352.23	482,327.23		21.0	2,653,510.37	2,146,859.37		51.9	56.2	42,623.98	1.5	242,484.42
Maine	1,617,560.00	76,276.11	76,276.11		2.6	1,463,037.70	1,427,470.75		73.2	41.6			113,813.14
Maryland	1,782,263.00					895,286.53	885,637.78		59.8	18.1	698,410.00	8.9	198,215.22
Massachusetts	1,101,716.00	302,095.72	224,899.82	69,984.24	6.4	1,110,847.88	795,188.24	315,659.64	79.6	31.4			81,627.94
Michigan	6,113,389.00	270,650.00	270,650.00		9.3	5,082,130.00	5,033,130.00	49,000.00	64.9	238.2	538,486.00	19.8	271,123.00
Minnesota	4,561,011.00	2,698,398.86	2,677,853.47	20,482.87	546.7	1,891,417.38	1,853,917.28	37,500.00	43.4	213.2	29,240.25	.3	
Mississippi	3,489,337.00	627,836.64	309,340.68	279,864.02	30.7	4,300,664.97	2,365,366.18	1,935,298.79	56.1	224.1	307,893.81	34.3	506,736.33
Missouri	5,237,532.00	1,559,105.53	1,243,198.23	50,048.60	67.8	3,926,151.13	3,697,624.66	18,500.00	78.5	133.4	191,710.97	5.2	104,998.14
Montana	4,463,849.00	2,562,377.02	2,382,361.02	100,000.00	162.9	2,445,871.45	2,070,284.84	237,025.83	51.7	207.1	7,929.31	30.1	3,273.83
Nebraska	3,914,481.00	2,759,539.55	2,114,469.77	108,538.00	251.1	2,337,947.73	1,787,417.04		72.5	108.4	12,594.19	3.3	
Nevada	2,909,387.00	1,500,634.77	1,500,634.77		178.0	1,439,841.73	1,392,892.85	43,327.07	37.1	86.8	15,000.00		859.38
New Hampshire	725,739.00	160,195.08	159,372.67		.9	493,032.39	487,347.39		99.3	10.0	79,018.94	.4	
New Jersey	3,099,370.48	111,869.84	111,869.84		6.8	3,064,165.82	2,909,244.81	139,466.42	43.8	40.3	4,740.85		73,514.98
New Mexico	2,846,648.00	1,957,784.83	1,957,784.83		210.6	1,022,007.56	878,078.14	143,929.42	37.4	63.6			10,785.03
New York	10,271,846.00	928,422.64	749,432.64	43,000.00	15.5	11,734,208.68	9,445,253.68	364,000.00	69.0	230.9	23,197.80		53,961.88
North Carolina	4,761,147.00	1,424,297.21	1,049,605.22	374,691.99	130.5	3,189,161.49	2,875,275.31	311,308.24	55.4	469.4	307,745.35	26.3	528,521.12
North Dakota	2,902,224.00	1,486,571.12	1,473,111.20	13,339.85	605.3	1,541,295.21	1,211,659.62	329,635.59	45.0	339.4	198,884.64	75.0	18,568.54
Ohio	7,277,758.00	2,169,012.46	2,129,011.63	19,665.00	54.1	5,423,848.00	5,058,603.00	31,745.00	75.5	133.1	60,200.00	4.7	29,943.37
Oklahoma	4,608,399.00	1,682,236.39	1,676,979.36		112.7	2,520,280.92	2,520,280.92		75.5	185.0	168,753.42	6.2	242,385.30
Oregon	3,053,448.00	1,936,395.21	1,719,646.15	168,449.56	115.6	1,290,323.94	1,196,071.48	50,403.39	55.6	66.9	137,730.37	1.0	
Pennsylvania	6,691,194.00	711,084.21	710,717.19		16.9	6,010,365.93	5,752,500.31		55.6	114.6	125,458.48	.5	102,518.02
Rhode Island	999,354.00	139,340.98	139,340.98		5.3	856,688.72	793,821.44	62,867.28	92.8	15.2			66,191.58
South Carolina	2,729,583.00	343,363.57	343,363.57		35.2	2,079,642.30	2,076,912.68	2,729.62	57.0	181.7	140,211.60	8.5	169,095.15
South Dakota	3,005,739.00	1,206,505.07	1,120,137.97	86,367.10	212.2	1,794,665.15	1,488,741.73	305,923.42	35.5	246.1	151,421.36	50.1	245,437.94
Tennessee	4,246,309.00	1,628,893.51	1,401,404.58	227,488.93	76.6	2,953,134.41	2,607,593.10	345,541.31	51.4	103.7	83,509.35	8.4	153,801.97
Texas	12,122,012.00	5,442,306.35	4,622,269.64		599.7	6,285,926.39	5,903,939.63		51.9	404.2	185,655.01	8.7	1,410,147.72
Utah	2,374,205.00	1,443,894.80	1,434,018.24		146.0	845,783.41	845,783.41		71.5	49.2	1,259.33		93,144.02
Vermont	928,184.00	144,575.68	143,005.72		11.1	794,619.98	765,170.43		73.1	33.7	20,007.85	.2	
Virginia	3,708,379.00	1,620,899.80	1,593,064.20	25,807.50	85.7	1,675,125.67	1,553,830.55	119,975.07	64.9	45.0	345,141.61	14.8	216,342.64
Washington	3,057,934.00	1,456,437.94	1,451,522.65	3,356.82	61.3	1,520,818.24	1,520,818.24		32.9	44.3	64,640.67	1.4	20,952.44
West Virginia	2,013,405.00	670,620.15	670,620.15		25.5	1,264,231.40	1,258,231.40		73.9	46.6	34,019.28	.2	50,534.17
Wisconsin	4,615,429.00	1,446,789.22	1,415,236.86	22,690.00	66.9	3,179,952.20	3,100,207.46	17,000.00	57.4	157.4	85,536.83	5.9	14,447.85
Wyoming	2,250,663.00	1,012,099.08	889,645.00	80,400.00	177.9	1,433,341.37	1,290,181.15	85,908.57	70.1	279.4	49,990.60	3.7	20,846.25
District of Columbia Hawaii	1,683,956.00	196,114.99	144,003.03	52,099.15	10.4	1,724,330.28	1,389,715.33	252,930.99	31.9	25.1	144,921.48	4.1	5,316.16
TOTALS	186,025,483.18	62,481,360.23	56,089,342.22	3,253,955.10	5,301.8	130,776,958.32	114,797,677.68	8,147,842.04	60.3	6,299.3	8,337,062.71	476.8	6,801,400.57

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS II—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF JULY 31, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS II PROJECTS IN MUNICIPALITIES	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS II PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$2,175,100.00	$223,762.97	$223,762.97		4.1	$1,361,007.02	$1,361,007.02		28.6	41.1	$496,975.57	17.2	$93,354.44
Arizona	807,982.36	263,907.75	263,907.75		6.8	360,269.48	360,269.48		35.8	6.0	142,116.51	.3	41,688.62
Arkansas	1,889,534.00	356,495.25	328,897.18	$27,598.07	10.4	1,178,579.17	1,113,124.96	$65,204.21	48.0	27.9	412,494.36	4.8	35,017.50
California	4,213,986.00	1,478,043.98	1,303,555.11		18.6	2,774,346.14	2,471,287.26		27.8	32.8	387,370.86	1.6	51,772.77
Colorado	1,718,633.00	964,715.98	918,908.33		19.7	678,862.12	678,862.12		47.9	12.4	110,656.43	3.5	10,206.12
Connecticut	802,407.00	137,086.77	137,086.77		1.7	667,390.37	664,248.49	3,141.88	89.1	8.5			1,071.74
Delaware	454,772.00	97,453.47	89,261.31		.9	189,143.40	189,143.40		95.7	1.8	139,750.00	4.9	36,617.29
Florida	1,405,007.67	654,184.02	447,261.53	206,922.49	7.6	969,060.19	938,217.47	30,842.72	39.8	10.5	16,361.04	.8	3,167.63
Georgia	2,724,620.00	402,753.22	402,753.22		18.3	1,060,754.45	1,060,754.45		38.4	36.4	235,234.32	8.9	1,025,878.01
Idaho	1,197,829.00	468,778.19	461,999.27		9.6	688,461.87	669,269.67		23.6	8.7			66,560.06
Illinois	7,718,839.00	414,935.84	414,196.33		6.8	6,216,719.90	6,216,719.90		69.1	62.1	1,087,922.77	2.0	
Indiana	4,416,651.00	96,725.13	95,140.81		3.1	2,771,921.33	2,771,921.33		41.2	56.1	1,013,016.62	11.6	536,572.24
Iowa	2,815,585.00	908,400.96	863,545.00		28.4	1,160,142.48	1,097,150.00		66.5	21.2	195,924.50	1.2	658,965.50
Kansas	2,522,401.00	1,625,226.97	1,620,823.52		29.5	1,033,258.55	888,404.75		73.2	7.7	13,156.36	.1	16.37
Kentucky	2,029,687.00	263,336.87	261,307.81		7.3	841,494.55	833,580.08		41.9	17.7	239,109.61	4.9	695,689.50
Louisiana	1,457,148.00	354,928.11	354,928.11		7.4	1,083,677.45	1,057,084.02	26,593.43	21.2	18.7	45,135.87	1.5	
Maine	909,878.00	177,466.09	176,340.52		3.1	655,987.00	654,615.70		73.0	13.6			78,921.78
Maryland	891,132.00					390,738.31	386,588.31		42.2	3.6			504,543.69
Massachusetts	5,007,199.00	101,295.60	73,850.68	23,000.00	1.8	4,725,640.23	4,686,564.07	39,076.16	38.4	14.7			246,784.25
Michigan	3,438,781.00	222,700.00	222,700.00		2.5	3,094,395.00	3,092,245.00		63.3	38.3	103,575.00	.7	20,261.00
Minnesota	3,719,143.00	1,202,411.93	1,201,843.47		62.5	1,798,217.35	1,771,448.38	2,500.00	36.6	34.1	206,134.68	4.3	539,716.47
Mississippi	1,744,669.00	122,848.45	110,388.95	12,459.50	3.7	776,777.74	776,777.74		31.7	29.1	186,508.90	5.1	670,993.41
Missouri	4,019,501.00	965,642.55	933,056.09		27.4	2,769,422.53	2,316,905.75		48.2	25.9	210,018.96	4.8	559,520.20
Montana	1,115,962.00	437,197.70	437,197.70		12.4	583,117.18	583,117.18		13.5	17.9	95,647.12	6.5	
Nebraska	1,957,240.00	364,129.51	363,440.22		14.2	1,548,723.73	1,548,723.73		77.3	18.8	33,507.06	.2	11,568.99
Nevada	500,051.00	47,203.38	47,203.38		1.2	405,748.52	405,748.52		39.2	7.0			47,099.10
New Hampshire	706,640.00					679,850.12	664,365.95	1,484.17	96.6	15.6			42,274.05
New Jersey	3,190,118.00	312,610.44	312,610.44		4.7	2,670,995.95	2,616,862.95	30,000.00	55.2	17.8	178,521.34	.3	82,123.27
New Mexico	1,674,158.00	575,161.70	575,161.70		17.9	791,139.25	773,114.46		49.9	14.4	76,307.45	.8	249,574.39
New York	8,449,487.00	635,973.17	635,591.87		8.0	7,695,767.60	7,179,335.00	39,000.00	59.4	54.3	255,408.24		379,151.89
North Carolina	2,380,573.00	870,337.74	867,734.17	166.10	36.4	806,577.74	801,326.02	2,278.81	36.7	34.1	448,033.71	7.6	263,479.10
North Dakota	1,451,112.00	271,819.40	271,819.40		14.8	477,381.36	476,619.40	761.96	38.6	14.8	604,896.53	26.5	97,776.67
Ohio	4,335,686.00	1,184,452.41	1,065,124.08		18.4	3,512,684.43	3,109,861.80		66.2	39.0	156,100.00	1.9	4,600.12
Oklahoma	2,304,200.00	450,336.08	449,978.40		11.6	1,529,724.52	1,529,724.52		62.3	30.6	156,798.84	3.1	167,698.24
Oregon	1,526,724.00	474,796.66	457,974.29	14,126.97	12.4	956,403.34	955,734.34		40.1	15.0	35,519.42	1.0	77,495.95
Pennsylvania	4,854,988.00	1,326,815.61	1,300,189.02		26.6	2,889,856.83	2,834,707.17		48.2	31.2	270,194.39	1.4	449,897.42
Rhode Island	499,677.00	113,760.62	113,760.62		2.2	436,293.20	385,916.38		52.3	5.2			
South Carolina	1,364,791.00	199,118.11	199,118.11		6.5	851,705.71	851,300.70	405.01	41.2	32.5	52,076.48	2.1	262,295.71
South Dakota	1,502,870.00	476,303.77	476,303.77		14.6	563,735.76	563,735.76		14.2	21.1	131,119.01	3.9	331,711.46
Tennessee	2,123,155.00	762,114.07	762,114.07		11.9	836,463.75	836,463.75		28.9	11.1	415,341.98	4.6	109,235.20
Texas	6,061,006.00	1,852,766.36	1,744,821.21		65.0	3,320,305.79	3,284,376.68		28.5	42.6	316,968.01	6.8	714,840.10
Utah	771,826.00	618,071.80	602,012.21		13.9	54,015.64	53,422.98		63.6	2.8			116,390.81
Vermont	500,509.00	100,611.71	100,529.21		3.5	425,571.35	399,979.79	5,838.96	53.5	11.1			
Virginia	2,008,458.00	628,596.85	606,285.79	8,760.49	15.4	1,175,897.91	983,194.07		50.0	8.5	279,235.89	3.2	139,742.25
Washington	1,977,260.00	1,410,034.83	1,394,292.37		26.0	558,454.84	558,454.84		15.0	6.4			24,512.79
West Virginia	1,342,270.00	132,299.32	132,299.32		3.0	1,011,297.22	986,951.48		58.1	16.0	97,820.12	1.4	125,199.08
Wisconsin	2,684,067.00	565,853.20	559,428.25		17.9	1,883,688.38	1,848,284.77	25,898.24	61.9	32.7	178,244.87	1.2	98,109.11
Wyoming	1,125,332.00	166,606.97	166,105.65		3.2	870,740.33	870,154.49		55.0	19.7	8,847.19	.2	80,224.67
District of Columbia	959,235.00	289,445.89	289,445.89		2.4	680,633.97	663,650.15		68.3	2.3			6,138.96
Hawaii													
TOTALS	115,447,880.03	25,769,517.40	24,836,055.87	293,033.62	645.3	74,463,041.05	71,821,316.23	273,025.55	50.5	1,051.4	9,032,050.01	150.9	9,758,457.92

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS III—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF JULY 31, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS III PROJECTS ON SECONDARY HIGHWAYS	COMPLETED			UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS III PROJECTS	STATE
		Total cost	Public works funds	Mileage	Estimated total cost	Public works funds allotted	Percentage completed	Mileage	Public works funds allotted	Mileage		
Alabama	$ 2,072,033.00	$ 66,645.33	$ 66,645.33	4.9	$ 1,006,244.00	$ 1,006,244.00	15.5	70.4	$ 942,293.45	81.0	$ 56,850.22	Alabama
Arizona	525,422.53	90,857.40	90,857.40	6.3	441,468.95	429,341.96	58.9	36.0			5,223.17	Arizona
Arkansas	1,484,634.00	42,221.95	42,128.61	16.9	1,047,299.74	1,047,299.74	41.2	125.0	131,723.58	8.0	263,482.07	Arkansas
California	3,589,691.00	1,186,149.60	971,493.89	29.3	2,756,807.09	2,338,072.55	31.7	148.6			280,124.56	California
Colorado	1,718,632.00	1,013,438.39	1,012,735.11	120.9	769,334.06	678,180.40	65.8	58.7			27,716.49	Colorado
Connecticut	659,120.00				664,915.58	659,120.00	47.0	14.5				Connecticut
Delaware	454,772.00				202,680.00	202,680.00	42.4	9.1	93,631.90	4.9	158,460.10	Delaware
Florida	1,307,815.74	397,589.88	397,589.88	25.9	870,879.31	870,879.31	73.3	45.6	9,179.72	3.5	30,166.83	Florida
Georgia	2,320,973.00	344,460.45	344,460.45	23.3	846,311.09	846,311.09	47.4	76.6	246,859.15	15.7	883,342.31	Georgia
Idaho	1,121,562.00	707,943.49	636,399.59	84.7	493,929.76	485,162.41	69.9	57.2				Idaho
Illinois	5,265,960.00	291,848.28	291,848.28	42.5	4,672,720.58	4,672,720.58	54.2	273.9	301,391.14	4.9		Illinois
Indiana	602,271.00				517,006.54	517,006.54	60.0	69.2			85,264.46	Indiana
Iowa	2,212,245.00	300,353.28	289,200.00	62.7	2,143,005.30	1,790,095.00	64.5	242.9	75,150.00	16.5	57,800.00	Iowa
Kansas	2,522,401.00	723,007.82	722,534.55	56.0	1,793,975.81	1,793,425.97	69.7	107.9	6,440.48	1.7		Kansas
Kentucky	1,879,340.00	708,405.33	703,474.35	106.2	1,137,115.31	1,135,730.07	76.3	109.3	30,000.00	5.5	10,135.58	Kentucky
Louisiana	1,457,148.00	73,405.37	73,405.37	2.4	1,067,586.45	1,067,586.45	41.6	43.8	141,363.06	10.6	174,793.12	Louisiana
Maine	842,479.00	709,143.59	693,368.84	66.5	216,334.52	139,693.54	95.2	15.0			9,416.62	Maine
Maryland	891,132.00	192,659.52	192,659.52	14.6	509,242.53	495,316.53	62.2	38.8	153,461.75	9.5	49,694.20	Maryland
Massachusetts	488,185.00				469,741.41	469,741.41	89.2	15.2			18,443.59	Massachusetts
Michigan	3,184,057.00	116,000.00	116,000.00	10.0	2,945,500.00	2,930,600.00	54.1	217.3	28,600.00	1.1	108,857.00	Michigan
Minnesota	2,376,415.00	905,579.76	893,735.08	117.6	1,385,991.29	1,380,936.50	56.8	154.7	60,402.89	2.8	41,340.53	Minnesota
Mississippi	1,744,669.00				902,518.02	902,518.02	47.1	104.2	447,394.76	35.8	394,756.22	Mississippi
Missouri	2,923,273.00	1,094,008.67	1,092,983.38	266.6	1,753,804.68	1,753,688.68	84.1	233.1	9,573.06	.8	67,027.88	Missouri
Montana	1,859,937.00	855,681.20	855,681.20	112.4	1,001,787.98	991,338.80	33.5	111.7	12,917.00	2.0		Montana
Nebraska	1,957,240.00	248,252.51	248,252.51	76.3	1,656,273.96	1,646,528.79	76.4	207.2			62,458.70	Nebraska
Nevada	1,136,479.00	724,453.61	724,453.61	70.9	283,576.27	283,576.27	56.1	27.9	89,943.76	6.4	38,505.36	Nevada
New Hampshire	477,460.00	82,647.15	82,647.15	2.5	435,560.52	394,736.67	84.4	23.1			76.18	New Hampshire
New Jersey	56,550.52				56,550.52	56,550.52	99.0	.5				New Jersey
New Mexico	1,272,129.00	478,000.00	478,000.00	81.2	768,115.17	768,115.17	68.0	224.2			26,013.83	New Mexico
New York	3,606,768.00	386,721.33	386,721.33	12.3	3,649,200.00	3,211,550.00	70.7	87.3			10,496.67	New York
North Carolina	2,380,573.00	762,541.19	762,142.86	54.0	1,102,730.32	1,079,749.19	45.2	130.2	232,876.97	30.2	305,803.98	North Carolina
North Dakota	1,451,112.00	52,056.52	52,056.52	11.7	283,592.61	283,592.61	21.9	67.4	513,915.00	155.3	601,547.87	North Dakota
Ohio	3,871,148.00	1,133,640.00	1,115,443.10	210.5	3,001,520.00	2,705,494.90	63.0	94.4			50,210.00	Ohio
Oklahoma	2,304,199.00	231,335.80	231,335.80	17.6	1,981,352.00	1,898,190.44	33.9	237.8	174,672.76	15.7		Oklahoma
Oregon	1,526,724.00	902,896.44	799,061.94	75.4	796,315.25	715,320.06	33.4	33.0	12,342.00			Oregon
Pennsylvania	7,344,822.00	1,118,787.59	1,118,787.59	122.1	6,064,927.09	5,979,263.69	61.7	517.1	237,622.92	19.9	9,147.80	Pennsylvania
Rhode Island	499,677.00	40,435.61	40,435.61	3.4	372,029.41	372,029.41	67.5	29.8			87,211.98	Rhode Island
South Carolina	1,364,791.00	70,489.60	70,489.60	1.7	1,208,978.13	1,208,978.13	64.6	143.9	85,323.27	9.2		South Carolina
South Dakota	1,502,870.00	307,575.39	307,575.39	119.9	559,555.01	559,555.01	34.5	158.8	263,313.66	106.3	372,425.94	South Dakota
Tennessee	2,123,155.00	389,758.24	389,758.24	33.8	1,168,419.96	1,168,419.96	43.7	96.0	379,551.16	21.6	185,425.64	Tennessee
Texas	6,061,006.00	2,951,630.94	2,303,113.90	468.3	3,419,971.99	3,204,690.28	60.1	307.4	117,416.66	2.5	435,785.16	Texas
Utah	1,048,677.00	643,566.32	594,909.31	123.7	409,214.65	384,800.00	49.9	37.9	68,967.69	5.9		Utah
Vermont	438,880.00	14,823.57	14,747.37	.4	471,232.11	424,132.63	53.5	36.4				Vermont
Virginia	1,699,920.00	652,265.58	619,791.33	102.3	1,040,001.81	1,001,217.88	55.2	102.7	20,201.61	.3	58,709.18	Virginia
Washington	1,080,673.00	433,957.50	423,957.50	29.2	622,286.51	622,286.51	42.6	34.6	27,739.30	3.9	6,689.69	Washington
West Virginia	1,118,559.00	42,815.06	42,815.06	.7	877,265.11	877,265.11	52.9	50.0	54,854.78	3.2	143,624.05	West Virginia
Wisconsin	2,425,385.00	1,103,933.27	1,063,936.01	67.9	1,214,598.55	1,131,017.19	35.6	99.8	82,821.53	3.0	147,610.27	Wisconsin
Wyoming	1,125,332.00	734,193.01	722,890.00	110.1	357,686.93	342,524.00	39.1	38.1	59,918.00	9.6		Wyoming
District of Columbia	959,234.00	284,601.50	284,601.50	3.4	674,427.20	674,427.20	48.2	4.4			205.30	District of Columbia
Hawaii	187,106.00				177,717.69	177,717.69	49.0	4.9			9,388.31	Hawaii
TOTALS	92,526,636.79	23,610,687.04	22,365,124.06	2,969.0	62,269,298.77	59,775,418.86	56.1	5,173.5	5,111,863.01	597.3	5,274,230.86	TOTALS

PUBLICATIONS of the BUREAU OF PUBLIC ROADS

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D.C. As his office is not connected with the department and as the department does not sell publications, please send no remittance to the United States Department of Agriculture.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1927. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1928. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1929. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1932. 10 cents.

DEPARTMENT BULLETINS

No. 136D . . Highway Bonds. 20 cents.

No. 347D . . Methods for the Determination of the Physical Properties of Road-Building Rock. 10 cents.

No. 532D . . The Expansion and Contraction of Concrete and Concrete Roads. 10 cents.

No. 583D . . Reports on Experimental Convict Road Camp, Fulton County, Ga. 25 cents.

No. 660D . . Highway Cost Keeping. 10 cents.

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

TECHNICAL BULLETINS

No. 55T . . Highway Bridge Surveys. 20 cents.

No. 265T . . Electrical Equipment on Movable Bridges. 35 cents.

MISCELLANEOUS CIRCULARS

No. 62MC . . Standards Governing Plants, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects. 5 cents.

No. 93MC . . Direct Production Costs of Broken Stone. 25 cents.

MISCELLANEOUS PUBLICATIONS

No. 76MP . . The results of Physical Tests of Road-Building Rock. 25 cents.

No. ——— . . Federal Legislation and Regulations Relating to Highway Construction. 10 cents.

No. 191 . . Roadside Improvement. 10 cents.

REPRINT FROM PUBLIC ROADS

Reports on Subgrade Soil Studies. 40 cents.

Single copies of the following publications may be obtained from the Bureau of Public Roads upon request. They can not be purchased from the Superintendent of Documents.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio. (1927.)

Report of a Survey of Transportation on the State Highways of Vermont. (1927.)

Report of a Survey of Transportation on the State Highways of New Hampshire. (1927.)

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio. (1928.)

Report of a Survey of Transportation on the State Highways of Pennsylvania. (1928.)

Report of a survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States. (1930.)

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to the U.S. Bureau of Public Roads, Willard Building, Washington, D.C.

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

SUMMARY OF CLASSES I, II, AND III

AS OF JULY 31, 1934

STATE	TOTAL APPORTIONMENT OF PUBLIC WORKS FUNDS	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR ALL NEW PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
Alabama	$ 8,370,133	$ 2,070,874.23	$ 1,275,576.36	$ 795,297.87	78.5	$ 6,779,173.35	$ 4,837,970.80	$ 1,941,202.55	39.1	375.7	$ 1,818,663.00	140.2	$ 437,922.84
Arizona	5,211,960	2,525,390.79	2,482,237.56		175.2	2,993,315.34	2,413,086.80	70,684.50	46.7	164.2	238,857.49	11.0	77,778.15
Arkansas	6,748,335	866,735.63	739,206.34	127,435.95	41.5	5,236,683.53	4,735,999.84	494,278.34	52.2	292.9	808,770.02	31.1	464,358.80
California	15,607,354	6,856,651.29	5,474,838.44		200.3	12,198,599.51	9,396,304.27		38.8	335.0	393,370.86	11.2	342,840.43
Colorado	6,874,530	3,862,601.94	3,805,510.66		244.7	3,136,148.06	2,911,366.03	27,435.65	57.9	117.9	110,656.43	3.5	46,996.88
Connecticut	2,865,740	172,371.73	172,371.73		1.8	2,871,997.51	2,687,281.11	178,920.82	57.8	53.7	584.30		5,502.86
Delaware	1,819,088	412,180.12	403,095.53		8.1	966,630.00	966,630.00		70.5	21.3	239,151.90	10.1	210,210.57
Florida	5,231,834	3,188,834.74	2,368,756.43	819,468.21	106.8	2,945,788.44	2,724,445.95	221,342.49	52.2	98.8	63,225.86	4.9	75,405.76
Georgia	10,091,185	2,454,833.18	2,454,833.18		148.3	3,984,436.69	3,984,436.69		40.9	263.1	937,255.91	54.6	2,714,659.22
Idaho	4,486,249	2,081,914.96	1,983,678.65		186.0	2,392,422.08	2,327,610.24		52.1	149.5	5,180.27		169,779.84
Illinois	17,570,770	875,515.27	874,109.87		54.6	13,536,195.03	13,536,195.03		61.3	377.0	3,149,264.04	20.3	11,201.06
Indiana	10,037,843	253,528.41	251,944.09		10.2	7,396,756.60	7,396,756.60		47.5	243.8	1,531,270.78	21.0	857,871.53
Iowa	10,055,660	2,568,343.11	2,479,345.00		181.1	7,125,320.07	6,428,425.00		76.8	434.2	419,600.00	26.7	728,290.00
Kansas	10,089,604	4,433,468.08	4,427,100.44		346.4	6,010,263.08	5,604,423.61	113,490.85	81.2	252.5	39,766.35	1.8	18,313.60
Kentucky	7,517,359	1,927,868.76	1,911,337.87		211.5	4,274,676.84	4,247,925.51		71.1	272.2	652,270.54	20.4	705,825.08
Louisiana	5,828,591	910,685.71	910,660.71		30.8	4,804,774.27	4,271,529.84	26,593.43	41.7	118.7	229,122.91	13.6	417,277.54
Maine	3,369,917	962,885.79	945,985.47		72.2	2,335,359.22	2,221,779.99		74.5	70.2			202,151.54
Maryland	3,564,527	192,659.52	192,659.52		14.6	1,795,267.37	1,767,542.62		56.6	60.5	851,871.75	18.4	752,453.11
Massachusetts	6,597,100	403,391.32	298,750.50	92,984.24	8.2	6,306,229.52	5,951,493.72	354,735.80	47.9	61.3			346,855.78
Michigan	12,736,227	609,350.00	609,350.00		21.8	11,122,025.00	11,055,975.00	49,000.00	61.6	493.8	670,661.00	21.6	400,241.00
Minnesota	10,656,569	4,806,390.55	4,773,432.02	20,482.87	726.8	5,075,626.02	5,006,302.16	40,000.00	44.7	402.0	295,777.82	7.4	581,057.00
Mississippi	6,978,675	750,685.09	419,729.63	292,323.52	34.4	5,979,960.73	4,044,661.94	1,935,298.79	49.4	357.4	941,797.47	75.2	1,572,485.96
Missouri	12,180,306	3,618,756.75	3,269,237.70	50,048.60	361.8	8,449,378.34	7,768,219.09	18,500.00	70.7	392.4	411,302.99	10.8	731,546.22
Montana	7,439,748	3,855,255.92	3,675,239.92	100,000.00	287.7	4,030,776.61	3,644,740.82	237,025.83	40.7	336.7	116,493.43	38.6	3,273.83
Nebraska	7,828,961	3,371,921.57	2,726,162.50	108,538.00	341.6	5,542,945.42	4,982,669.56		75.3	334.4	46,101.25	3.5	74,027.69
Nevada	4,545,917	2,272,291.76	2,272,291.76		250.1	2,129,166.52	2,082,217.64	43,327.07	40.1	121.7	104,943.76	6.4	86,463.84
New Hampshire	1,909,839	242,842.23	242,019.82		3.4	1,608,443.03	1,546,450.01	1,484.17	94.3	48.7	79,018.94	.4	42,350.23
New Jersey	6,346,039	424,480.28	424,480.28		11.5	5,791,712.29	5,582,658.28	169,466.42	49.7	58.6	183,262.19	.3	155,638.25
New Mexico	5,792,935	3,010,946.53	3,010,946.53		309.7	2,581,261.98	2,419,307.77	143,929.42	51.1	302.2	76,307.45	.8	286,373.25
New York	22,330,101	1,951,117.14	1,771,745.84	43,000.00	35.8	23,079,176.28	19,836,138.68	403,000.00	65.8	372.5	278,606.04		443,610.44
North Carolina	9,522,293	3,057,176.14	2,679,482.25	374,858.09	220.9	5,098,469.55	4,756,350.52	313,587.05	50.0	633.7	988,656.03	64.1	1,097,804.20
North Dakota	5,804,448	1,810,447.04	1,796,987.12	13,339.85	631.8	2,302,269.18	1,971,871.63	330,397.55	40.1	421.6	1,317,696.17	256.8	717,893.08
Ohio	15,484,592	4,487,104.87	4,309,578.81	19,665.00	283.0	11,938,052.43	10,873,959.70	31,745.00	69.8	266.5	216,300.00	6.6	84,753.49
Oklahoma	9,216,798	2,363,908.27	2,358,293.56		141.9	6,031,357.44	5,948,195.88		58.8	453.4	500,225.02	25.0	410,083.54
Oregon	6,106,896	3,314,088.31	2,976,682.38	182,576.53	203.4	3,043,042.53	2,867,125.88	50,403.39	44.9	114.9	185,591.79	2.0	77,495.95
Pennsylvania	18,891,004	3,156,687.41	3,129,693.80		165.6	14,965,149.85	14,566,471.17		56.7	662.9	633,275.79	21.8	561,563.24
Rhode Island	1,998,708	293,537.21	293,537.21		10.9	1,665,011.33	1,551,767.23	62,867.28	76.7	50.2			153,403.56
South Carolina	5,459,165	612,971.28	612,971.28		43.4	4,140,326.14	4,137,191.51	3,134.63	56.0	358.1	277,611.35	19.8	431,390.86
South Dakota	6,011,479	1,990,384.23	1,904,017.13	86,367.10	346.7	2,917,955.92	2,612,032.50	305,923.42	30.7	426.0	545,854.03	160.3	949,575.34
Tennessee	8,492,619	2,780,765.82	2,553,276.89	227,488.93	122.3	4,958,018.12	4,612,476.81	345,541.31	45.4	210.8	878,402.49	34.6	448,462.81
Texas	24,244,024	10,246,703.65	8,670,204.75		1,133.0	13,026,204.17	12,393,006.59		47.8	754.2	620,039.68	18.0	2,560,772.98
Utah	4,194,708	2,705,532.92	2,630,939.76		283.6	1,309,013.70	1,284,006.39		64.7	89.9	70,227.02	5.9	209,534.83
Vermont	1,867,573	260,010.96	258,282.30		15.0	1,691,423.44	1,589,282.85	5,838.96	62.9	81.2	20,007.85	.2	
Virginia	7,416,757	2,901,762.23	2,819,141.32	34,567.99	203.4	3,891,025.39	3,538,242.50	119,975.07	58.0	156.2	644,579.11	18.3	414,794.07
Washington	6,115,867	3,300,430.27	3,269,772.52	3,356.82	116.5	2,701,559.59	2,701,559.59		31.5	85.3	92,379.97	5.3	52,154.92
West Virginia	4,474,234	845,734.53	845,734.53		29.2	3,152,793.73	3,122,447.99		63.0	112.6	186,694.18	4.8	319,357.30
Wisconsin	9,724,881	3,116,575.69	3,038,601.12	22,690.00	152.7	6,278,239.13	6,079,509.42	42,898.24	54.7	289.9	346,603.23	10.1	260,167.23
Wyoming	4,501,327	1,912,809.06	1,773,640.65	80,400.00	291.2	2,661,768.63	2,502,859.64	85,908.57	60.6	337.2	118,755.79	13.5	101,070.92
District of Columbia	1,918,469	574,047.39	574,047.39		5.8	1,355,061.17	1,338,077.35		58.1	6.7			6,344.26
Hawaii	1,871,062	196,114.99	144,003.03	52,099.15	10.4	1,902,047.97	1,567,433.02	252,930.99	33.8	30.0	144,921.48	4.1	14,704.47
TOTALS	394,000,000	111,861,564.67	103,290,522.15	3,546,988.72	8,916.1	267,509,298.14	246,394,412.77	8,420,867.59	56.4	12,524.2	22,480,975.73	1,225.0	21,834,089.35

U. S. GOVERNMENT PRINTING OFFICE: 1934