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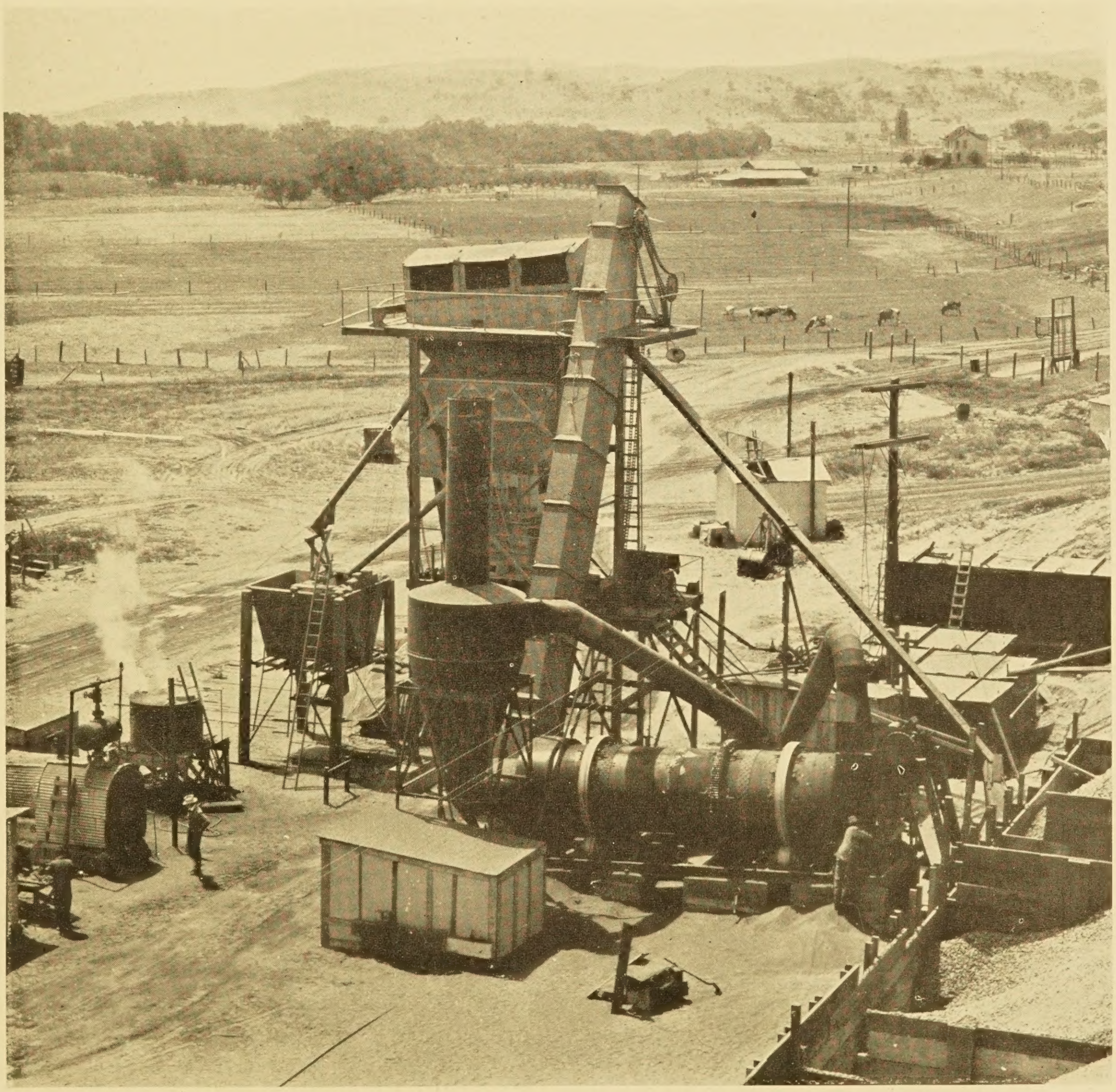

A BITUMINOUS CONCRETE MIXING PLANT

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

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BUREAU OF PUBLIC ROADS

G. P. St. CLAIR, *Editor*

Volume 15, No. 2 April 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

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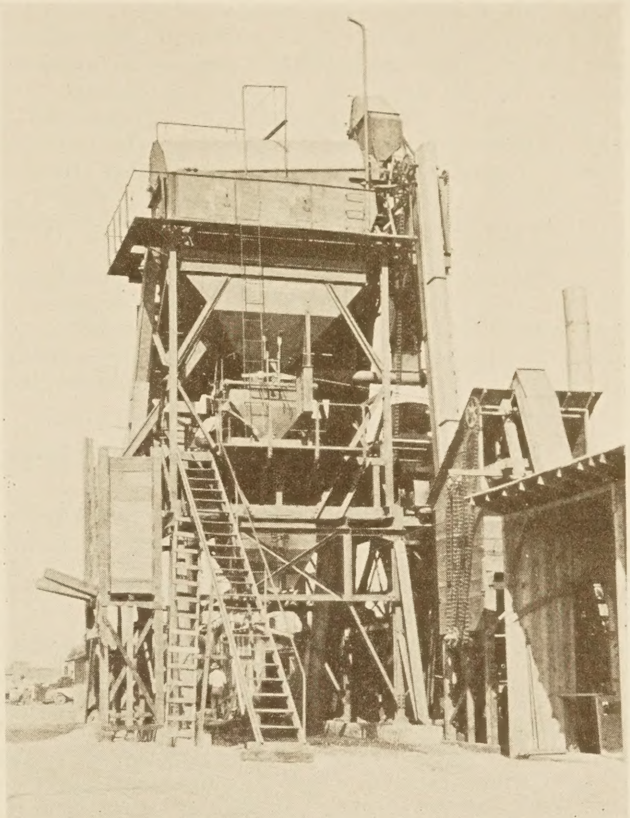
THE CONSTRUCTION OF HIGH-TYPE BITUMINOUS PAVEMENTS

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

Reported by C. F. ROGERS, Assistant Highway Engineer

IN 1926 the Bureau of Public Roads undertook a study of construction methods and costs on bituminous concrete highway projects. Twenty-three projects in 7 States with an aggregate length of 150 miles were selected for study. Each of the projects was designated by a job number which is used throughout this report. Details concerning the lengths of the projects, tons of surfacing for different courses and thickness of courses are given in table 1. The projects range in size from a minimum of 1,600 tons to a maximum of 49,000 tons.

To facilitate comparison, actual mileages have been adjusted to mileages of pavement 20 feet wide and of equivalent area. The tonnage per square yard and per mile for base and surface courses is shown for each project. The tonnage of material in base courses includes material used as a base in surface widening, full-width base sections on relocation, and the course ordinarily referred to as the leveling course and placed on the base. Surface courses include only top or wearing courses whether constructed on base of similar or dissimilar type. The average base and surface thickness has been derived for each project by calculations based on actual specific gravities developed in the various courses and actual weights of each course. Averaging the figures for all projects results in an average project with a 20-foot surface, 5.15 inches of bituminous mixture, 6.5 miles in length and containing 3,142 tons of material per mile. This average project required 20,426 tons of material, but recent projects have required approximately 54,000 tons in 12 miles and 65,000 tons in 14 miles.



A Modern, Large-Capacity Plant Showing Screens, Bins, Mixer, and Storage Box. Trucks Drive Straight Through in Loading.

Table 1.—*Length, thickness, and quantities involved in projects studied*

Job no.	Length of 20-foot pavement equivalent in area	Quantities required			Surface area	Quantities per square yard			Quantities per mile			Number of courses	Thickness		
		Base	Surface	Total		Base	Surface	Total	Base	Surface	Total		Base	Surface	Total
	Miles	*Tons*	*Tons*	*Tons*	*Square yards*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*		*Inches*	*Inches*	*Inches*
1	8.28	16,294	9,458	25,752	97,104	0.168	0.097	0.265	1,968	1,142	3,110	3	3.25	1.79	5.04
2	9.09	18,877	9,954	28,831	106,653	.177	.093	.270	2,077	1,095	3,172	3	3.42	1.72	5.14
3	6.57	--------	5,599	5,599	77,082	--------	.073	.073	--------	851	851	1	--------	1.54	1.54
4	5.89	5,496	5,209	10,705	69,064	.080	.075	.155	933	884	1,817	2	1.55	1.42	2.97
5	13.94	17,134	21,392	38,526	163,504	.105	.131	.236	1,228	1,533	2,761	3	2.03	2.42	4.45
6	4.58	5,459	3,348	8,807	53,701	.103	.062	.165	1,192	731	1,923	2	1.99	1.17	3.16
7	4.40	6,967	5,951	12,918	51,672	.135	.115	.250	1,580	1,349	2,929	2	3.08	2.32	5.40
8	1.55	1,307	3,153	4,460	18,210	.072	.173	.245	843	2,034	2,877	2	1.65	3.52	5.17
9	6.59	15,353	7,733	23,086	77,332	.199	.100	.299	2,326	1,172	3,498	3	3.85	1.85	5.70
10	3.45	3,191	2,953	6,144	40,421	.079	.073	.152	925	856	1,781	2	1.53	1.38	2.91
11	6.26	8,934	9,724	18,658	73,457	.122	.132	.254	1,425	1,551	2,976	2	2.79	2.69	5.48
12	6.19	11,198	7,642	18,840	72,667	.154	.105	.259	1,809	1,234	3,043	3	2.98	1.99	4.97
13	2.75	--------	2,393	2,393	32,292	--------	.074	.074	--------	870	870	1	--------	1.50	1.50
14	1.41	--------	1,638	1,638	16,595	--------	.099	.099	--------	1,161	1,161	1	--------	1.99	1.99
15	2.29	3,946	2,252	6,198	26,831	.147	.084	.231	1,723	983	2,706	2	3.36	1.69	5.05
16	7.27	15,316	10,180	25,496	85,333	.180	.119	.299	2,107	1,400	3,507	3	3.48	2.20	5.68
17	4.34	4,286	3,862	8,148	50,925	.084	.076	.160	987	890	1,877	2	1.77	1.50	3.27
18	9.85	26,776	13,327	40,103	115,519	.232	.115	.347	2,721	1,355	4,076	3	4.49	2.13	6.62
19	12.20	29,680	19,270	48,950	143,162	.207	.135	.342	2,433	1,579	4,012	3	4.00	2.50	6.50
20	4.49	9,144	8,410	17,554	52,647	.173	.160	.333	2,037	1,873	3,910	3	3.34	2.96	6.30
21	9.63	26,238	13,447	39,685	112,992	.232	.119	.351	2,725	1,396	4,121	3	4.49	2.20	6.69
22	8.62	21,593	12,163	33,756	101,151	.214	.120	.334	2,505	1,411	3,916	3	4.13	2.22	6.35
23	9.89	29,823	13,733	43,556	115,984	.257	.119	.376	3,019	1,390	4,409	3	4.97	2.20	7.17
Weighted average	6.50	12,044	8,382	20,426	76,274	.158	.110	.268	1,853	1,289	3,142	--------	3.11	2.04	5.15

By far, the greater number of projects studied consisted of surfacing laid directly on old cement concrete pavements, although a few surfaces were placed on new subgrade or on new cement concrete base. In all cases, except one, the surfacing was placed between side forms of wood, steel, or concrete and finished to these forms. All of the single-course pavements were laid on cement concrete base of a lean mix, and a thickened-edge section with curbs for lateral support. In the case of the one project where side forms were not used the base was made 1 foot wider than the surface course.

The mixes used include those commonly referred to as sheet asphalt, fine aggregate bituminous (or asphaltic) concrete, coarse aggregate bituminous concrete, and modifications of certain patented types of pavement on which patents are no longer operative. In the study of rates of production and costs, only those items directly related to the actual pavement are included and such items as subgrading, form-setting, and production of materials are omitted.

The projects were all of such size as to justify construction with a single plant set-up. In most cases the plants were located near the center of the job but factors such as the location of satisfactory sidings, space rentals, and accessibility made it desirable to locate some plants at a distance from the center.

TYPICAL PROCEDURE IN BITUMINOUS CONCRETE CONSTRUCTION DESCRIBED

Figure 1 shows the plan and elevation of a typical bituminous concrete plant. Aggregates are usually delivered by rail to an adjacent siding. From 2 to 4 separated sizes are delivered. The aggregate is moved from the cars to stock piles from which the "cold bucket-elevator" is fed. At some plants the unloading is done by crane and at others the tracks of the siding are elevated permitting bottom-dumping of cars and gravity feed to bins or piles. Gravity feed from bins to the bucket elevator with the flow regulated by control gates is frequently used. Belt conveyors are also used, particularly for the sand. The different sizes of aggregate should be fed to the elevator in the proportions required for the mix as nearly as is possible.

The cold elevator hoists the material to the dryer for drying and heating. When this operation is completed the material is discharged by gravity to the hot pit beneath. At some plants, a blower and dust collector (see fig. 1) is used to by-pass the fine, dry material to prevent clogging the dryer. The fine material is wasted or deposited in the hot elevator pit with the larger heated aggregate.

An elevator raises the material from the hot pit to screens at the top of the plant where it is separated into the required sizes and then deposited in storage bins located over the weighing hopper. Where filler is used, it is generally conveyed from ground storage to a separate bin from which it may be fed by gravity or screw conveyor to the weighing box.

A boiler is used to furnish steam for heating materials and to operate the various power units. The boiler is usually heated by fuel oil which is stored in tanks and pumped to the boiler. Asphalt is drawn from cars and stored in an underground tank where it is heated by steam coils or tubes. The asphalt is pumped from this pit to the mixing platform on the main tower of the plant just above the pug mill.

A batch is proportioned by allowing each size of aggregate to flow into the weighing box in the proper amount as determined by weight. The aggregates are then dumped into the pug mill, which is in continuous operation, and the asphalt is admitted while the materials are being agitated. On completion of the mixing the batch is discharged through a steam-activated discharge gate to a storage box or directly to hauling equipment.

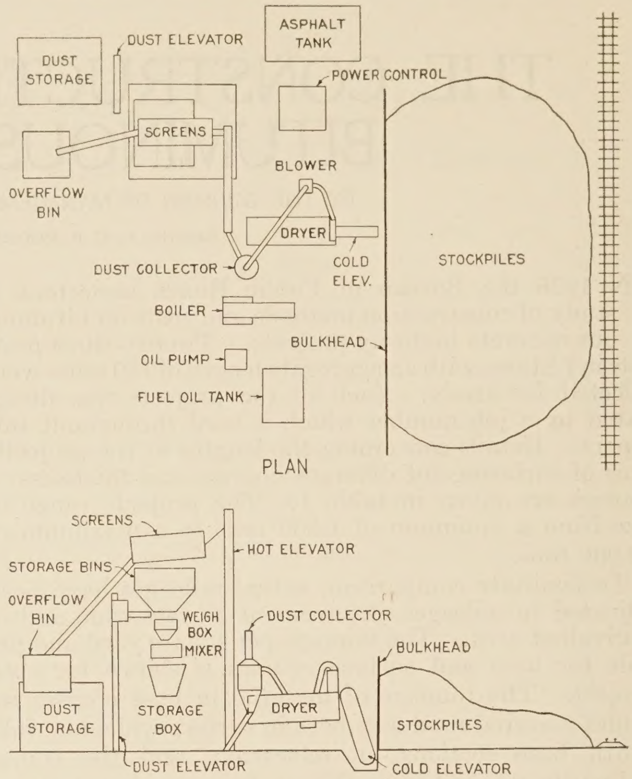


FIGURE 1.—TYPICAL ARRANGEMENT OF MIXING PLANT.

The mixed material is hauled to the road and deposited directly on the surface or in spreader boxes. It is then either shoveled and raked into place or it is spread with the spreader boxes. Following the initial spreading, the final spreading and raking is often done by hand but recently, particularly in the west, the mechanical finishing machine has to a large extent replaced hand finishing.

Rolling is done with a variety of types of rollers. Both the macadam and tandem type are used and weights range from 3 to 15 tons.

PLANT MODIFICATIONS DESCRIBED

Many modifications from the plant arrangement which has been described were observed but the general methods remained unchanged. On some projects in the Middle Western States the various plant accessories were built around a mixing unit mounted on a railroad flat car. With such plants the economy of easy movement is largely offset by small capacity which is inherent in the design. At one large plant, an elevator fed hot material to screens and batcher on one tower and a second elevator raised the batches to a hopper supplying the mixer on another tower. This arrangement reduced the over-all height of the plant. At another plant of medium capacity the units were arranged horizontally on low towers with furnace, dryer, screen hopper, and mixer assembly, and power plant in the order named. Most of the plants studied had very desirable jacking and other devices for assembling units with speed and facility. The plant design which provides a balanced flow of materials through the several units with a minimum number of simple mechanical devices will also provide the greatest freedom from breakdown and delay.

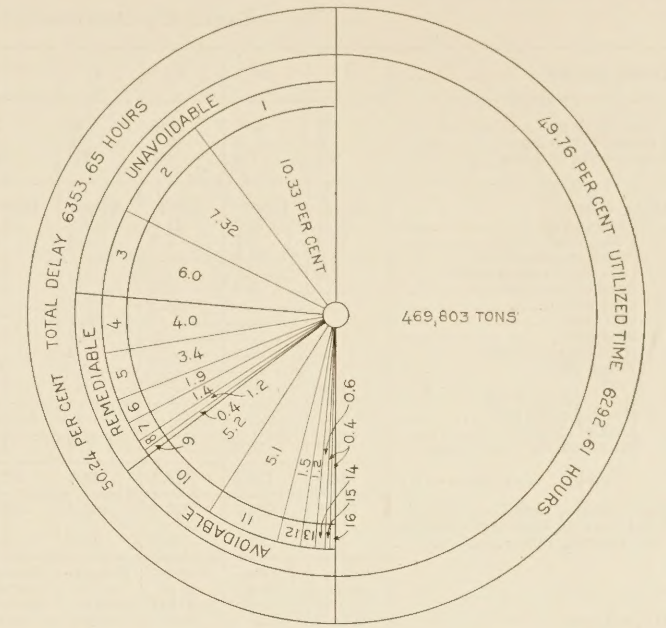
TIME DISTRIBUTION AND DELAY STUDIED

Although the plants studied varied somewhat in their arrangement, the particular functions of the various units were comparable. On every project there was a limiting unit or bottle neck, past which the materials could flow only in definitely limited amount. The removal of this bottle neck at one unit would only transfer it to some other unit which would then fix the rate of production. The purpose of the time study has been to derive the limiting rate for each unit or part of the plant and gradually to synchronize the several units by adjustment of size and speed or improvement of control of moving parts.

Stop-watch studies covering thousands of hours were made of repetitive operations, such as loading, batching, and mixing. Analysis of these data resulted in detailed information concerning operating cycles and capacity of each unit. An accurate record was kept of the cause and amount of all delays. Delay or lost time was classed as "major" or "minor." Major delays are definite stops in excess of 15 minutes and may occur during working hours or as a prolonged shut-down. Minor delays occur only during working hours under full expense and are usually of greater relative cost than major delays. They may be only a few seconds in duration but may recur frequently in cyclical operation. Study of stop-watch records for typical hours of operation indicated the extent of each kind of delay and comparisons were made on a percentage basis. It has been assumed that such percentages reflect the time distribution during all of the working hours. The correctness of this assumption has been checked by comparison with records covering protracted periods and the error is found to be less than one tenth of 1 percent.

Job time or "available time" is based on the length of the average working day and the days of job duration with the exception of Sundays and holidays. The elimination of major delays from available time results in "working time" during which the full crew is always on the job. The subtraction of minor delays from working time results in "utilized time" during which the plant is operating at 100 percent efficiency. In conducting the study both major and minor delays were classified as to causes and also as to whether they were avoidable, partly remediable by good management, or unavoidable.

The results of such studies are shown in tables 2 and 3 and figure 2. The nature and extent of all major and minor delays observed in the time studies on each of the 23 jobs are shown in table 2. The available time on each project is shown in days and the average working day is shown in hours. The product of these two yields the total available hours for each project, and the summation of all projects gives 12,646 hours total available time. Major delays resulting from 15 general causes are responsible for the loss on all jobs of 4,552 hours, or 36 percent of all available time. Minor delays resulting from 9 general causes account for the loss of 1,801 hours out of 8,094 working hours—a loss of 22 percent of working time and 14 percent of available



DELAY LEGEND

1 RAIN AND SNOW
2 WET BASE OR SUBGRADE
3 COLD AND FOGGY WEATHER
4 MISCELLANEOUS
5 MECHANICAL TROUBLE AT PLANT
6 MOVING, CHANGING MIX, ETC.
7 MECHANICAL TROUBLE ON STREET
8 LACK OF MATERIALS AT PLANT
9 HEATING MATERIALS
10 HAULING EQUIPMENT SUPPLY AND OPERATION
11 BINS EMPTY OR OVERFLOWING
12 HANDLING AGGREGATE AT PLANT
13 OPERATIVE DELAY AT PLANT
14 LACK OF SUBGRADE
15 HANDLING ASPHALT AND FUEL
16 LATE START - MANAGEMENT

FIGURE 2.—AVAILABLE TIME DISTRIBUTED ACCORDING TO TIME UTILIZED AND TIME LOST.

time on all jobs. Of the 12,646 available hours, but 6,293 hours are utilized in the direct production of paving mixtures.

Table 3 is a recapitulation of table 2, distributing all delays according to 18 general causes, and subdividing each kind of delay as unavoidable, partly remediable or avoidable. Under these heads the delays are further classified as major and minor. The last column of the table showing the number of jobs on which each type of delay occurred shows that certain well-defined types of time loss were found on nearly every project studied. The data of table 3 are shown graphically in figure 2.

EFFICIENCY OF MANAGEMENT VARIES GREATLY ON DIFFERENT PROJECTS

The extent to which production on the various projects suffered from major and minor delays combined may be shown by computing utilized time as a percentage of available time. Such percentages are given in the third column of table 4. The effect of minor delays only (utilized time as a percentage of working time) is shown in the second column. Projects are listed in the table in the ascending order of these percentages which range from 55 to 97 percent. The last column of the table shows the over-all efficiency on each of the jobs derived by computing actual utilized time as a percentage of possible utilized time (available time less unavoidable delays).

TABLE 2.—*Distribution of time losses on 23 projects*

Project number	1	2	3	4	5	6	7	8	9	10	11	12	13
Available days	75	91	48	50	73	60	41	28	40	78	81	57	36
Average day, hours	8	8	9.1	10	8	13.5	12.8	9.9	8	12.3	9.7	8	8
Total available hours	601	728	437	502	584	814	525	277	321	960	783	459	288
Major delays:	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*
Rain and snow	54.2	70.5	31.0	69.0	62.7	94.6	55.0	29.5		168.7	48.3	43.4	27.0
Plant, mechanical	11.9	5.7	2.0	7.3	7.0	16.9	23.0		3.3		35.5	6.3	0.8
Street, mechanical	5.0	32.8			4.6				3.0		4.0		6.1
Late start, management	5.0				3.8		5.9						
Lack of materials		6.5	2.0		3.2			5.1		52.0	16.9	6.4	
Cold and fog			143.5	95.2									148.8
Wet base				59.1		128.7	65.2			272.8			
Moving				20.3	2.0	140.6					.5		
Hauling equipment				1.5			24.3		7.5	5.0			
Power belts					2.8								
Fuel					6.8								
Handling materials						25.8		27.0	3.3	5.5	12.3	15.7	.6
Heating materials								12.6		5.2		17.5	
Lack of subgrade										31.6	10.0		
Miscellaneous	8.0	13.0		7.3	14.6	12.4	17.7			22.6	4.0	8.9	2.7
Total	84.1	128.5	178.5	259.7	107.5	419.0	191.1	74.2	17.1	563.4	131.5	98.2	186.0
Total working time	516.9	599.5	258.5	242.3	476.5	395.0	333.9	202.8	303.9	396.6	651.5	360.8	102.0
Total working time as pereentage of available time	86.0	82.4	59.2	48.3	81.6	48.5	63.6	73.2	94.7	41.3	83.2	78.6	35.4
Minor delays:	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*
Hauling equipment	8.9	17.0	4.4	4.6	2.0	4.3	17.5	24.7	11.5	11.6	5.4	3.7	7.0
Bin shortage	8.5	12.0	7.2	10.6	4.3	8.0	15.3	14.9	9.0		6.7	12.8	10.4
Plant, mechanical	1.1	.7	.4	1.0	2.7	5.0	1.6	1.9	1.6	1.6	2.5	1.2	
Plant, operative	.1	.8	.6	4.4	1.6	3.0	1.5	2.7	1.0	2.5	1.1	2.8	2.1
Handling aggregate	5.9		.4			2.0	4.1	.6		2.2		.5	.1
Finishing					3.4								3.3
Changing or inspecting mix					.6				.5			.5	.3
Handling asphalt							1.4		4.5				.1
Miscellaneous	1.2		2.4	1.0	2.2	2.5	.7	.4		.7	2.0	1.2	.2
Total	25.7	30.5	15.4	21.6	16.8	24.8	42.1	45.2	28.1	18.6	17.7	22.7	23.5
Total minor delay, hours	133.0	183.0	39.9	52.3	80.2	97.8	140.6	91.5	85.5	73.8	115.6	81.9	24.0
Total utilized time, hours	383.9	416.5	218.6	190.0	396.3	297.2	193.3	111.3	218.4	322.8	535.9	278.9	78.0
Utilized time as percentage of—													
Working time	74.3	69.5	84.6	78.4	83.2	75.2	57.9	54.8	71.9	81.4	82.3	77.3	76.5
Available time	63.9	57.2	50.1	37.8	67.8	36.5	36.8	40.1	66.8	33.7	68.4	60.8	27.1

TABLE 3.—*Recapitulation of delays by classes, showing time lost in hours and as a percentage of available time*

Cause of delay	Class of delay												All classes		Number of projects on which delay occurred
	Unavoidable				More or less remediable				Avoidable						
	Major		Minor		Major		Minor		Major		Minor				
	Hours	*Percent*	*Hours*	*Percent*	*Hours*	*Percent*	*Hours*	*Percent*	*Hours*	*Percent*	*Hours*	*Percent*	*Hours*	*Percent*	
Rain and snow	1,307	10.3											1,307	10.3	21
Wet base or subgrade	926	7.3											926	7.3	10
Cold and foggy weather	729	5.8											729	5.8	6
Hauling equipment, supply and operation									44	0.3	613	4.9	657	5.2	23
Bins empty or overflowing											638	5.0	638	5.0	21
Miscellaneous					421	3.3	89	0.7					510	4.0	20
Mechanical trouble at plant	6	0			311	2.5	112	.9					429	3.4	23
Moving on street					198	1.6							198	1.6	10
Handling aggregate at plant									107	.8	90	.7	197	1.5	17
Mechanical on street					176	1.4							176	1.4	14
Lack of materials at plant					151	1.2							151	1.2	12
Operative at plant											146	1.2	146	1.2	23
Lack of subgrade									75	.6			75	.6	6
Handling asphalt and fuel									7	.1	46	.4	53	.5	10
Heating materials at plant					48	.4							48	.4	6
Late start—management									46	.4			46	.4	8
Finishing							44	.3					44	.3	6
Inspecting or changing mix			23	.2									23	.2	7
Total major delay	2,968	23.4			1,305	10.4			279	2.2			4,552	36.0	
Total minor delay			23	.2			245	1.9			1,533	12.2	1,801	14.3	
Total major and minor delay:															
Hours	2,991				1,550				1,812				6,353		*Average*
Percent	23.6				12.3				14.4					50.3	13.5

TABLE 2.—*Distribution of time losses on 23 projects*—Continued

Project number	14	15	16	17	18	19	20	21	22	23	Total for all projects	Percentage of available time
Available days	39	29	113	28	50	114	86	102	39	42.5		
Average day, hours	8.5	11.5	8	11.8	8	8	8	8	8	8		
Total available hours	332	335	904	330	397	912	688	816	312	341	12,646	100.0
Major delays:	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	
Rain and snow	92.8	48.5	71.5	0.5		65.8	208.0	47.5	4.0	14.5	1,307	10.3
Plant, mechanical	18.1	.8	81.0		3.0	41.3	13.6	19.7	8.7	5.1	311	2.5
Street, mechanical	4.7	7.0	50.6		.3	7.3	11.8	33.2	5.6		176	1.4
Late start, management		1.0		1.4		12.0		9.9	7.0		46	.4
Lack of materials		1.5	6.0			47.4			3.3	.7	151	1.2
Cold and fog	111.1		9.5			220.9					729	5.8
Wet base	27.0	65.8	41.7				135.9	113.8	16.0		926	7.3
Moving		3.3		3.5	1.4	4.7	16.3	5.4			198	1.6
Hauling equipment		2.3		.8			.3	2.3			44	.3
Power belts					1.8					1.4	6	
Fuel					.2						7	.1
Handling materials		6.5			2.3		4.8	3.2			107	.8
Heating materials		7.3			3.7					1.7	48	.4
Lack of subgrade		6.8	18.2		.7			7.7			75	.6
Miscellaneous	5.3	1.5	250.5	8.9			.5	43.1			421	3.3
Total	259.0	152.3	529.0	15.1	13.4	399.4	391.2	285.8	44.6	23.4	4,552	36.0
Total working time	73.0	182.7	375.0	314.9	383.6	512.6	296.8	530.2	267.4	317.6	8,094	
Total working time as percentage of available time	22.0	54.5	41.5	95.4	95.6	56.2	43.1	65.0	85.7	93.1	64.0	
Minor delays:	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Percentage of working time*	*Hours*	
Hauling equipment	3.9	9.9	3.9	16.7	1.5	4.9	3.0	7.5	1.2	0.1	613	4.9
Bin shortage	5.2	6.7	18.5		9.1	3.5	1.8	8.8	9.1	1.0	638	5.0
Plant, mechanical	.1	2.7	1.2	2.5	.9	.3	.5	.1			112	.9
Plant, operative	1.1	2.1	1.6	1.8	1.5	3.1	2.5	2.4	2.0	.7	146	1.2
Handling aggregate	.5	8.7	.8						1.9		90	.7
Finishing	2.7				1.5			2.4		1.3	44	.3
Changing or inspecting mix		2.7	1.5		1.6						23	.2
Handling asphalt	3.7	6.0	.2			1.6	1.6				46	.4
Miscellaneous						.5	5.4	1.3	1.9		89	.7
Total	17.2	38.8	27.7	21.0	16.1	13.9	14.8	22.5	16.1	3.1	*Percentage* 22.3	14.3
Total minor delay, hours	12.5	70.8	103.8	66.2	61.8	71.0	43.8	119.3	43.0	9.7	1,801	
Total utilized time, hours	60.5	111.9	271.2	248.7	321.8	441.6	253.0	410.9	224.4	307.9	6,293	
Utilized time as percentage of—												
Working time	82.8	61.2	72.3	79.0	83.9	86.1	85.2	77.5	83.9	96.9	77.7	
Available time	18.2	33.3	30.0	75.4	81.1	48.4	36.8	50.4	71.9	90.3	49.8	

The over-all efficiency for the average job is computed as follows:

		Hours
Available time		12,646
Unavoidable delay:		
Major	3,889	
Minor	228	
		4,117
Possible utilized time		8,529
Avoidable delay:		
Major	663	
Minor	1,573	
		2,236
Actual utilized time		6,293
Actual utilized time as a percentage of possible utilized time		74

These data are shown graphically in figure 3. The upper graph shows the distribution of available time between the two kinds of delays and productive work. The lower graph shows the distribution of working time between minor delays and productive work and a comparison of over-all efficiency at the various plants. The close agreement of utilized time as a percentage of working time with over-all efficiency indicates that the minor delays were largely avoidable and that the major delays were largely unavoidable.

These data are an index of the efficiency of management in making use of available time. However, they do not reflect the mechanical efficiency of the plants while in full production.

TABLE 4.—*Utilized time as a percentage of available time and of working time and over-all efficiency at all plants*

Job no.	Utilized time as a percentage of working time	Utilized time as a percentage of available time	Total working time as a percentage of available time	Over-all efficiency
	Percent	*Percent*	*Percent*	*Percent*
8	55	40	73	46
7	58	37	64	52
15	61	33	55	56
2	69	57	82	69
9	72	67	95	71
16	72	30	42	66
1	74	64	86	75
6	75	37	49	65
13	77	27	35	76
12	77	61	79	71
21	78	50	65	73
4	78	38	48	76
17	79	75	95	80
10	81	34	41	65
11	82	68	83	81
14	83	18	22	81
5	83	68	82	84
18	84	81	97	85
22	84	72	86	82
3	85	50	59	86
20	85	37	43	89
19	86	48	56	78
23	97	90	93	96

The frequency and extent of delays from a variety of causes warrants a detailed discussion of the manner in which they creep into highway construction operation either as a result of adopted practices of management, or as a result of circumstances not directly controlled by management. Discussion of these matters will be delayed in order to first consider other losses which are

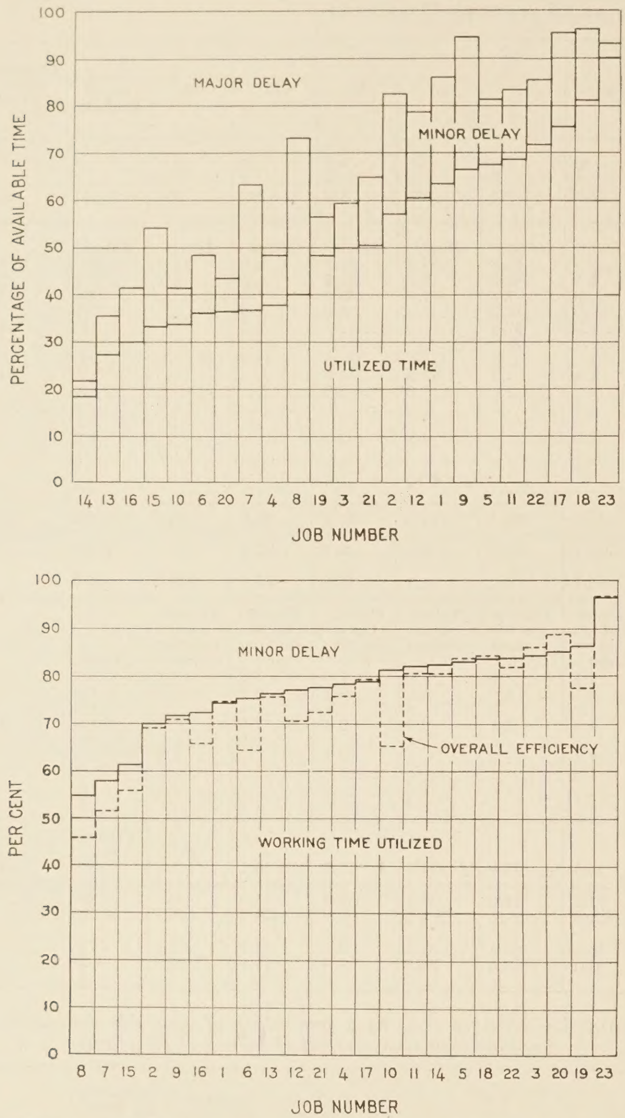


Figure 3.—Utilized Time and Major and Minor Delays as Percentages of Available Time (Upper Graph) and Working Time Utilized and Over-all Efficiency at all Plants.

equally great in their effect on the potential profits of the contractor.

PROJECTS RATED ACCORDING TO EFFICIENCY OF PRODUCTION

Efficiency of production during utilized time involves the inherent rates of production of the units making up the plant, practices in operating the plant and specification requirements. Table 5 shows details concerning the mixing cycles on each of the 23 jobs, the output of the plants and their over-all efficiency. The mixing cycles shown represent the actual average performance during utilized time.

Mixing cycles range from 46.8 seconds to 87.4 seconds with the corresponding batches per hour ranging from 76.9 to 41.2. The plant with the smallest batch (0.309 ton) had a mixing cycle of 58.6 seconds with a resulting possible output of 19 tons per hour. A plant producing batches in excess of 2 tons in a cycle of 49.2 seconds, had a possible output of 150 tons per hour or 8 times the amount of the smaller plant.

In table 5 the total job tonnage and the utilized time (table 2) are used to determine the rate of production per utilized hour. Since utilized time represents operation at maximum efficiency, this figure also represents maximum possible production or plant capacity. Working hours and total tons produced are used to determine the production per working hour. The percentage of plant capacity attained is the same as the percentage of working time utilized. Production per available hour is also shown. The over-all efficiencies, which reflect the management's use of available time exclusive of unavoidable delays are repeated from table 4 for comparative purposes.

The production of a plant depends on both the inherent limitations of the plant equipment and on the efficiency with which it is operated. An index of production may be obtained by multiplying the plant capacity in tons per hour by the over-all efficiency. Such an index for each plant is shown in table 6, which is arranged in descending order of indices. If the job with the highest index of production, no. 23, be accepted as having maximum production, or 100 percent, we can then compute the percentage of maximum attained on the other projects as shown in the table.

The production of job no. 23, as controlled by the combined plant and management characteristics was 2½ times that of the average and 11 times that of job no. 10. A later section of the report will show that the unit costs for labor and equipment on each project are in substantially the same order as the indices of production. Job no. 23 was a large project and used a large plant, and it should not be assumed that every project should use such a plant or should attain 100 percent on the basis used in table 6.

The data of table 5 are shown graphically in figure 4 in which the jobs are arranged in numerical order. The upper diagram shows the time of charge, mixing, and discharge for each plant. The middle diagram is a comparison of batch size with a superimposed comparison of the possible batches per hour at each plant—the two factors which determine the possible output. The lower diagram shows the rates in tons per utilized hour, per working hour, and per available hour. These rates are also referred to as plant capacity, attained production, and gross production. These rates cover production on whole road projects and therefore represent average characteristics.

RATES OF PRODUCTION ON THREE PROJECTS COMPARED

In a study of production with a view to increasing efficiency we must go beyond average characteristics and examine the fluctuations in output from day to day. Good management will be reflected by a consistent high daily production while inefficient management which permits delays to creep in will show fluctuations.

Figure 5 shows the cumulative rates of production during working time expressed as a percentage of the maximum possible rate on each day of operation on three typical projects. The figures for any day represent the average for all days up to and including that day. There is a marked difference in the general average rates attained at the three plants, which are affected by the size of the plant, specification requirements as to the mixing cycle, and the efficiency of management. The projects were selected particularly to show variations in the effect of fortuitous conditions.

Table 5.—*Operating characteristics and efficiency of plants studied*

Job no.	Operating characteristics of mixer: Charge	Mix	Discharge	Cycle	Possible batches per hour	Average batch	Possible production per hour	Production during study	Attained production per working hour	Ratio of attained production to plant capacity	Production per available hour	Over-all efficiency
	Seconds	*Seconds*	*Seconds*	*Seconds*		*Tons*	*Tons*	*Tons*	*Tons*	*Percent*	*Tons*	*Percent*
1	9.2	43.3	10.5	63.0	57.1	1.174	67.1	25,752	49.8	74.3	42.8	74.6
2	11.1	45.4	12.8	69.3	51.9	1.333	69.2	28,831	48.1	69.5	39.6	69.3
3	10.7	59.0	14.6	84.3	42.7	.599	25.6	5,599	21.6	84.4	12.8	86.3
4	8.1	51.6	3.4	63.1	57.1	.987	56.3	10,705	44.2	78.5	21.3	75.7
5	8.4	39.8	9.8	58.0	62.1	1.566	97.3	38,526	80.9	83.1	66.0	84.2
6	18.6	35.6	5.0	59.2	60.8	.487	29.6	8,807	22.3	75.4	10.8	64.5
7	7.3	38.5	4.0	49.8	72.3	.923	66.8	12,918	38.7	57.9	24.6	51.6
8	8.2	34.8	3.8	46.8	76.9	.523	40.2	4,460	22.0	54.8	16.1	45.7
9	14.0	40.0	8.0	62.0	58.1	1.819	105.7	23,086	75.9	71.9	71.9	70.9
10	12.5	34.3	11.8	58.6	61.4	.309	19.0	6,144	15.5	81.5	6.4	65.1
11	8.1	38.9	4.2	51.2	70.3	.495	34.8	18,658	28.6	82.2	23.8	80.7
12	10.4	41.5	11.4	63.3	56.9	1.188	67.6	18,840	52.2	77.3	41.0	70.8
13	10.8	61.0	9.2	81.0	44.4	.690	30.7	2,393	23.5	76.5	8.3	75.8
14	5.4	72.1	9.9	87.4	41.2	.659	27.1	1,638	22.5	82.9	4.9	80.6
15	10.6	56.6	5.6	72.8	49.5	1.124	55.6	6,198	34.0	61.2	18.5	55.9
16	7.0	41.3	10.0	58.3	61.7	1.523	94.1	25,496	68.0	72.3	28.2	65.5
17	10.0	42.7	8.0	60.7	59.3	.552	32.8	8,148	25.9	79.0	24.7	79.5
18	12.1	33.0	13.7	58.8	61.2	2.035	124.6	40,103	104.5	83.9	101.0	84.5
19	10.0	40.3	13.2	63.5	56.7	1.956	110.9	48,950	95.5	86.1	53.7	77.7
20	8.2	43.4	13.8	65.4	55.0	1.262	69.4	17,554	59.1	85.2	25.5	88.9
21	6.0	40.0	12.2	58.2	61.8	1.563	96.6	39,685	74.8	77.5	48.6	72.6
22	10.8	24.2	14.2	49.2	73.2	2.055	150.4	33,756	126.2	83.9	108.2	82.2
23	9.8	31.3	14.5	55.6	64.8	2.186	141.7	43,556	137.4	97.0	127.9	96.2
Average or total	9.9	43.0	9.7	62.6	57.5	1.299	74.7	469,803	58.4	78.2	37.1	73.9

Table 6.—*Indices of production and comparison of production based on assumption that maximum production was attained on job no. 23*

Job	Index of production	Percent of maximum	Job	Index of production	Percent of maximum
23	136.2	100.0	4	42.7	31.3
22	123.8	90.0	7	34.5	25.3
18	105.2	77.3	15	31.1	22.8
19	86.1	63.2	11	28.1	20.6
5	81.9	60.1	17	26.1	19.2
9	75.0	55.1	13	23.3	17.1
21	70.2	51.5	3	22.1	16.2
20	61.7	45.3	14	21.9	16.1
16	61.6	45.2	6	19.1	14.0
1	50.1	36.8	8	18.4	13.5
2	47.9	35.2	10	12.4	9.1
12	47.8	35.1			

Table 7 shows for each of these three jobs the factors controlling production as actually recorded during working hours and as specified or interpreted in practice. On some of the jobs studied the specifications required a standard mixing time and also limited the number of batches per working hour at a rate not in harmony with the mixing time—a double standard frequently encountered in this class of work. On the projects studied the limitation on batches per hour was the one usually enforced. Lack of adequate devices for timing the mixing period and the consequent lack of control is the probable cause of the limitation of batches per hour. On recent projects, satisfactory timing devices have been in use and there appears no need for additional limitation.

On job no. 4 different mixing times were specified for base and surface course. With the necessary charge and discharge time the average cycle (specified) was 56 seconds, which permitted 64.3 batches per hour. The mixer was designed for a 1-ton batch, which limited production to 64.3 tons per hour.

On job no. 18 the specification, as interpreted, permitted a mixing time plus one half the discharge time of 45 seconds or alternately a maximum rate of 65 batches per hour. The latter requirement governed. Using a 2-ton batch for which the mixer was designed gave a maximum permissible rate of 130 tons per hour.

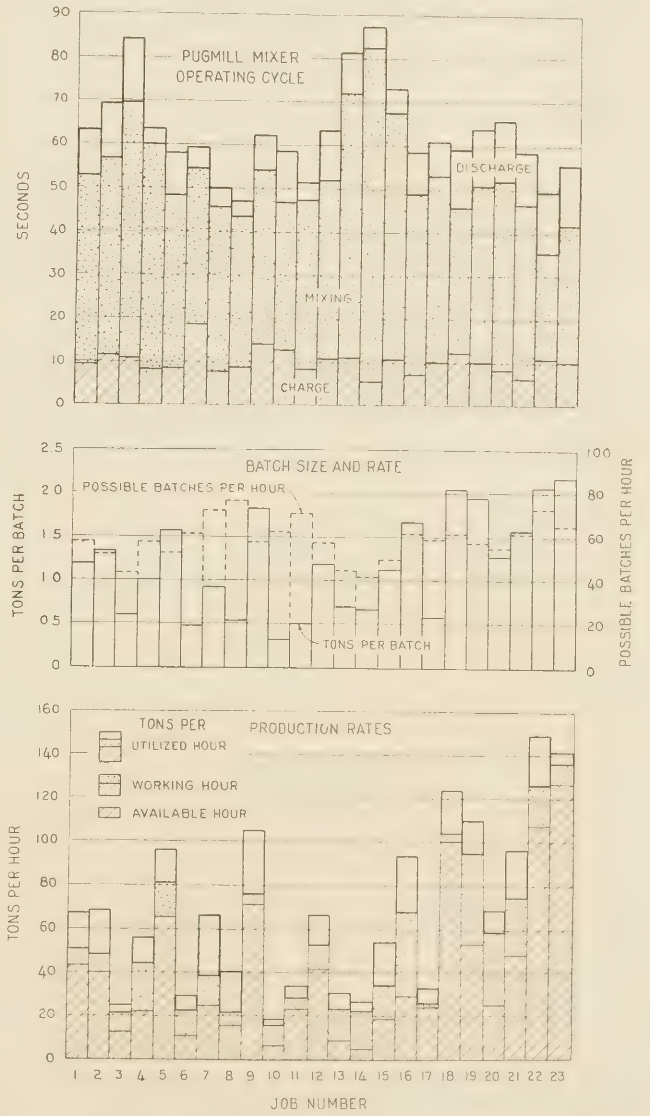


Figure 4.—Effect of Operating Cycle and Batch Size on Production Rate.

Table 7.—*Factors controlling production at 3 plants whose production rates are shown in figure 5*

	Actual limitations			Specified or plant limitation		
	Base	Surfacing	Total or average	Base	Surfacing	Total or average
Project no. 4						
Charge, seconds	7.2	8.6	8.1	7.2	8.6	7.9
Mix, seconds	33.5	60.7	51.6	30.0	60.0	44.6
Discharge, seconds	4.0	3.0	3.4	4.0	3.0	3.5
Cycle, seconds	44.7	72.3	63.1	41.2	71.6	56.0
Batches per working hour	63.2	39.1	44.8	87.4	50.3	64.3
Tons per batch	.944	.889	.987	1.0	1.0	1.0
Tons per working hour	59.6	34.7	44.2	87.4	50.3	64.3
Working hours	92.2	150.0	242.2	62.9	103.5	166.4
Total tons	5,497	5,208	10,705	5,497	5,208	10,705
Project no. 18						
Charge, seconds	9.9	14.3	12.1	9.9	9.9	9.9
Mix, seconds	44.6	46.4	44.4	32.2	31.4	31.8
Discharge, seconds	13.3	14.1	13.7	13.3	14.1	13.7
Cycle, seconds	67.8	74.8	70.2	55.4	55.4	55.4
Batches per working hour	53.1	48.1	51.3	65	65	65
Tons per batch	2.048	2.009	2.035	2.0	2.0	2.0
Tons per working hour	108.8	96.8	104.5	130	130	130
Working hours	246.0	137.6	383.6	205.9	102.5	308.4
Total tons	26,776	13,327	40,103	26,776	13,327	40,103
Project no. 22						
Charge, seconds	8.6	14.7	10.8	8.6	8.6	8.6
Mix, seconds	33.6	33.9	33.7	29.0	36.5	31.8
Discharge, seconds	13.8	14.9	14.2	13.8	14.9	14.2
Cycle, seconds	56.0	63.5	58.7	51.4	60.0	54.6
Batches per working hour	64.3	56.7	61.3	70.0	60.0	66.0
Tons per batch	2.056	2.053	2.055	2.1	2.1	2.1
Tons per working hour	132.2	116.5	126.2	147.0	126.0	138.6
Working hours	163.1	104.3	267.4	146.9	96.5	243.4
Total tons	21,593	12,163	33,756	21,593	12,163	33,756

On project no. 22 the specification as interpreted required 45 seconds mixing time or alternately permitted 70 batches per hour on base and 60 on surface course. With a 2.1-ton batch the maximum permissible rate (average for two courses) was 138.6 tons per hour. There is a great difference in the efficiency with which these plants were operated. On project no. 22 the cumulative rate of production rose to 90 percent of the maximum within 7 days after beginning work, and the job was completed in 39 days with an average rate of 91 percent. On project no. 18 the average rate for the job was slightly more than 80 percent.

On project no. 4 work was greatly hampered by bad weather and the cumulative rate of production did not reach 70 percent until the twenty-ninth day and remained at approximately this figure for the remainder of the job. The plant on project no. 18 could have completed this project in 10 days.

A combination of time losses, slow operation, and small plant reduced the output at one plant to 4.9 tons per available hour (see table 5) even though operating at 80.6 percent efficiency, while another plant reached five times that production while operating at 51.6 percent efficiency. Still another project produced 108.2 tons per available hour with an efficiency of 82.2 percent.

The low rates of production attained at some plants indicate that not only should more attention be given to the elimination of avoidable time losses but that consideration should be given to the use of plants of larger capacity. Time losses due to weather cannot be controlled, but when such losses are followed by production which cannot exceed a fixed low rate the unit costs are certain to be high. The desirable size of plant will be affected by fixed daily cost of the outfit, relative plant costs, size of project, and other matters. Equipment and practice is not yet sufficiently standardized to attempt to lay down rules for size of plant but it is quite evident that many jobs justify greater plant capacity with a consequent greater daily production during available time.

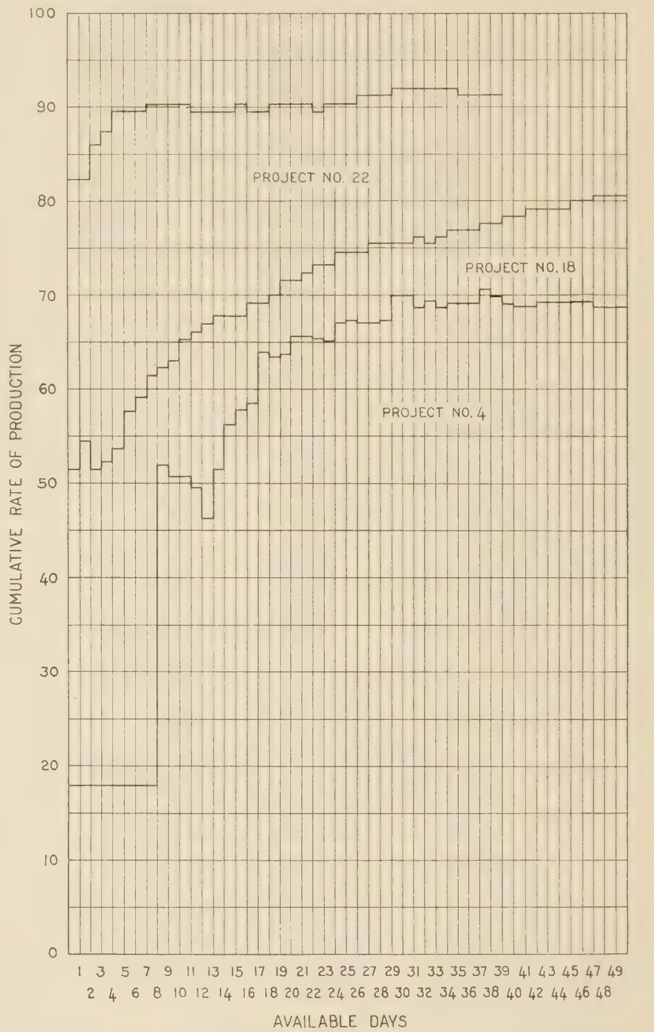


Figure 5.—Cumulative Rates of Production at 3 Plants During Working Time Expressed as Percentage of the Maximum Possible Rate. The Plant on Project No. 4 Was Small, Poorly Managed, and Weather Conditions Were Bad. On Project No. 18 the Plant Was Large, Well Managed, and Weather Conditions Were Good. On Project No. 22 the Plant Was Large and Well Managed but Weather Conditions Were Only Fair.

LOSSES OF TIME DUE TO WEATHER DISCUSSED

Referring to tables 2 and 3, it will be noted that 23.4 percent of all available time is lost because of the weather and that such delays occurred on 21 out of the 23 projects. Delays due to rain, snow, wet base or subgrade, and cold or foggy weather, are classed as major unavoidable delay. However, there is the possibility of minimizing their effect on production and unit cost by adjusting the construction season in accordance with weather records.

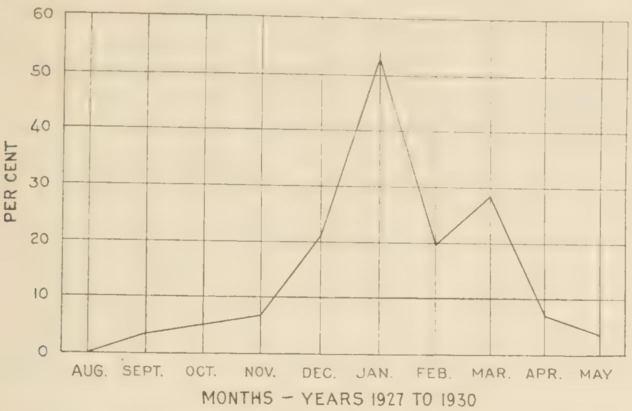


Figure 6.—Percentage of Available Time Lost Because of Weather Conditions on California Projects, 1927–30.

States should and do cooperate with the contractors in the letting of contracts so as to permit construction of high-type surfacing during the most advantageous seasons of the year. Periods of greatest freedom from time loss due to weather conditions may be determined for sections of the country as shown by figure 6. This chart shows the percentage of available time lost due to weather on California projects and for all months except June and July. The data were collected in the years 1927 to 1930 and the observations covered from 300 to 1,000 available hours in each month. No data were collected for the months of June and July. It is believed that the chart is fairly accurate for most coast and San Joaquin Valley points. The months between April and November, inclusive, had relatively favorable weather for construction. Such data can be developed for any section of the United States and the records of the United States Weather Bureau are particularly useful for such purpose.

Weather losses occur almost invariably as major delays, and halt rather than retard operations. On the projects studied only 76 percent of the time available could be used as working time. Other losses which also detract from available time are found in both the major and minor classifications. Late starts in the morning and at noon and occasional early stops are not tolerated under competent supervision. A regular and consistent working day should be the rule. The occasional practice of working extra hours to make big runs one day only to suffer a corresponding loss the following day is not recommended. Asphalt paving construction requires a high degree of consistency since costs for such items as hauling units and heating of materials continue through all short delays.

The orderly delivery of purchased materials is at times beyond the control of management but frequently lapses in placing orders are observed and a loss from this cause is clearly avoidable. In one case, laxity in inspection of plant requirements led to failure of the fuel supply. In other cases failures of belt and bucket lines were not anticipated or failure to maintain a proper inventory of spare parts resulted in prolonging delays. In general, such delays have been classified as partly remediable. Their prevalence indicates that the plant management should definitely place responsibility among employees for keeping up stocks of materials, supplies and spare parts, and anticipating breakdowns of units.

Preventable or partly remediable delays were recorded on more than half of the projects studied. Uncommon delays, principally accidental in character but not infrequently due to carelessness also resulted in loss of production. The explosion of a boiler, destruction of plant by fire in two cases and the accidental death of an employee are typical examples. These were classed as miscellaneous delays.

All these delays, common and uncommon, fortuitous or otherwise, indicate the need for alertness, since they robbed 23 contractors of 12.3 percent of their available time.

The total loss of 4,553 hours on 23 projects because of major delays is a serious one. However, major delays generally result in cessation of operation, and are therefore usually accompanied by a partial reduction in cost of labor, fuel, etc. With minor delays such is not the case. Minor delays appear in the countless repetitive operations where a single loss of time is of negligible moment but when regularly repeated they amount to a considerable portion of the working time. They occur under full operating costs and are of greater importance than idling costs to the extent that hourly operating costs exceed hourly idling costs. Most minor delays are avoidable.

Materials Yard, and Arrangement of Bulkheads. Dust Collector in Foreground.

"BIN DELAYS" OUTSTANDING AS A CAUSE OF MINOR DELAYS

The outstanding minor delay is "bin shortage" caused by inability to furnish aggregate to multiple bins in the proportions required in the mix. Failure to do this results in shortage in one bin or overflow in another. Bin shortage accounted for the loss of more than 613 hours on the 23 jobs and was found on every project. On recent jobs under good management definite steps were taken to reduce this loss with excellent results.

When aggregates are fed to the elevator in proportions differing from those required in the mix a shortage is bound to follow in one bin or overflow in another. Where the different sizes of aggregate are combined when delivered or are combined in stock piles or bunkers at the plant there is always more or less trouble with bin supply. Complete separation of each required size in stock piles is a first essential to the necessary control. With the necessary sizes readily available the problem can be completely solved by proper functioning of feed controls.

Figure 7 shows several different methods of feeding aggregates to elevators. At one plant the method of handling was as follows (method A, fig. 7): Four sizes of aggregate were required. The materials were stored at ground level against a bulkhead with 2 partitions to provide 3 bunkers. Sand and the largest size of rock were combined in 1 of these bunkers according to the judgment of the crane operator while the other 2 were filled with correctly separated sizes. Adjustable vertical gates in the bulkhead permitted materials to flow to a pit where they were picked up by the "cold elevator." The gates were adjusted from time to time as the need was indicated. Bin conditions were indicated by a system of rope "feelers" and visual signals.

The sand was mixed with coarse rock to overcome the resistance of sand to flow. The control of the two mixed sizes was not positive and the feeding of the small stone through vertical gates was not entirely satisfactory.

Another plant was operated on the same general plan except the sand was stored in a separate bunker with a sand trap feeding a belt conveyor which deposited the sand in the elevator pit (method B, fig. 7). Here there was also difficulty with the vertical gates and a need for constant alertness in regulating the controls.

Improved operation was observed at a third plant with four raised bunkers feeding a belt conveyor in front of the stone bunkers and beneath the sand bunker (method C, fig. 7). Sand was fed through a trap and stone through angular sloped feed gates. Rate of feed from bunkers could be observed while inspecting the condition of bins—a considerable advantage. Such an installation costs more than those previously described but the cost was more than offset by the saving in working time.

A fourth method gives such positive control as practically to eliminate bin delays (method D, fig. 7). It consists of four bunkers placed over an excavated and shored tunnel in which a belt conveyor is placed. Each bin has two gates in the bottom which are used alternately to induce breaking down of reposed material. The open gates drop the material to an automatic, power-driven plate feeder which can be set to deliver material in the exact quantity desired. On the job where this arrangement was used it practically eliminated bin delays and the savings thus effected were considerably more than the cost of the installation. In 100 hours of operation bin delay amounted to less than one tenth of 1 percent.

DELAYS FROM SHORTAGE OF HAULING EQUIPMENT OF CONSIDERABLE IMPORTANCE

Next in importance to bin delay is the time loss arising from a shortage of hauling equipment or faulty operation of hauling units. Some loss of this type occurred on every project and such losses accounted for 657 hours on all projects or 5.2 percent of the total available time. Time losses arising from hauling are thought to be largely avoidable since they occur most extensively on poorly managed work. Referring to table 2 it will be noted that on 4 poorly managed jobs, hauling equipment delay varied from 16 percent to 24 percent of operating time, whereas on 4 well managed projects, it was reduced to less than 2 percent and on one of these jobs to less than one tenth of 1 percent.

Frequently, it is difficult to determine whether a delay is the result of shortage of hauling units or to road conditions. Timing of the hauling units should indicate the source of the trouble and the remedy to be applied.

Delay resulting from hauling operations may have its origin in faulty plant arrangement, failure to provide sufficient storage of mixed batches, poor and indifferent

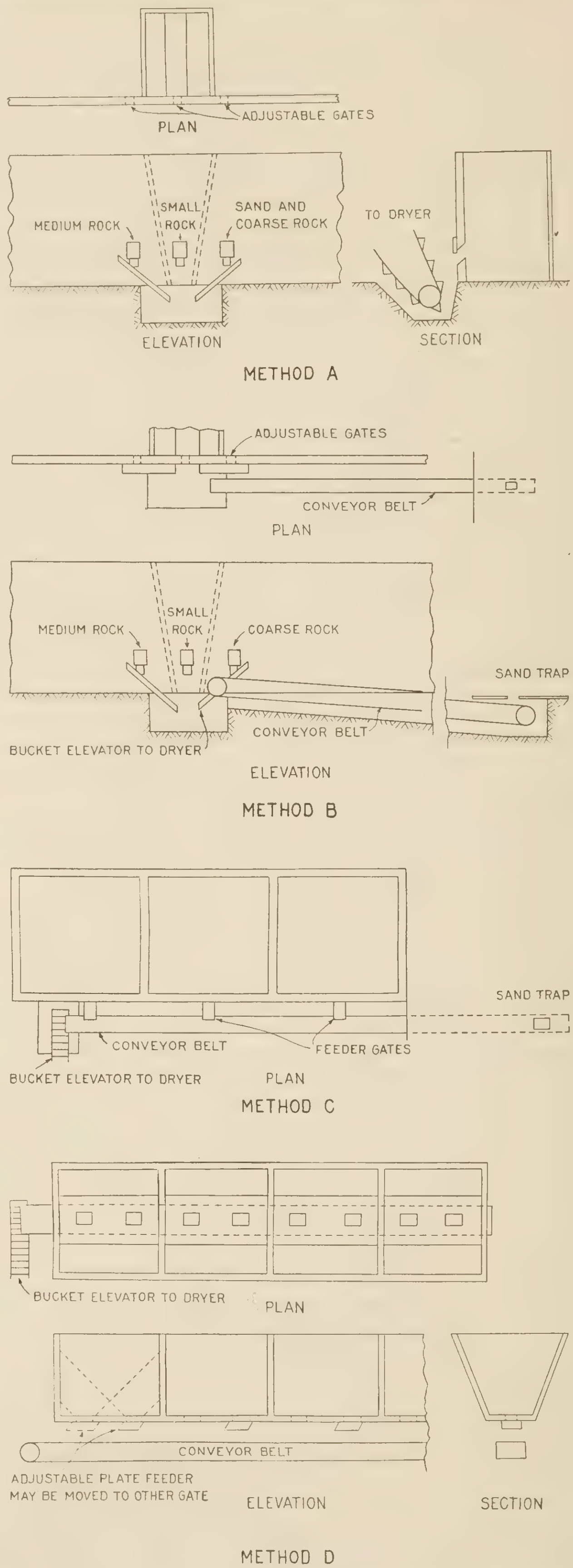


FIGURE 7.—METHODS OF FEEDING AGGREGATE TO ELEVATOR.

operators, poor equipment, bad roads, traffic interference, lack of correlation between plant and road capacity, or may be due to an insufficient number of hauling units.

The routine operation of taking on the load at the plant should be smooth and systematic. Oiling of bodies should be done at necessary stops on the plant loop. Nearly all plants are equipped for storage of one or more truck loads of mixed material, but some contractors delay truck operation by requiring trucks to wait and receive batches as they are mixed. Trucks should pass over a loop at the plant and should not be required to back in turning or to reach the loading point. Scales for weighing should be on the most direct route from the plant to the job. Experienced mechanics should be at hand to promptly correct mechanical troubles with the hauling equipment. Roads should be regularly maintained and some conditions may require constant maintenance. The value of increased travel speed will more than pay maintenance costs.

Equipment and personnel on the street or road should be sufficient to handle the production of the plant without delaying trucks in depositing loads.

Often, failure to provide an adequate supply of hauling equipment is due to inability to determine needs rather than to inability to obtain an ample supply. To assist in rectifying this condition, contractors are frequently furnished hauling charts, graphically simplifying the determination of a proper supply. Figure 8 is a Z-type nomograph designed particularly for use on asphaltic concrete work and based on the formula $N=\frac{Q}{60W}\left(\frac{10,560L}{S}+T\right)$. The symbols are defined below. Instructions for use are given on the chart and the steps in the progressive solution are numbered correspondingly. The application of this chart to a specific problem is shown by guide lines. To arrive at a solution for a particular job it is necessary to know the length of haul, L; the usual average round-trip speed of units on the road, S; the time constant which is the total time consumed in performing necessary operations other than travel, T; the capacity of the hauling unit, W; and the plant capacity, Q. The number of trucks required for any length of haul up to 17 miles may be determined with this chart.

The shorter the haul the larger is the relative importance of the time constant. Large hauling units have a greater time constant but the frequency of occurrence is less. Figure 8 may also be used to determine the economical size of hauling unit. The number of trucks required may be determined for alternative sizes, using the operating constants for each size of truck. Knowing the number of trucks required the total cost may be determined from the cost of ownership or rental of each size. On the projects studied, loads carried varied from 1.17 tons to 6.57 tons and the lowest unit cost was produced by the largest trucks.

Hauling cost is sufficiently important to justify analysis before the job is begun. Careful advance planning is very likely to result in substantial savings.

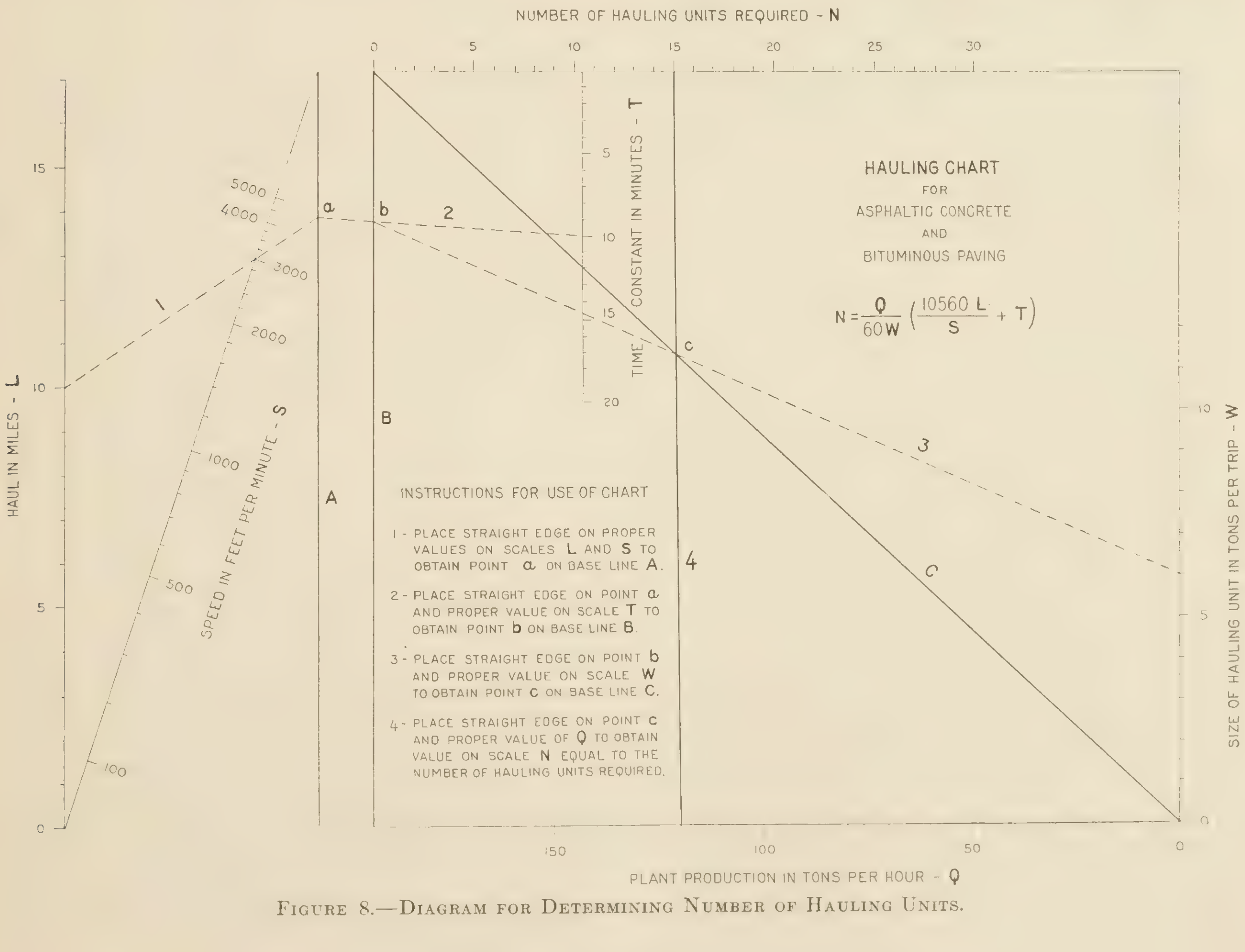
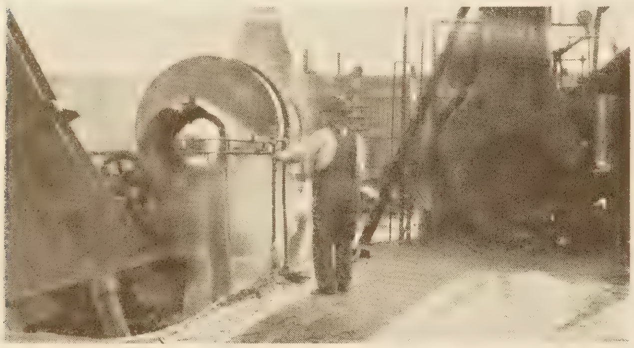


FIGURE 8.—DIAGRAM FOR DETERMINING NUMBER OF HAULING UNITS.

The possible economy of an extra plant set-up for the purpose of reducing average haul distance should be investigated. It should be borne in mind that total hauling cost is the summation of daily costs while hauling at varying distances and that calculations based on the average haul distance are misleading. Occasionally it has been found uneconomical to furnish the hauling equipment necessary to maintain full plant production on extremely long hauls. However, it is believed that a careful comparison of the cost of an additional plant set-up with the additional hauling costs and losses in plant production will often indicate the desirability of moving the plant in such cases.

MANY MINOR DELAYS CAN BE EITHER MINIMIZED OR PREVENTED

Delays at the plant include those classed as "mechanical" or failure of machinery to function properly; "operative" or failure of labor to function properly;



A Typical Dryer Arrangement.

"handling aggregate" (exclusive of bin delays); interruption of operation to inspect or change the mix; and a variety of miscellaneous short delays of infrequent occurrence. Such minor delays accounted for a total of 4.34 percent of all working time, a matter of 550 hours.

Many mechanical failures could not reasonably have been anticipated. However, careful, periodic inspections will accomplish a definite reduction in the frequency of breakdowns. The maintenance of carefully inventoried stocks of repair parts such as chain links, belt laces, pipe line connections, cables, dipper or clamshell teeth and gear sprockets has proven to be low-premium insurance.

Operative delays occur as the result of failure of a particular machine to keep up with the pace which can be set on the rest of the job and may be due to inadequacy if the machine itself or to the manner in which it is operated. A study of time records is convincing that the majority of such delays are the result of habits of operators which can be corrected. It is as easy for operators to form the habit of consistently maintaining output at the capacity of the machine as it is to fall into careless operation which is perhaps affected by another equally careless operator at another machine. Such operation is most often due to lack of thought rather than indifference. The high cost of operative delays makes it desirable to place skillful operators in key positions at wages commensurate with the responsibility of the position.

Delays incident to handling materials may occur at any point along the line of progress through the plant. Adequate crane capacity is essential and must be accompanied by good operation or output will suffer. A poor machine with a good operator or a good operator and machine with a poor arrangement of facilities for unloading, stock piling and feeding to the dryer, may fix the limit of production considerably below that attainable in other parts of the plant. Reference is again made to figure 1 which shows a typical, orderly arrangement with the crane runway between spur track and stock piles and within easy reach of all sizes of aggregate. With proper arrangement of facilities, the ordinary ¾-yard crane is suitable for production up to 1,200 tons in an 8-hour day of plant operation.

MANY DRYERS FOUND TO PRODUCE UNSATISFACTORY RESULTS

Delays at the dryer may result from the use of a dryer of inadequate capacity, or from the use of excessively moist material. Dryer capacity depends on a number of variables and calculations of capacity are based on an empirical formula. Table 8 shows the dimensions and characteristics of dryers at 11 of the plants studied.

Examination of the data shows that the capacity of a dryer is, to a considerable extent, dependent upon the degree of agitation of the material. Agitation is affected by the details of the dryer design and particularly by the baffling which controls the height of fall. Table 9 demonstrates this relationship.

Table 8.—*Characteristics of typical dryers*

Job no.	Length	Diameter	Pitch	Revolutions per minute	Empirical capacity in tons per hour under various conditions		
					Poor	Average	Good
	Feet	*Inches*	*Inches per foot*				
1	24.0	66	0.88	9.7	70	90	110
2	20.5	60	.75	10.3	60	70	90
5	18.0	60	1.00	6.6	60	75	95
9	24.0	72	.76	5.3	70	90	110
16	24.0	54	1.00	9.5	65	85	100
18	22.0	72	.75	8.0	97	124	150
19	22.0	72	.85	7.0	83	108	135
20	23.0	60	1.00	7.7	70	90	110
21	20.5	60	1.25	7.0	60	70	90
22	22.0	72	.75	8.0	97	124	150
23	22.0	72	.75	8.0	97	124	150
Average	22.0	66	.89	7.9	75	95	117
Typical	24.0	72	.75	8.0	90	120	150

Table 9.—*Relation between height of fall of material in the dryer and output at 4 typical plants*

Height of fall of material	Capacity per hour	Material in dryer at any instant	Time required to produce a ton of material
Feet	*Tons*	*Tons*	*Seconds*
3.48	150	5.21	24.0
2.82	118	6.72	30.5
2.11	89	2.42	40.8
1.25	69	1.17	52.2

Efficiency of dryer operation is to be judged not only by rate of output but also by the temperature of the materials as they leave the plant. Variations in the temperature of mixed materials affect every operation in laying the surface and frequently result in lack of smoothness and density. Samples of compacted pavement of the same mix have shown a percentage of voids ranging from 7 to more than 16. The excessive void content was attributed to low temperature during compaction. Figure 9 shows the average and extreme temperatures of batches leaving the plant on five jobs.

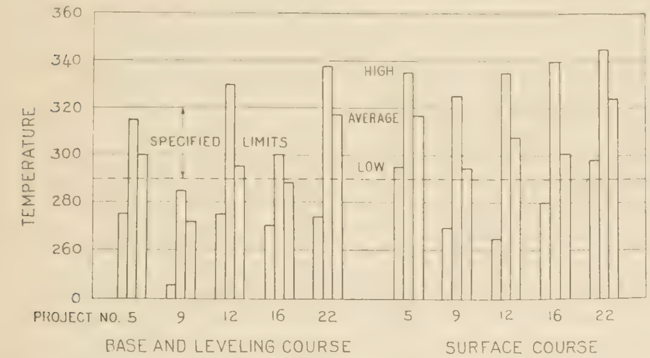


Figure 9.—Average and Extreme Temperatures of Loads Leaving Plant on Five Projects.

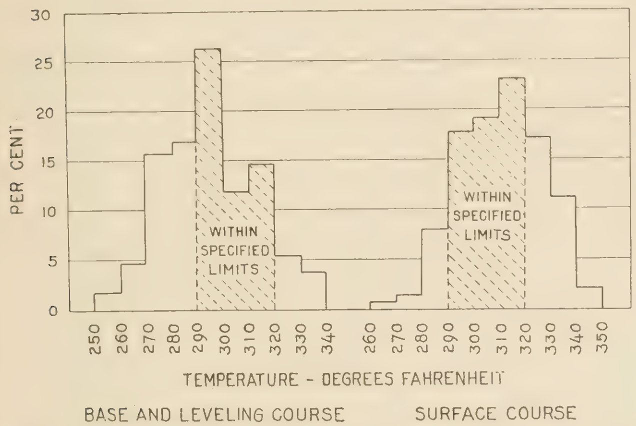


Figure 10.—Daily Average Temperatures of Loads Leaving Plant Compared on a Percentage Basis. Based on Observations on 7 Projects. Mixtures for Base and Leveling Course Observed 172 Days and Mixtures for Surface Course Observed 152 Days.

Figure 10 shows percentage of batches of different temperatures as combined for seven projects. Temperature observations were made on both base and surface mixes at 7 plants on 324 days and in only 55.8 percent of the cases were the temperatures within the specified limits. Extreme ranges of temperature exceeded 100°. Failure to meet the specification for temperature on base and leveling course was most often due to low temperature but in the case of surface course it was most often due to excessive temperature.

Hot materials are transported from the dryer to the screens by a bucket elevator. It is important that both the elevator and screens be housed and insulated to prevent a waste of heat and unsatisfactory results in laying the surface.

SCREENS AND BINS SHOULD BE OF ADEQUATE CAPACITY

In designing a plant for a given capacity it is readily possible to determine the amount of material to be handled by each size of screen. However, the output of a screen depends on a number of variables and designs are based on empiric formulas. The observations which have been made indicate that a margin of production should be provided to care for uncertainties of operation. Troubles arising from inadequate capacity cannot be overcome by overloading screens, increasing the speed of revolving screens beyond a certain limit, or using an excessive pitch. Such measures invariably result in inaccurate screening and should be prohibited by inspectors.

At several plants material coming from the dryer was dumped first on a fixed, sloping screen (scalping screen) with openings which passed all acceptable sizes and which was arranged to by-pass all oversize material and thus avoid burdening the other screens. At some plants the material coming from the dryer or scalping screen was divided equally between two rotary screens of identical characteristics. Single screens varied from 18 to 24 feet in length where 4 sizes of aggregate were required. The speed of screens varied from 6.3 to 10.3 revolutions per minute and averaged approximately 8 revolutions per minute. Diameters ranged from 5 to 6 feet and the pitch from ¾ to 1¼ inches per foot.

A Modern Plant with Housed Elevator for Hot Materials. A Large Truck Is Loading From the Storage Box.

In general, a single screen 24 feet in length, 6 feet in diameter, with a pitch of ¾ inch to the foot, and revolved 8 times per minute should produce 1,200 tons per 8-hour day.

Screened material falls directly in storage bins and these should be large enough to offset irregularities in supply and demand. The bins should be equipped with openings for discharging material, should the supply of a given size become excessive, and also for the removal of cold aggregate. The required bin capacity is closely linked with the accuracy with which the sizes of aggregate are fed to the cold-aggregate elevator. Mistakes in proportioning material in stockpiles soon become evident as trouble with bin supply.

FEW DELAYS RESULT FROM BATCHER OPERATION

In all cases the operation of withdrawing materials from bins in the proper amount for a batch, as determined by weight, was accomplished well within the time required for mixing the previous batch. On some jobs the clogging of filler dust in chutes leading from the bin occasioned delay. Well-designed plants now have screw conveyors for supplying filler if it is used.

STUDY OF PUG MILL OPERATION INDICATES NEED FOR IMPROVEMENTS

Discharge of material from the weighing box to the pug mill was done in a single operation at nearly all plants. In a few cases this practice coupled with large batches and a poorly designed pug mill resulted in the segregation of aggregate in the mix. As a corrective measure it was required in such cases that half a batch be weighed and dumped at a time. This requirement added considerably to the charging time and mixing cycle. The average charging rate on all projects was 263 pounds of material per second and the half-batch charging method lowered this rate to 127 pounds per second. On jobs using a large batch with a single charge the rate was 520 pounds per second. Such a charging rate allows ample time for the accurate weighing of sizes during almost a complete mixing cycle. A single charge is desirable to permit a short period of premixing of the entire dry batch before the asphalt is added.

The mixer is the key unit in the plant set-up. Figure 11 is a sketch of a typical twin-shaft pug mill mixer. The two shafts shown are of heavy steel and each mounts four groups of paddles set at 90° intervals. The faces of the paddles are set at 45° to the plane of rotation. The two shafts rotate at equal speeds so as to force the material inward. The paddles, when in a horizontal position, mesh as shown in the drawing.

Some of the faults of mixers observed in the study are as follows:

1. Dimension A (fig. 11) too large with respect to dimension C resulting in poor end-to-end distribution of material and confining mixing action primarily to planes of rotation.
2. Facing of paddles arranged in a haphazard manner so as to set up uninterrupted paths of flow rather than intercepting paths of flow to cause intermingling.
3. Dimensions D and E too small to permit rotation of paddles at speeds which have been found desirable for good mixing without forcing material over the sides of the box.
4. Dimensions G and H of the discharge opening so small and the discharge rate so low that the paddles are adjusted to aid in discharge rather than set as a result of consideration of mixing requirements only.
5. Speed of revolution too low to impart the necessary violence to the mixing action.
6. Net volume of pug mill reduced too much by the volume of shafts, arms, and paddles.

A satisfactory mixer is one which distributes each size of aggregate and the asphalt uniformly throughout the mix. A better distribution of asphalt might be accomplished by changes in the method of introducing the asphalt in the mix. Studies indicate that where the asphalt is introduced at a single point it should be admitted gradually. The greater the dispersion of the flow the greater the speed of flow which can be permitted and still obtain uniform coating of aggregate.

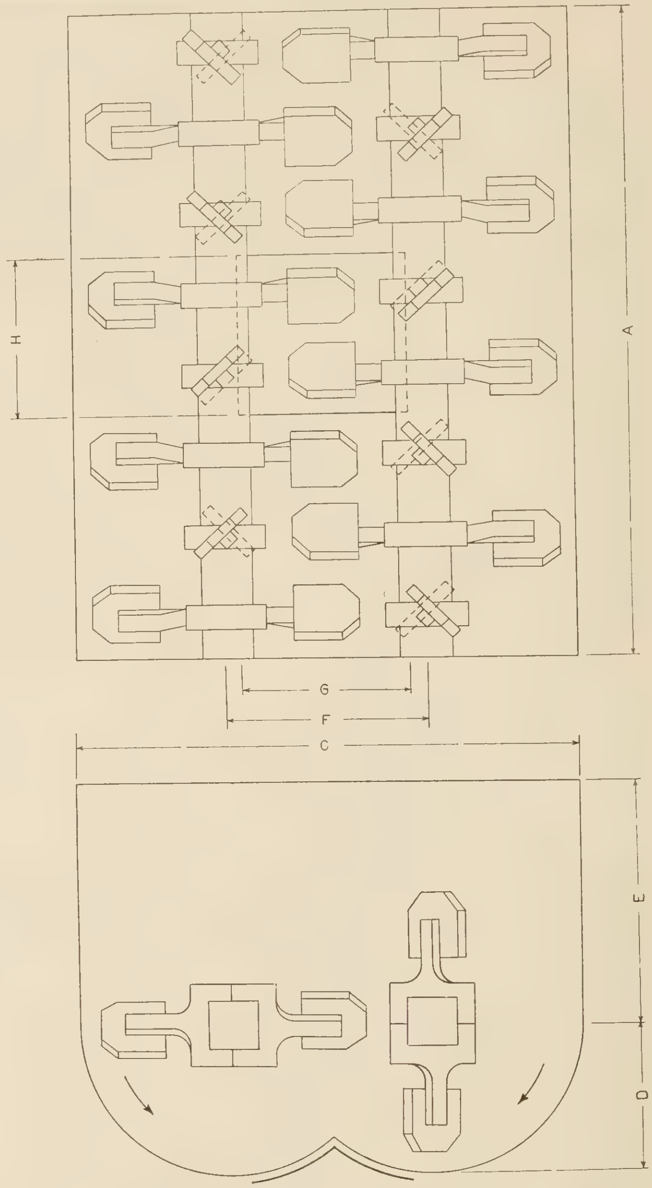


FIGURE 11.—TYPICAL TWIN-SHAFT PUGMILL MIXER.

Chutes with diverging channels have been used to spread the asphalt over a large area of aggregate. It is believed that improved results might be obtained by forcing the asphalt through pipes leading to a number of points in the mixing box. A piston could be arranged to supply the pressure with the piston adjusted so as to measure the correct amount of asphalt for a batch.

In general, the time required for asphalt distribution is greater than that required for aggregate distribution. It seems possible that practical methods of accelerating asphalt distribution can be developed and this should permit a reduced mixing cycle and increased production.

Wide variations in mixing time were found on practically all of the projects studied. Figure 12 shows the results of the timing of over 280,000 mixing cycles. The observations have been grouped at 5-second intervals and the number of observations in each group plotted as a percentage of the total number of observations in the group. On a typical project in an Eastern State more than 70 percent of the batches were mixed either more or less than the specified time of 45 seconds.

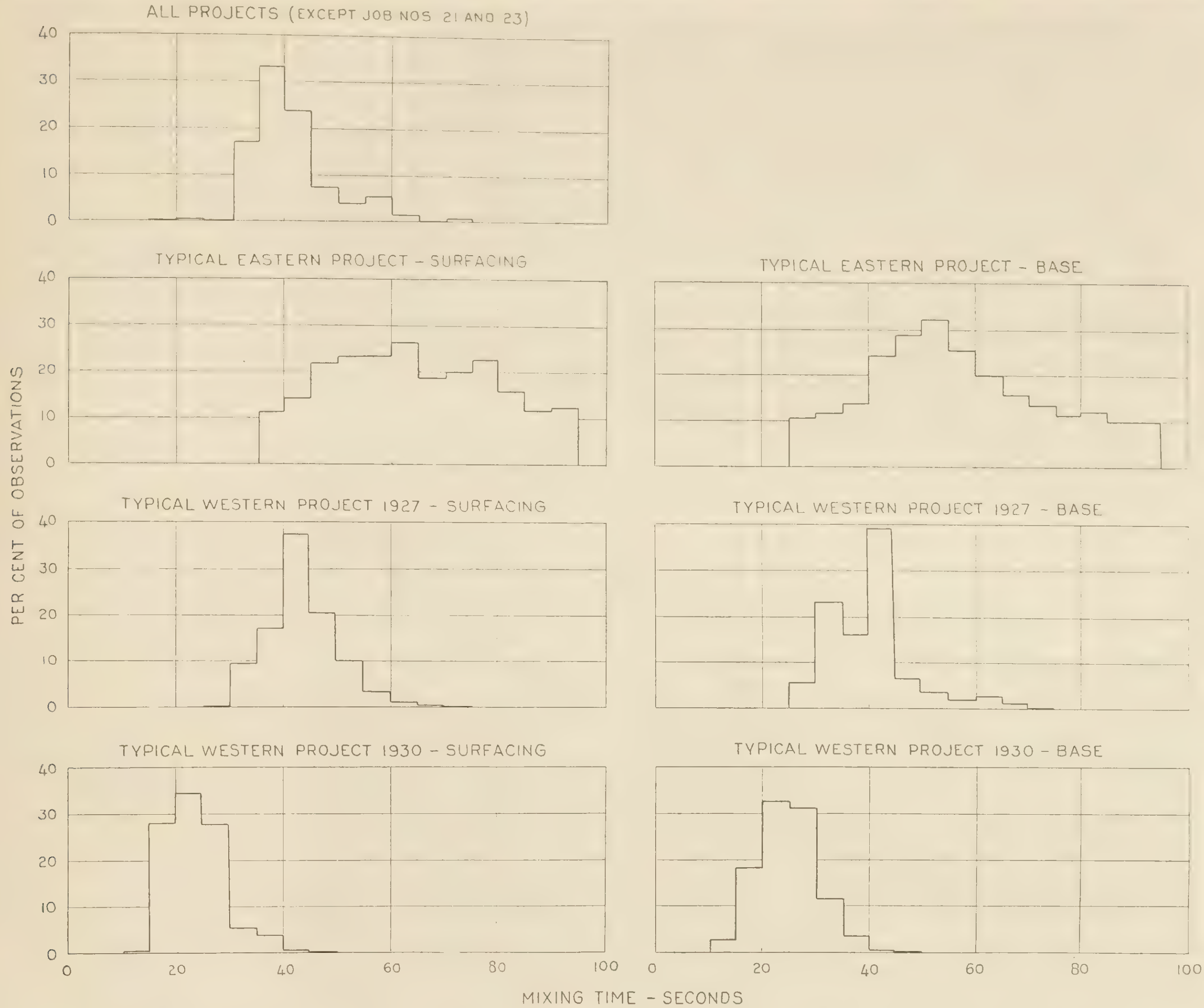


Figure 12.—Mixing Times Grouped at 5-Second Intervals and Plotted on a Percentage Basis.

The typical western project shows a somewhat closer adherence to the 45-second mixing time.

The wide variation in the mixing time found on practically all projects indicates the need for a timing device to control the mixing period. There is also need for research to determine the efficiency of different arrangements of mixers and the mixing time required under any set of conditions.

It has been definitely demonstrated that marked improvements in efficiency of mixing are possible. Representatives of the Bureau of Public Roads cooperated with an asphalt plant manufacturer and a contractor to develop a pug mill of improved design. The ordinary design was altered by decreasing the length of mill and increasing the width and depth. The net volume was increased by reducing the size of paddle and shaft connections. These changes permitted a higher speed of paddle rotation. This machine made possible the lowest mixing cycle yet observed and a record breaking production with full adherence to specifications. A consistent charging time of 4 seconds was obtained ("split" charging not necessary) as compared with an average of 9.9 seconds on other work. A large discharge opening was used through which a batch could be discharged in 3 or 4 seconds as compared with an average discharge time of 13 seconds. No change was made in actual mixing time. The mixing cycle was 51 seconds as compared with an average of 61 seconds.

A box for storage of mixed batches, commonly called the "gob box" is essential to allow for temporary differences in mixer production and hauling rate. If the size of batch is less than a truck load a storage box is the only means of avoiding a wait on every truck trip. In such cases delay is wholly unwarranted when so simple and inexpensive a remedy exists.

FINISHING OPERATIONS ON SURFACE COURSE OFTEN LAG BEHIND PLANT PRODUCTION

When mixed material is delivered on the road or street it may be handled by one of several methods. The spreading may be entirely by hand or almost entirely by machine methods. Spreader boxes for attachment to trucks have been devised which are very satisfactory in spreading full-width base and surface course and also the narrow strips on widened sections.

Initial Spreading with Spreader Boxes.

Final Spreading with Finishing Machine.

Compaction with Different Types of Rollers.

Steps in Spreading and Rolling.

For upper courses the use of half-width spreader boxes of either the sled or roller type followed by a full width mechanical spreader is particularly recommended.

Mechanical finishers have been used with results that are very satisfactory both in quantity of paving laid and in smoothness of the surface. Such machines have enabled the handling of a larger plant production than could well be handled by hand methods. Finishing machines have been used on standard widths up to 30 feet and have been adapted to narrow strips 9 and 10 feet wide.

It occasionally happens that production is limited by finishing operations rather than plant mixing, and in such cases the finisher is the key unit. For example, on three projects with large capacity plants, a thin surface course required only 1,399 tons per mile or 0.265 ton per lineal foot of road. The plant could supply material for surface course at a rate requiring a finishing speed of 9.46 feet per minute. This speed of finishing could not be consistently maintained and few machines have been observed capable of such a rate. In laying the thicker base course requiring 1,809 tons per mile a speed of 7.32 feet per minute was required. The machines on this job and most of those timed on other jobs were capable of this speed. It would have been possible to adjust the quantities of material for the two courses so as to maintain full plant production with a consistent gross speed of finishing of 8.25 feet per minute. In determining the relative thickness of courses the relation between probable plant production and finishing speed should be considered as a factor affecting cost.

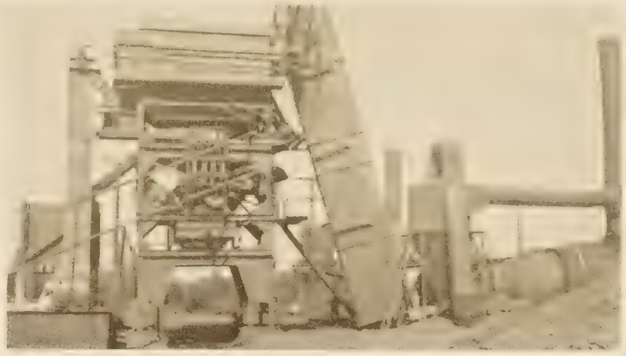
Finishing speeds as high as 12.9 feet per minute during periods of efficient operation were observed, but in only one instance was the finisher capable of maintaining an average speed which matched the maximum production of a large-capacity plant while laying thin surfaces. Reductions in average speed result from insufficient traction and time losses. Tractive losses vary with the number of drive wheels, type and condition of forms or form rails and height of material for some distance ahead of the screed. Time losses result from derailments caused by spreading forms and narrow wheel flanges; faulty spreading of material ahead of the screed requiring backing to fill holes and delays in performing initial spreading.

Tractive losses normally reduce the speed by 8 or 9 percent, but losses of 30 percent have been observed under extreme conditions. Table 10 shows finishing machine speeds observed on several projects.

Very satisfactory finishing machines have been built using a special power unit, special gears, and with four-wheel drive. Such machines have kept pace with a plant production of 187 tons per hour where there was a favorable relation between thickness of base and top course. No great difficulty should be encountered in spreading and finishing operations with a properly designed cross section and mix and properly mixed batches.

STUDY INDICATES NEED FOR MORE EXACT DETERMINATION OF ROLLING REQUIREMENTS

The purposes of rolling are to reduce the voids in the pavement and thereby increase the density and stability and also to produce surface smoothness necessary for riding comfort. In the western States the initial compaction is generally done by longitudinal rolling with three-wheel (macadam type) rollers weighing from 10 to 14 tons and of the gas-engine type. This is followed by longitudinal, transverse, and diagonal rolling with tandem rollers weighing from 6 to 8 tons. Details of typical rollers are shown in table 11.



GENERAL VIEW OF A MODERN WELL-DESIGNED PLANT SET-UP.

TABLE 10.—*Speed of finishing machines on several projects*

Job no.	Average speed during working time	Average speed with delays and tractive losses eliminated	Reduction in average speed due to delays and tractive losses	
			Base	Surface
	Feet per minute	*Feet per minute*	*Percent*	*Percent*
12	8.70	10.40	16.3	
12	5.20	7.95		34.6
13	3.04	6.70		54.7
16	8.00	9.00	11.1	
18	7.25	9.70	25.3	
19	7.22	11.50		37.2
21	5.00	11.80		57.6
22 [1]	10.32	12.90		20.0
Average	6.84	9.99	17.6	40.8

[1] 4-wheel drive.

As a basis of comparison of amount of rolling on base and surface courses on different projects a "rolling factor" has been derived. This is the product of wheel widths and distance traversed on a given section of pavement divided by the area of the section. Roughly, this factor represents the number of times each unit of area is traversed by a roller wheel. Table 12 shows the successive steps in rolling on two projects.

On job A both the base and the surface course were given nearly twice the amount of rolling as on job B. Assuming a plant production which would require 4 rollers with the rolling factor of job B, substitution of the rolling factor of job A would make 3 additional rollers necessary. These and other observations lead to the conclusion that either some surfaces are insufficiently compacted or there is a waste doing more rolling than is necessary on other surfaces. There is need for a more exact determination of rolling requirements.

TABLE 11.—*Dimensions and weights of typical rollers*

Type	Weight	Wheel weight		Wheel width		Pounds per inch of wheel width	
		Front	Rear	Front	Rear	Front	Rear
	Tons	*Pounds*	*Pounds*	*Inches*	*Inches*		
3-wheel	12.1	6,530	17,620	40.8	40.8	160	430
Do	11.1	6,280	15,880	40.2	43.2	156	367
Tandem	8.6	5,140	12,110	50.4	50.4	102	240
Do	8.5	5,170	11,900	50.4	50.4	103	236

TABLE 12.—*Comparison of amount of rolling on two projects*

Job	Course	Roller type	Weight	Operation	Rolling factor
			Tons		
A	Base	3-wheel	11.1	Initial	5.2
		Tandem	8.5	Final	5.8
	Total				11.0
	Surface	3-wheel	12.1	Initial	12.4
		Do	11.1	Longitudinal	3.5
		Tandem	8.5	Diagonal	6.0
		3-wheel	11.1	Longitudinal	3.1
		Tandem	8.6	Transverse	3.8
	Total				28.8
B	Base	3-wheel	12.0	Initial	3.76
		Tandem	9.2	Final	2.80
	Total				6.56
	Surface	3-wheel	12.0	Initial	7.33
		Tandem	9.0	Longitudinal	4.12
		Do	9.2	Diagonal and transverse	4.28
	Total				15.73

ROLLING DONE AFTER PAVEMENT HAS COOLED THOUGHT TO BE INEFFECTIVE

Time studies reveal that the average roller operates but 70 percent of working time with nonproductive delays as follows:

	Percent
Waiting for material	6
Operator idle	6
Take on fuel	11
Mechanical	6
Miscellaneous	1
Total	30

Wide ranges in roller speed were observed. Speeds of 1.2 to 1.4 miles per hour or 110 to 125 feet per minute appear to be satisfactory and do not result in excessive shoving. In general, higher speeds are used on the base than on the surface course. Typical rates observed were 2,833 square yards per hour on surface and 3,080 on base. The number of rollers required on a project might be estimated as follows:

	Base	Surface
Plant production—lineal feet of road per hour	439	567
Surface laid per hour (20-foot width), square yards	975	1,260
Number of times rolled	4.39	11.13
Area to be rolled per hour, square yards	4,280	14,030
Square yards per hour per roller exclusive of time losses	3,080	2,833
Percentage of working time utilized	51.7	88.3
Square yards per hour per roller allowing for time losses	1,590	2,500
Number of rollers required	3	6

Here again the difference in thickness of base and surface course leads to an increase in the equipment required to keep pace with maximum production. In this case the thicknesses might have been adjusted so that 4 rollers would have been adequate for the project instead of 6.

Observations of volume reduction resulting from rolling were made on selected sections of project A (table 12). Measurements of thickness before and after rolling are based on level readings taken at 1-foot intervals on transverse pavement sections. On given days observations were confined to a particular course and measurements taken on 15 or 20 transverse sections. The results are shown in table 13. Each figure in the table is the average of observations at over 200 points.

These data show that the reduction of volume of the surface course was somewhat less than that of the base course, although the top course received twice as much rolling as the base. The variation from the average was much greater for the surface course than for the base. The base and leveling courses were of identical mix and the average reductions in volume are identical. The surface was composed of a quite different mix and showed different characteristics under rolling. Variations in the temperature of the material as delivered possibly affected the results.

TABLE 13.—*Reduction in thickness of base and surface courses due to rolling*

Course	Loose thickness	Compacted thickness	Reduction in volume
Base:	*Inches*	*Inches*	*Percent*
First day	3.77	2.77	26.5
Second day	4.96	3.81	23.2
Third day	3.63	2.62	27.8
Average	4.12	3.07	25.6
Leveling:			
First day	2.55	1.75	28.6
Second day	2.42	1.85	23.6
Third day	2.68	2.02	24.6
Average	2.52	1.87	25.6
Surface:			
First day	2.44	2.01	17.6
Second day	2.36	1.70	28.0
Third day	1.78	1.26	29.0
Fourth day	2.69	2.12	21.2
Average	2.32	1.77	23.5

These facts suggested the existence of inherent qualities in the mix affecting the uniformity of volume reduction and led to a series of investigations of the effect of rolling. Batches of various proportions were prepared, spread on the road surface, and subjected to various amounts of rolling with rollers of different weights. The general indication resulting from these tests is that the voids in the mixture are reduced to a minimum value early in the rolling process. On jobs using a light roller on sheet asphalt the point at which there appeared to be no further void reduction or increase in stability was reached after 8 to 12 rollings, depending upon the composition of the mix.

In the rolling tests of asphaltic concrete mixtures, determinations of the density of samples cut from the rolled pavement were made and compared with the theoretical maximum density (no voids) as computed from the quantities and specific gravities of the constituent materials. These data were determined from analysis of samples.

The results of the tests indicate that in general the weight of the roller and the number of rollings above an essential minimum has less effect on the density attained than does the gradation of the aggregate.

It is believed that rolling to produce compaction should be done entirely in a longitudinal direction and that rolling to produce surface smoothness should follow immediately in transverse and longitudinal directions. The entire rolling should be completed before a considerable drop in temperature has taken place and curved or diagonal rolling should be avoided because of the detrimental effect on smoothness. The data shown in the table 14 are typical of the rate at which cooling may take place. The heaviest rollers were used in the first stages of rolling and those of lighter weight were used in the finishing operations which took place about 3 hours after spreading and with the mixture approaching normal temperature. There is considerable reason for believing that the last stages of rolling produced practically no effect on the pavement.

The spreading and rolling operations are conducted so as to produce smoothness and riding comfort. The test for smoothness is usually made with a 10-foot straightedge. However, with cars traveling 40 miles per hour or 59 feet per second a surface which meets the requirement as to smoothness within 10 feet may have variations over greater distances which will produce riding discomfort. The regularity of the surface left by the finishing machine is entirely dependent on the vertical alinement of the side forms and the firmness of their support. It is therefore important that the forms be set conforming to the proper vertical alinement and be supported so as not to deflect under the weight of the finishing machine.

TABLE 14.—*Elapsed time in rolling operations and corresponding drop in temperature of pavement*

Operation	Temperature drop		Elapsed time
	From—	To—	
	° F.	*° F.*	*Minutes*
Spreading	290	275	2
Finishing	275	245	7
First rolling	245	216	15
Second rolling	216	174	41
Third rolling	174	170	43
Fourth rolling	170	161	58
Fifth rolling	161	158	63
Sixth rolling	158	129	143
Seventh rolling	129	128	183

COSTS OF LABOR, EQUIPMENT, AND MATERIALS DERIVED

The preceding discussion has dealt with relative amounts of output under various conditions. It remains to discuss the actual unit costs under these conditions and to determine the actual savings which may be effected by practices which have been advocated.

These costs will be developed under the three main heads of supervision and labor, equipment, and materials. These items are common to all projects and a few miscellaneous items not common to the general run of projects have been omitted from consideration.

The supervision and labor costs are segregated in table 15. The main headings of the table cover the following items:

1. "Supervision and general" includes cost of superintendents, foremen, and labor in connection with supply trucks and other automotive equipment with the exception of trucks hauling mixed material.
2. "Handling material at plant" includes cost of labor in connection with the siding, crane, storage facilities, dryer, and boiler.
3. "Mixing and loading" includes cost of labor in connection with weighing, mixing, elevators, filler storage, and storage of mixed batches.
4. "Hauling" includes cost of labor in connection with hauling mixed batches.
5. "Placing and finishing" includes cost of labor in connection with those operations following delivery of mixed material on the road or street.

Under each of these items there are shown the number of men ordinarily employed, the number of man-hours for the job, the average wage per hour, and the average cost of labor per ton of mixed material.

The hours of labor and payments to labor include those arising during working time and also those resulting from the maintenance of a skeleton organization on full day periods when the plant is not operating.

Table 16 is an analysis of equipment costs under the same general heads as used for labor in table 15. The qualification of these heads as applied to labor apply also to the equipment costs. The costs include such items as fuel, materials (other than for mix), storage, interest, insurance, taxes, repairs and depreciation. The item of depreciation includes that taking place during actual time of operation and also the depreciation occurring during periods when not in operation. An estimate was made for each unit of equipment according to a method which was applied uniformly on all projects.

The cost of materials at the various plants as shown in table 17 is not the true cost but a fictitious value based on the assumption that each plant paid $1.20 per ton for crushed rock, $1 per ton for sand, $16 per ton for asphaltic cement and $6 per ton for filler, all delivered on the job. This procedure was adopted so that the costs would reflect the effect of variations in specifications and construction practices. The above prices are approximately the averages of the prices prevailing on the projects studied. Combined aggregates were delivered on many projects and in such cases the proportions to be classed as coarse aggregate and sand were determined and the assumed costs were applied to these proportions. The average cost of materials per ton of mix is $2.27 of which 33.1 percent is for crushed rock, 16.2 percent for sand, 41.5 percent for asphalt, and 9.2 percent for filler.

The costs of labor, equipment, and materials involved in a ton of mixed material on each project are shown in table 18 which also shows these items on a percentage basis. The cost per ton of paving mixtures ranges from $2.71 to $6.16. The unweighted average cost for all projects is $3.80 per ton and the weighted average is $3.25 per ton, reflecting the lower costs obtained on the larger projects. Figure 13 shows graphically the average costs of each item involved in placing a ton of mixed material in the road surface and also the average cost per ton of material for base and surface course.

AVOIDABLE DELAYS LARGE IN COST

The costs of labor and equipment are almost equal and together they produce approximately 40 percent of the total cost. Elimination of time losses effects a direct saving in labor costs and also tends to reduce equipment costs but does not necessarily reduce the amount of equipment required. It should not be assumed that greater efficiency will adversely affect the employment of labor. There will be a decrease in the hours of labor per mile of road but the decreased costs will permit the construction of a greater total mileage and cause an increase in the production and transportations of materials and machinery.

Table 19 shows the amount and cost of avoidable delay for all projects combined by causes and includes both major and minor delays. Table 20 shows the amount and cost of such delays on each project. This dissipation of potential profit on all projects amounts to nearly 8 percent of the cost of the projects. On one project delays arising from a shortage of hauling equipment resulted in losses equal to the cost of two 5-ton trucks. In another case bin delays caused a loss of $6,000 when half of this amount would have provided facilities which would have completely eliminated this delay. Losses from insufficient dryer capacity have been found large enough to supply a battery of dryers. A contractor purchased a new asphalt pump to replace one causing delay and within a week the savings had offset the cost of the pump. These are typical examples of conditions found on many projects.

Table 15.—*Supervision and labor requirements and costs according to type of operation on each of 23 projects*

Project no.	Supervision and general						Handling materials at plant						Mixing and loading					
	Average number of men	Total man-hours	Total cost of labor	Average wage per hour	Man-hours per ton of mix	Labor cost per ton of mix	Average number of men	Total man-hours	Total cost of labor	Average wage per hour	Man-hours per ton of mix	Labor cost per ton of mix	Average number of men	Total man-hours	Total cost of labor	Average wage per hour	Man-hours per ton of mix	Labor cost per ton of mix
1	7	4, 123	$3, 362	$0. 82	0. 16	$0. 13	6	2, 450	$1, 517	$0. 62	0. 10	$0. 06	5	2, 585	$1, 716	$0. 66	0. 10	$0. 07
2	9	6, 040	4, 695	. 78	. 21	. 16	9	5, 019	2, 702	. 54	. 17	. 09	6	3, 600	2, 124	. 59	. 12	. 08
3	8	2, 962	1, 687	. 57	. 53	. 30	6	1, 554	518	. 33	. 28	. 09	5	1, 295	544	. 42	. 23	. 10
4	6	2, 752	1, 479	. 54	. 26	. 14	13	2, 641	625	. 24	. 25	. 06	7	1, 694	484	. 29	. 15	. 04
5	5	2, 920	2, 774	. 95	. 08	. 07	9	3, 846	2, 487	. 64	. 10	. 07	4	1, 904	1, 214	. 64	. 05	. 03
6	9	5, 231	2, 603	. 49	. 59	. 29	5	1, 351	290	. 21	. 16	. 03	5	1, 975	790	. 40	. 22	. 09
7	6	2, 768	1, 355	. 49	. 21	. 10	7	1, 822	439	. 24	. 14	. 03	6	2, 004	635	. 32	. 16	. 05
8	2	554	512	. 92	. 12	. 11	5	965	406	. 42	. 22	. 09	3	609	264	. 43	. 14	. 06
9	9	2, 838	2, 490	. 88	. 12	. 11	7	1, 766	920	. 52	. 08	. 04	6	1, 824	1, 295	. 71	. 08	. 06
10	5	4, 237	2, 307	. 54	. 69	. 37	5	1, 788	487	. 27	. 29	. 08	6	2, 382	715	. 30	. 39	. 12
11	5	3, 915	2, 506	. 64	. 21	. 13	9	5, 868	2, 386	. 41	. 32	. 13	5	3, 260	1, 402	. 43	. 18	. 07
12	10	4, 198	3, 147	. 75	. 22	. 17	8	2, 528	1, 495	. 59	. 13	. 08	4	1, 444	1, 079	. 75	. 08	. 06
13	9	1, 848	1, 382	. 75	. 77	. 58	8	816	369	. 45	. 34	. 15	5	510	292	. 57	. 21	. 12
14	6	1, 733	1, 462	. 84	1. 06	. 89	12	876	350	. 40	. 53	. 22	5	365	209	. 57	. 22	. 13
15	5	1, 523	827	. 54	. 25	. 13	8	1, 222	351	. 30	. 20	. 06	4	732	229	. 31	. 12	. 04
16	4	3, 087	3, 192	1. 03	. 12	. 13	6	2, 250	1, 358	. 60	. 09	. 05	4	1, 500	1, 031	. 69	. 06	. 04
17	6	1, 965	1, 443	. 73	. 24	. 18	9	2, 537	1, 315	. 52	. 31	. 16	5	1, 575	914	. 58	. 19	. 11
18	11	4, 328	5, 013	1. 16	. 11	. 12	5	1, 448	1, 190	. 82	. 04	. 03	5	1, 920	1, 586	. 83	. 04	. 04
19	11	8, 037	6, 188	. 77	. 16	. 12	9	4, 007	2, 260	. 56	. 08	. 05	5	2, 565	1, 770	. 69	. 05	. 04
20	6	3, 346	3, 470	1. 04	. 19	. 20	5	1, 485	1, 007	. 68	. 09	. 06	5	1, 485	1, 007	. 68	. 08	. 06
21	7	4, 568	4, 048	. 89	. 11	. 10	16	8, 180	4, 488	. 55	. 21	. 11	5	2, 650	1, 834	. 69	. 07	. 05
22	14	3, 967	4, 728	1. 19	. 12	. 14	8	1, 974	1, 596	. 81	. 06	. 05	6	1, 603	1, 250	. 78	. 05	. 04
23	14	4, 624	5, 255	1. 14	. 11	. 12	8	2, 118	1, 754	. 83	. 05	. 04	6	1, 902	1, 483	. 78	. 04	. 03
Total or average	8	81, 564	65, 925	. 81	. 17	. 14	8	58, 511	30, 310	. 52	. 12	. 07	5	41. 383	23, 867	. 58	. 09	. 05

Project no.	Hauling						Placing and finishing						Totals					
	Average number of men	Total man-hours	Total cost of labor	Average wage per hour	Man-hours per ton of mix	Labor cost per ton of mix	Average number of men	Total man-hours	Total cost of labor	Average wage per hour	Man-hours per ton of mix	Labor cost per ton of mix	Average number of men	Total man-hours	Total cost of labor	Average wage per hour	Man-hours per ton of mix	Labor cost per ton of mix
1	10	5, 170	$3, 877	$0. 75	0. 20	$0. 15	21	9, 250	$5, 498	$0. 59	0. 36	$0. 21	49	23, 578	$15, 970	$0. 68	0. 92	$0. 62
2	6	3, 600	2, 700	. 75	. 13	. 09	13	7, 143	4, 777	. 67	. 25	. 17	43	25, 402	16, 998	. 67	. 88	. 59
3	13	3, 367	1, 347	. 40	. 60	. 24	17	4, 403	1, 684	. 38	. 79	. 30	49	13, 581	5, 780	. 43	2. 43	1. 03
4	7	1, 694	508	. 30	. 16	. 05	52	10, 892	3, 534	. 32	1. 02	. 33	85	19, 673	6, 630	. 34	1. 84	. 62
5	9	4, 284	3, 213	. 75	. 11	. 08	15	6, 921	4, 956	. 72	. 18	. 13	42	19, 875	14, 644	. 74	. 52	. 38
6	5	1, 975	593	. 30	. 23	. 07	17	6, 715	2, 172	. 32	. 76	. 25	41	17, 247	6, 448	. 37	1. 96	. 73
7	6	2, 004	601	. 30	. 16	. 05	26	8, 522	2, 673	. 31	. 66	. 21	51	17, 120	5, 703	. 33	1. 33	. 44
8	4	812	406	. 50	. 18	. 09	12	2, 436	1, 320	. 54	. 55	. 30	26	5, 376	2, 908	. 54	1. 21	. 65
9	11	3, 344	2, 508	. 75	. 14	. 11	17	4, 987	3, 569	. 72	. 22	. 15	50	14, 759	10, 782	. 73	. 64	. 47
10	7	2, 779	834	. 30	. 45	. 14	17	6, 749	2, 303	. 34	1. 10	. 37	40	17, 935	6, 646	. 37	2. 92	1. 08
11	9	5, 868	2, 934	. 50	. 31	. 16	13	8, 476	4, 434	. 52	. 45	. 24	41	27, 387	13, 662	. 50	1. 47	. 73
12	6	2, 166	1, 625	. 75	. 12	. 08	18	5, 956	3, 974	. 67	. 32	. 21	46	16, 292	11, 320	. 70	. 87	. 60
13	11	1, 122	696	. 62	. 47	. 29	19	1, 938	981	. 51	. 81	. 41	52	6, 234	3, 720	. 60	2. 60	1. 55
14	6	438	219	. 50	. 27	. 13	15	1, 095	561	. 51	. 67	. 34	44	4, 507	2, 801	. 62	2. 75	1. 71
15	11	2, 013	604	. 30	. 32	. 10	15	2, 745	888	. 32	. 44	. 14	43	8, 235	2, 899	. 35	1. 33	. 47
16	5	1, 875	1, 650	. 88	. 07	. 06	14	5, 026	3, 083	. 61	. 20	. 12	33	13, 738	10, 314	. 75	. 54	. 40
17	11	3, 465	2, 079	. 60	. 43	. 26	14	4, 410	2, 630	. 60	. 54	. 32	45	13, 952	8, 381	. 60	1. 71	1. 03
18	8	3, 072	2, 703	. 88	. 08	. 07	22	8, 448	6, 805	. 81	. 21	. 17	51	19, 216	17, 297	. 90	. 48	. 43
19	11	5, 643	4, 232	. 75	. 12	. 09	19	9, 137	5, 907	. 65	. 19	. 12	55	29, 389	20, 357	. 69	. 60	. 42
20	6	1, 782	1, 336	. 75	. 10	. 07	13	3, 861	2, 382	. 62	. 22	. 13	35	11, 959	9, 202	. 77	. 68	. 52
21	7	3, 710	2, 783	. 75	. 09	. 07	15	7, 950	5, 750	. 72	. 20	. 15	50	27, 058	18, 903	. 70	. 68	. 48
22	8	2, 136	1, 709	. 80	. 06	. 05	19	4, 052	2, 942	. 73	. 12	. 08	55	13, 732	12, 225	. 89	. 41	. 36
23	8	2, 536	2, 029	. 80	. 06	. 05	19	4, 764	3, 441	. 72	. 11	. 08	55	15, 944	13, 962	. 88	. 37	. 32
Total or average	8	64, 855	41, 186	. 63	. 14	. 09	18	135, 876	76, 264	. 56	. 29	. 16	47	382, 189	237, 552	. 62	. 81	. 51

PRODUCTIVE ABILITY OF PLANT CONSPICUOUS IN AFFECTING COSTS

Figure 14 shows graphically the effect of length of mixing cycle, size of batch, efficiency, and productive ability of plant on the hours of labor per ton of mixed material (left column of fig. 14) and also the effect of these factors on the cost of labor and materials per ton of mixed material (right column of fig. 14). In these graphs each plotted point represents the data obtained on a single project and a line has been drawn to represent the trend as nearly as it can be estimated. The effect of length of cycle and efficiency on the amount of labor and cost of labor and equipment is not clearly marked since other factors affect the position of the plotted points. "Tons per batch" show a much clearer relationship and the effect of productive ability on hours of labor and cost stands out significantly.

The graph on the lower right of figure 14 shows the effect of productive ability on cost of labor and equipment combined. The same data with labor and equipment compared separately are shown in figure 15.

CONSIDERATION SHOULD BE GIVEN TO COSTS OF MATERIALS IN DESIGNING MIXES

Up to this point the discussion has dealt mainly with costs of labor and equipment which constituted 40.3 percent of the total cost. Elimination of all avoidable delays would have reduced the cost of labor and equipment by 21.7 percent, making them 34.5 percent of the total cost. Such efficiency is within the reach of the average contractor who will then have 65.5 percent of the total cost involved in materials. Under highly efficient management they may be much higher since on the most efficient project studied labor and equipment costs were 46 percent below the average. It is evident that a discussion of economy in construction of mixed bituminous pavements must take into consideration the relative quantities and costs of the materials.

Use of local materials sometimes offers the opportunity to make savings in their cost and in their transportation. There has been some tendency toward adopting this practice where conditions are favorable.

TABLE 16.—*Equipment costs on each of 23 projects*

Project number	Supervision and general		Handling material at plant		Mixing and loading		Hauling		Placing and finishing		Total all items	
	Total	Cost per ton of mix	Total	Cost per ton of mix	Total	Cost per ton of mix	Total	Cost per ton of mix	Total	Cost per ton of mix	Total	Cost per ton of mix
1	$1,570	$0.06	$2,475	$0.10	$4,420	$0.17	$5,200	$0.20	$2,330	$0.09	$15,995	$0.62
2	1,600	.05	2,860	.10	6,000	.21	9,370	.33	3,661	.12	23,491	.81
3	218	.04	1,236	.22	1,497	.27	2,234	.40	1,260	.22	6,445	1.15
4	20	.00	1,426	.13	3,829	.36	4,266	.40	1,282	.12	10,823	1.01
5	2,445	.06	2,229	.06	5,202	.14	10,436	.27	3,605	.09	23,917	.62
6	756	.09	159	.02	2,243	.26	3,652	.41	997	.11	7,807	.89
7	145	.01	601	.05	3,297	.25	2,146	.17	1,545	.12	7,734	.60
8	200	.04	523	.12	1,231	.28	1,087	.24	356	.08	3,397	.76
9	384	.02	642	.03	3,370	.14	4,958	.21	1,791	.08	11,145	.48
10	57	.01	1,165	.19	2,610	.43	2,921	.47	2,233	.36	8,986	1.46
11	595	.03	359	.02	3,392	.18	5,777	.31	1,638	.09	11,761	.63
12	535	.03	1,726	.09	3,357	.18	4,031	.21	2,456	.13	12,105	.64
13	292	.12	473	.20	1,185	.50	1,868	.77	831	.35	4,649	1.94
14	157	.10	312	.19	1,165	.70	666	.41	632	.39	2,932	1.79
15	24	.00	728	.12	1,194	.19	2,992	.48	845	.14	5,783	.93
16	530	.02	2,036	.08	5,960	.23	7,145	.28	5,184	.21	20,855	.82
17	14	.00	583	.07	1,294	.16	3,775	.47	1,384	.17	7,050	.87
18	270	.01	1,816	.05	5,773	.14	5,782	.14	4,971	.12	18,612	.46
19	2,732	.06	3,084	.06	10,845	.22	11,202	.23	4,935	.10	32,798	.67
20	360	.02	1,996	.12	4,367	.25	5,478	.31	3,192	.18	15,393	.88
21	407	.01	3,906	.10	7,092	.18	8,274	.21	5,671	.14	25,350	.64
22	1,017	.03	1,450	.04	4,669	.14	4,431	.13	3,140	.09	14,707	.43
23	1,439	.03	1,698	.04	5,471	.13	5,240	.12	3,501	.08	17,349	.40
Weighted average		.03		.07		.19		.24		.12		.65
Unweighted average		.04		.10		.25		.31		.15		.85

TABLE 17.—*Quantities of materials used and cost computed on basis of an assumed uniform cost for each item on all projects*

Project no.	Rock	Sand	Asphaltic cement	Filler	All materials	Total cost	Total cost per ton of mix
	Tons	*Tons*	*Tons*	*Tons*	*Tons*		
1	16,987	6,779	1,343	643	25,752	$52,510	$2.04
2	18,394	8,467	1,280	690	28,831	55,160	1.91
3	1,936	2,818	470	375	5,599	14,911	2.66
4	1,377	7,798	957	573	10,705	28,201	2.63
5	25,673	9,070	1,810	1,973	38,526	80,676	2.09
6	1,166	6,501	772	368	8,807	22,460	2.55
7	1,658	9,399	1,206	655	12,918	34,615	2.68
8	553	3,138	438	331	4,460	12,795	2.87
9	15,527	5,918	1,063	578	23,086	45,027	1.96
10	737	4,534	548	325	6,144	16,137	2.63
11	3,693	13,914	1,051	0	18,658	35,162	1.88
12	12,221	5,058	920	641	18,840	38,289	2.03
13	828	1,204	201	160	2,393	6,374	2.66
14	567	824	137	110	1,638	4,356	2.66
15	932	4,497	521	248	6,198	15,439	2.49
16	16,632	6,945	1,159	790	25,496	50,008	1.96
17	3,145	3,734	573	696	8,148	20,852	2.56
18	26,985	10,111	2,016	991	40,103	80,695	2.01
19	31,705	13,454	2,441	1,350	48,950	98,656	2.02
20	11,152	4,878	843	681	17,754	35,834	2.04
21	26,804	9,913	1,969	999	39,685	79,576	2.00
22	22,679	8,574	1,592	911	33,756	66,726	1.98
23	29,145	11,243	2,138	1,030	43,556	86,605	1.99

On two recent projects in the Western States four sizes of aggregate were produced from local deposits with excellent results. In each case a semiportable aggregate plant of considerable size was installed and the output was sufficient to care for the maximum production of the mixing plant.

The specification requirements as to composition of the mix produce considerable variation in the costs of material per ton of mix. Table 21 shows the composition of the mix on five typical projects in different sections of the country and the corresponding costs of materials. For purposes of comparison the no. 10 sieve is taken as the dividing line between sand and rock. All percentages are computed on the assumption that the dry weight of aggregate and filler constitute 100 percent and the amount of asphalt is expressed as a percentage of this weight.

TABLE 18.—*Cost per ton of mix for labor, equipment, and materials (on assumed basis) on each of 23 projects*

Project no.	Cost per ton of mix				Percent of total cost		
	Supervision and labor	Equipment	Materials	Total	Supervision and labor	Equipment	Materials
					Percent	*Percent*	*Percent*
1	$0.62	$0.62	$2.04	$3.28	18.9	18.9	62.2
2	.59	.81	1.91	3.31	17.8	24.5	57.7
3	1.03	1.15	2.66	4.84	21.3	23.8	54.9
4	.62	1.01	2.63	4.26	14.6	23.7	61.7
5	.38	.62	2.09	3.09	12.3	20.1	67.6
6	.73	.89	2.55	4.17	17.5	21.4	61.1
7	.44	.60	2.68	3.72	11.8	16.2	72.0
8	.65	.76	2.87	4.28	15.2	17.8	67.0
9	.47	.48	1.96	2.91	16.1	16.5	67.4
10	1.08	1.46	2.63	5.17	20.9	28.2	50.9
11	.73	.63	1.88	3.24	22.5	19.5	58.0
12	.60	.64	2.03	3.27	18.4	19.6	62.0
13	1.55	1.94	2.66	6.15	25.2	31.6	43.2
14	1.71	1.79	2.66	6.16	27.8	29.0	43.2
15	.47	.93	2.49	3.89	12.1	23.9	64.0
16	.40	.82	1.96	3.18	12.6	25.8	61.6
17	1.03	.87	2.56	4.46	23.1	19.5	57.4
18	.43	.46	2.01	2.90	14.8	15.9	69.3
19	.42	.67	2.02	3.11	13.5	21.6	64.9
20	.52	.88	2.04	3.44	15.1	25.6	59.3
21	.47	.64	2.00	3.11	15.1	20.6	64.3
22	.36	.43	1.98	2.77	13.0	15.5	71.5
23	.32	.40	1.99	2.71	11.8	14.8	73.4
Unweighted average	.68	.85	2.27	3.80	17.9	22.4	59.7
Weighted average	.51	.65	2.09	3.25			

TABLE 19.—*Cost of avoidable delays on all projects by causes*

Cause of delay	Avoidable major delay	Cost of avoidable major delay	Avoidable minor delay	Cost of avoidable minor delay	Cost of all avoidable delay
	Hours		*Hours*		
Hauling equipment operation	44.0	$1,549	613.5	$37,208	$38,757
Bins empty or overflowing			638.5	38,725	38,725
Handling material at plant	108.6	3,823	83.4	5,058	8,881
Lack of material at plant	149.5	5,263			5,263
Operative at plant			146.2	8,866	8,866
Moving at street	80.3	2,827			2,827
Miscellaneous	73.9	2,602	1.8	109	2,711
Lack of subgrade	75.2	2,647			2,647
Heating material at plant	47.7	1,680			1,680
Late start, management	45.9	1,616			1,616
Handling asphaltic cement and fuel			45.3	2,747	2,747
Finishing			41.4	2,692	2,692
Mechanical at street	31.6	1,113			1,113
Mechanical at plant	7.1	250			250
Total	663.8	23,370	1,573.1	95,405	118,775

TABLE 20.—*Cost of avoidable delays by projects*

Project no.	Cost of labor and equipment per available hour	Avoidable major delay	Cost of avoidable major delay	Cost of labor and equipment per working hour	Avoidable minor delay	Cost of avoidable minor delay	Cost of all avoidable delay
		Hours			*Hours*		
1	$53.20	10.1	$537	$60.80	120.9	$7,351	$7,888
2	55.60	6.5	361	67.00	178.7	11,973	12,334
3	28.00	2.0	56	47.00	32.6	1,532	1,588
4	34.80	13.7	477	70.00	47.5	3,325	3,802
5	66.00	20.6	1,389	78.00	53.8	4,196	5,585
6	17.50	100.5	1,759	31.60	63.4	2,003	3,762
7	25.60	48.0	1,229	36.50	133.0	4,854	6,083
8	22.80	44.8	1,021	26.10	86.8	2,265	3,286
9	68.20	10.7	730	69.70	79.0	5,506	6,236
10	16.30	109.2	1,780	34.90	64.8	2,262	4,042
11	32.50	41.3	1,342	37.00	86.6	3,204	4,546
12	51.10	43.6	2,228	58.60	71.4	4,184	6,412
13	29.10	1.5	44	81.60	23.4	1,909	1,953
14	17.30	2.0	35	78.10	12.5	976	1,011
15	25.90	26.9	697	43.80	61.1	2,676	3,373
16	34.50	49.3	1,701	78.70	93.7	7,374	9,075
17	46.70	6.2	290	48.00	58.2	2,794	3,084
18	90.50	6.6	597	92.10	52.2	4,808	5,405
19	58.30	59.5	3,469	96.90	67.2	6,512	9,981
20	35.70	5.0	179	82.20	26.4	2,170	2,349
21	54.20	43.0	2,331	79.10	112.0	8,859	11,190
22	86.20	10.3	888	97.40	38.2	3,721	4,609
23	92.00	2.5	230	98.00	9.7	951	1,181
Average	35.20	28.9	1,016	60.65	68.4	4,148	5.164

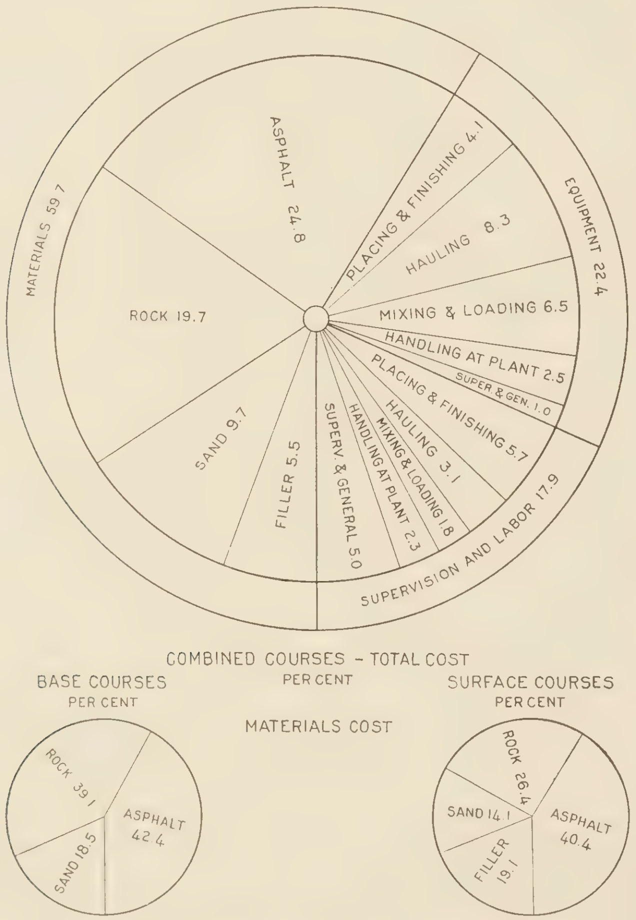


FIGURE 13.—DISTRIBUTION OF AVERAGE COSTS.

Considering the material passing the no. 10 sieve as mortar, table 21 shows that bases have been constructed with a mortar content as low as 23 percent with 5 percent asphalt and as high as 85 percent with 8 percent asphalt. The surface courses range from 33 percent mortar with 5.4 percent asphalt to 100 percent mortar with 10.5 percent asphalt.

Sand-asphalt mixes have been used in regions where rock would have to be transported such distances as to make its use uneconomic. However, there are wide differences in percentages or rock used in base course in regions where rock is readily available. Excellent pavements have been constructed with a high percentage of coarse aggregate in the base and it appears that low percentages of coarse aggregate with the consequent increase in asphalt required are often uneconomic designs.

TABLE 21.—*Composition of mix and costs of materials, equipment, and labor on 5 typical projects*

	Northern bituminous concrete base (4,100 tons) with sheet asphalt surface (3,500 tons)					Western bituminous concrete (225,000 tons in base and 140,127 tons in surface)				
	Rock	Sand	Filler	Asphalt	Cost per ton	Rock	Sand	Filler	Asphalt	Cost per ton
	Percent	*Percent*	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*	*Percent*	
Composition of base and cost of materials	77.1	22.9	------	5.0	$1.87	71.0	28.8	0.2	4.9	$1.85
Composition of surface and cost of materials	------	80.1	19.9	10.5	3.33	67.0	25.3	7.8	5.4	2.26
Composition of combined base and surface and cost of materials	45.1	49.3	9.2	7.6	2.56	69.4	27.5	3.1	5.1	1.99
Cost of—										
Equipment	------	------	------	------	0.87	------	------	------	------	0.60
Labor	------	------	------	------	1.03	------	------	------	------	0.45
Total	------	------	------	------	4.46	------	------	------	------	3.04

	Eastern bituminous concrete (8,400 tons in base and 9,200 tons in surface)					Southeastern sand-asphalt (24,400 tons in base and 20,300 tons in surface)				
	Rock	Sand	Filler	Asphalt	Cost per ton	Rock	Sand	Filler	Asphalt	Cost per ton
	Percent	*Percent*	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*	*Percent*	
Composition of base and cost of materials	21.0	79.0	------	6.0	$1.88	15.0	85.0	------	8.0	$2.14
Composition of surface and cost of materials	21.0	79.0	------	6.0	1.88	13.6	74.1	12.3	12.2	3.20
Composition of combined base and surface and cost of materials	21.0	79.0	------	6.0	1.88	14.3	80.1	5.6	9.9	2.63
Cost of—										
Equipment	------	------	------	------	0.63	------	------	------	------	0.91
Labor	------	------	------	------	0.73	------	------	------	------	0.63
Total	------	------	------	------	3.24	------	------	------	------	4.17

	Southwestern rock asphalt sheet mix for surface (8,800 tons)				
	Rock	Sand	Filler	Asphalt	Cost per ton
	Percent	*Percent*	*Percent*	*Percent*	
Composition of surface and cost of materials	37.8	54.9	7.3	9.2	$2.86
Composition of combined base and surface and cost of materials	37.8	54.9	7.3	9.2	2.86
Cost of—					
Equipment	------	------	------	------	1.46
Labor	------	------	------	------	1.28
Total	------	------	------	------	5.40

RELATION BETWEEN TIME OF MIXING AND UNIFORMITY OF MIX STUDIED

In the studies at various plants attention was given to the relation between time of mixing and the uniformity of the mixed material. A single test for uniformity consisted of taking a sample from each end of the pug mill, analyzing the contents of each sample and comparing the results on a percentage basis. The weight of a sample was approximately 50 times the

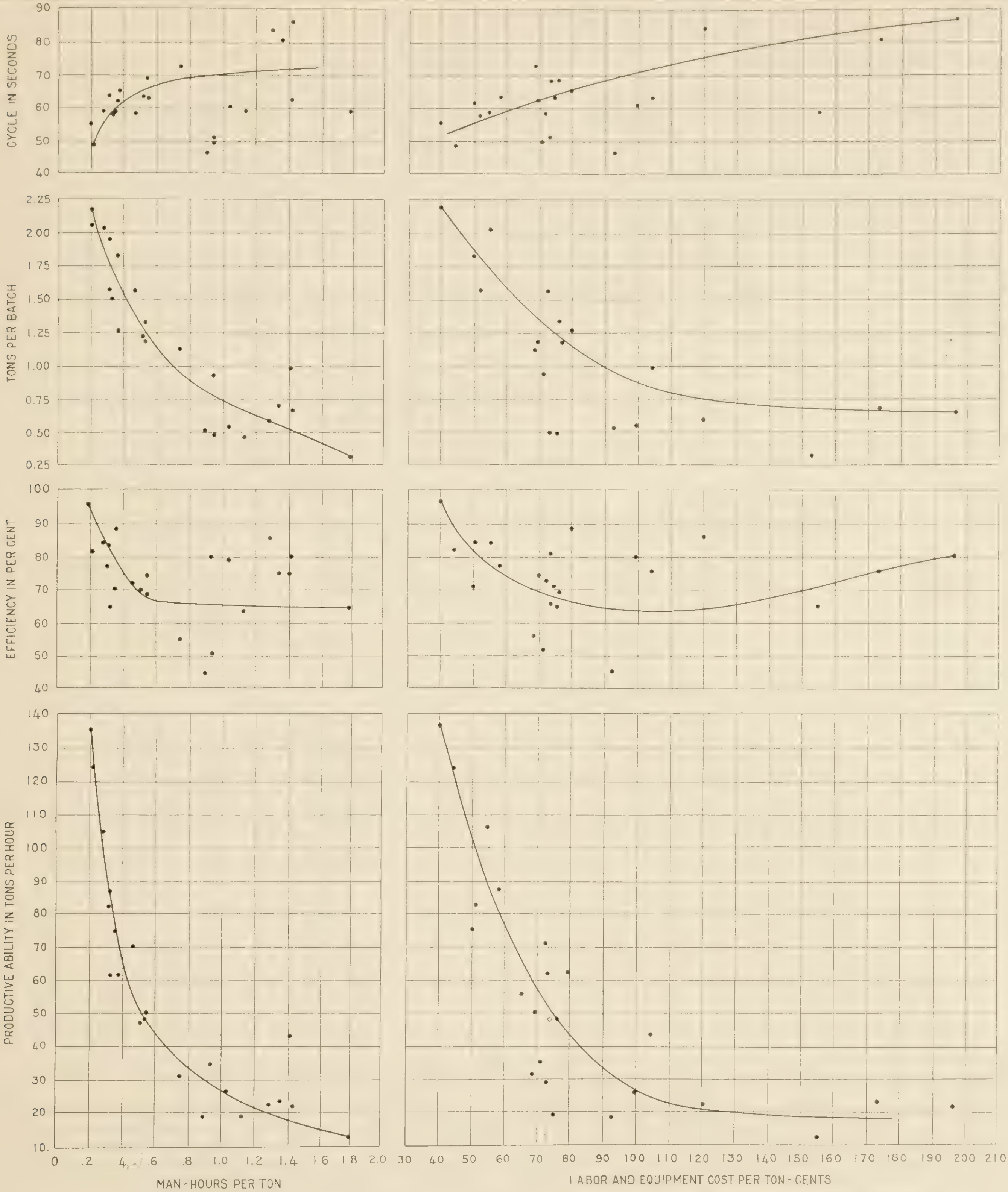


FIGURE 14.—EFFECT OF VARIOUS FACTORS ON HOURS OF LABOR AND COST OF LABOR AND EQUIPMENT.

weight of the largest particle. Asphalt was extracted using commercial benzol as a solvent. Screen analyses were made in an improvised field laboratory.

A series of tests consisted of taking a pair of samples at 10-second intervals through one minute of mixing and then at half-minute intervals up to 3 minutes of mixing. Conclusions are based solely on differences between samples taken at the same instant and no attempt was made to determine the composition of a batch as a whole. Twenty-five series of samples were taken, including different mixes and at five different plants.

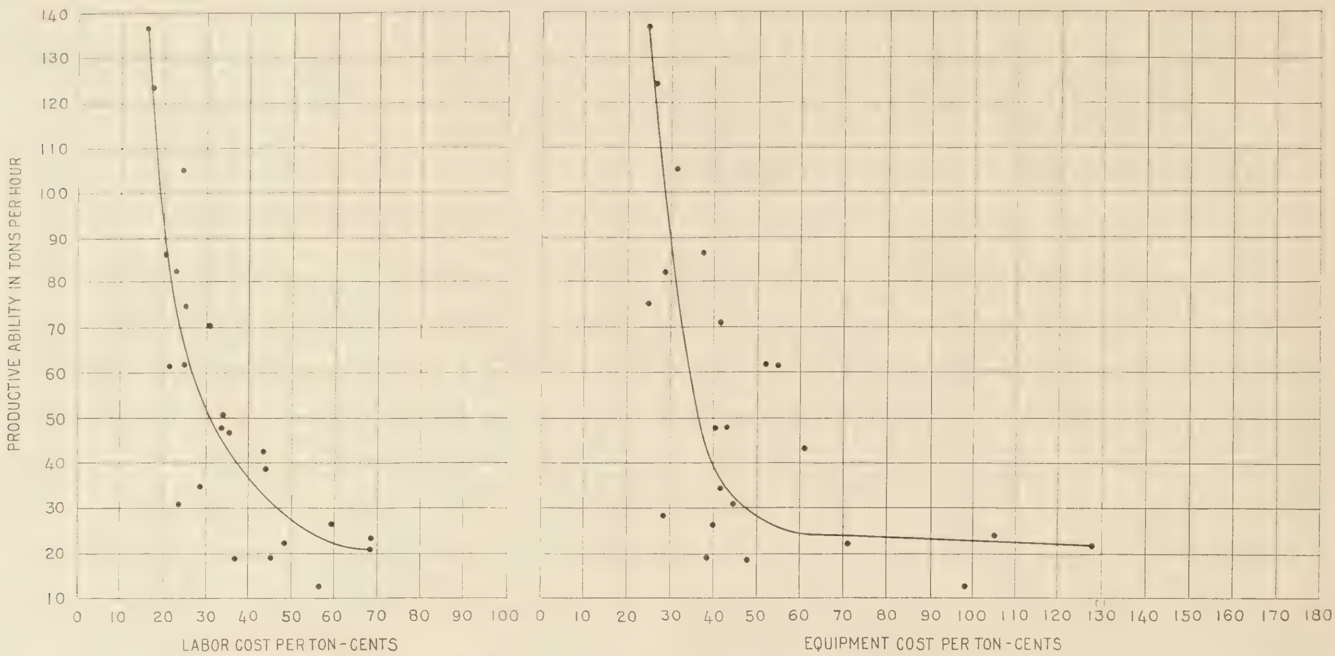


FIGURE 15.—EFFECT OF PRODUCTIVE ABILITY ON COST OF LABOR AND EQUIPMENT.

TABLE 22.—*Total percentage differences (see text) between 2 samples taken at same instant for various mixing times and for each series of tests*

Course	Sample series no.	Seconds of mixing: 10	20	30	40	50	60	90	120	150	180
Surface	1	44.6	17.0	22.8	24.0	15.2	9.8	14.0	11.8	23.0	14.0
	2	40.0	25.2	25.2	49.8	14.4	13.2	24.0	10.0	22.6	31.4
	3	31.0	22.0	24.8	9.4	34.4	12.4	2.2	8.6	14.2	13.4
	4	17.0	31.6	30.0	10.0	18.0	23.8	22.0	13.6	16.0	16.2
	5	39.6	21.4	21.8	24.0	33.6	10.4	11.0	24.2	15.2	19.4
	6	77.8	25.0	26.6	48.6	26.2	18.6	42.6	26.0	22.6	13.8
	7	30.2	22.0	23.4	21.8	28.4	20.2	13.4	14.6	13.6	18.6
	8	22.4	19.8	26.4	24.4	22.8	-----	-----	-----	-----	-----
	9	13.2	7.0	22.2	10.4	17.4	-----	-----	-----	-----	-----
	10	45.0	16.3	10.2	22.0	10.4	-----	-----	-----	-----	-----
	11	13.0	6.6	14.2	33.6	33.6	-----	-----	-----	-----	-----
Average	-----	33.98	19.45	22.51	25.27	23.13	15.48	18.46	15.54	18.17	18.11
Levelling	12	52.0	34.4	27.2	17.0	24.2	16.2	28.0	14.6	6.0	17.0
	13	-----	51.8	25.6	23.0	50.2	8.4	6.0	12.4	25.4	6.8
	14	38.0	36.8	24.4	23.8	20.2	21.6	29.2	28.0	30.8	29.8
	15	30.6	33.0	18.6	20.7	36.4	14.8	23.6	12.4	32.8	20.6
	16	43.0	25.6	28.0	37.4	15.0	23.8	24.0	18.4	12.8	22.0
	17	34.2	39.0	30.0	33.2	27.0	31.0	13.8	25.4	12.4	23.2
	18	14.6	33.4	27.8	12.6	25.6	-----	-----	-----	-----	-----
	19	14.8	20.6	16.0	36.4	21.8	-----	-----	-----	-----	-----
	20	27.8	16.8	19.6	25.2	18.2	-----	-----	-----	-----	-----
	21	26.4	18.2	30.4	15.8	24.2	-----	-----	-----	-----	-----
Base	22	44.8	46.2	37.8	34.2	19.2	30.2	11.2	13.2	18.6	19.4
	23	21.6	15.6	13.6	20.2	19.2	-----	-----	-----	-----	-----
	24	36.2	9.4	32.8	48.0	13.0	-----	-----	-----	-----	-----
	25	44.8	16.4	27.8	14.0	24.4	-----	-----	-----	-----	-----
Average, base and leveling		32.97	28.37	25.69	25.82	24.19	20.86	19.40	17.77	19.83	19.83

For each pair of samples the percentage of asphalt and of each size of aggregate were tabulated in adjacent columns. The differences between corresponding percentages were tabulated and then totaled for the pair of samples. These total percentage differences reflect the variation between the two samples. Such totals for each mixing time and for each series of tests are shown in table 22. The average results for all samples show improved mixing with increased mixing time. However, certain of the series show a rise and fall in uniformity such as to suggest the possibility of segregation due to overmixing.

TABLE 23.—*Variations in pairs of samples in the percentage of material of a given screen or sieve size, averaged for all series, and for each mixing time*

SURFACE COURSE

Seconds of mixing	Screen or sieve size: 1¼ inches	¾ inch	No. 3	No. 10	No. 40	No. 80	No. 200	Asphalt cement
10	6.81	9.55	5.34	2.71	4.01	3.32	2.24	2.25
20	4.88	4.70	2.47	1.30	2.17	1.97	1.96	1.75
30	6.28	5.53	4.28	1.70	1.46	1.82	1.44	1.80
40	9.33	4.94	3.40	1.61	2.46	1.55	1.98	1.65
50	7.57	4.74	4.43	2.15	1.41	1.27	1.56	1.59
60	3.24	5.20	1.34	1.50	1.44	1.53	1.23	1.10
90	5.70	3.43	3.54	1.67	1.59	1.19	1.34	.80
120	5.16	3.13	1.87	1.63	1.20	.88	1.67	1.16
150	5.20	6.31	1.92	1.71	.64	.87	1.52	.86
180	6.56	4.70	2.38	1.20	1.04	.59	1.64	.99

LEVELING AND BASE

Seconds of mixing	1¼ inches	¾ inch	No. 3	No. 10	No. 40	No. 80	No. 200	Asphalt cement
10	10.74	7.90	6.81	2.10	2.27	2.38	0.77	0.90
20	6.97	9.41	4.79	2.22	2.28	2.05	.65	.91
30	8.74	6.36	5.01	1.23	2.04	2.02	.29	.88
40	8.46	6.41	4.80	1.55	2.41	1.61	.58	.94
50	7.24	5.07	4.54	2.15	2.27	2.29	.63	.87
60	5.06	7.30	4.81	.70	1.34	1.06	.59	.24
90	5.99	3.67	5.23	.93	1.67	1.40	.51	.61
120	5.53	4.14	4.74	.91	1.29	.79	.37	.84
150	5.39	8.17	3.17	.69	1.01	.89	.51	.93
180	7.57	4.33	4.13	.84	1.23	.94	.79	.70

Variations in pairs of samples in the percentage of material of a given screen size or sieve size, averaged for all series, and for each mixing time are shown in table 23.

The data of table 23 when cross totaled cumulatively (excluding asphalt) reflect the relative degree of uniformity of various portions of the mix for the various mixing times. Such totals have been used in plotting figure 16 which also shows the uniformity of the distribution of asphalt. Improvement in uniformity takes place rapidly during the first 60 seconds and at a slower rate thereafter.

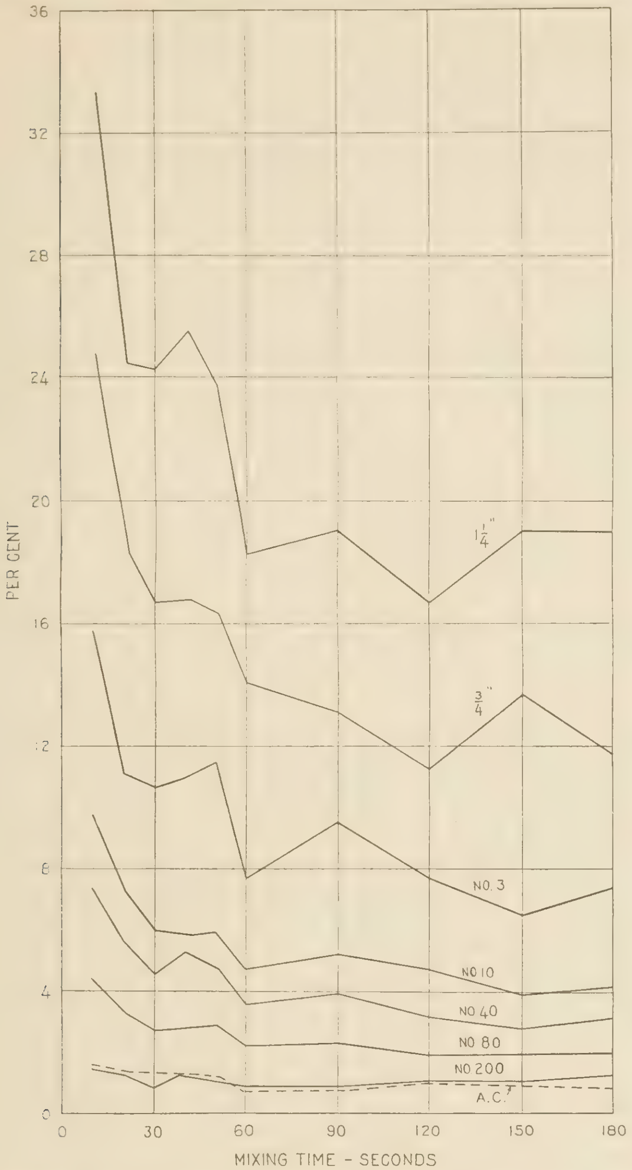


Figure 16.—Percent Difference of Samples from Opposite Ends of Pugmill, Results of All Tests.

ADVANTAGE OF ONE-COURSE PAVEMENT DISCUSSED

In seeking to reduce the cost of asphaltic concrete pavements thought should be given to the design of a mix which will be satisfactory for one-course or monolithic construction. The preceding discussion has demonstrated the increased costs for proportioning, mixing, spreading, and rolling which may result when two unequal courses of different mixes are constructed. The broad range in types of mixes which are being successfully used indicates the possibility of designing satisfactory mixes for one-course pavements. The matter of compacting the necessary thickness in one course does not appear to be a serious obstacle. Table 1 shows the average total thickness of the pavements studied to be slightly over 5 inches. On five of the projects studied single courses in excess of 4 inches were satisfactorily compacted and on one project the depth approached 5 inches.

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 MARCH 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	$ 4,185,067					$ 5,281,579.81	$ 2,920,146.40	$ 2,361,433.41	40.7	292.1	$ 287,850.00	24.7	$ 977,070.60
Arizona	3,804,731	$ 497,522.54	$ 497,522.54		33.0	3,150,514.11	2,639,237.56		45.0	219.9	239,779.49	18.0	428,191.41
Arkansas	3,374,167	75,315.69	40,650.69	$ 34,665.00	2.3	1,876,452.07	1,445,942.71	430,509.36	43.9	86.6	989,523.71	71.8	898,049.89
California	7,803,677	587,454.88	496,864.74		11.3	8,013,425.13	6,004,547.70		36.6	244.9	833,188.92	41.9	469,075.64
Colorado	3,437,265	728,229.51	728,229.51		53.4	1,766,437.55	1,755,857.20		39.7	69.3	653,584.14	15.8	299,594.15
Connecticut	1,404,213					1,536,551.82	1,360,772.88	175,778.94	6.8	30.7	39,685.88	.1	3,754.24
Delaware	909,544	133,532.30	133,532.30			742,815.70	742,815.70		25.8	17.4			33,196.00
Florida	2,615,917	176,839.08	97,261.49	79,577.59	6.4	2,848,267.22	2,141,960.60	705,696.52	47.2	102.6	220,909.03	7.0	155,785.88
Georgia	5,045,592	231,655.40	231,655.40		9.8	2,411,144.77	2,411,144.77		41.9	152.7	570,032.06	45.9	1,832,759.77
Idaho	2,166,858	307,083.11	303,761.80		36.1	1,413,185.82	1,401,763.97		45.9	100.4	225,638.63	24.3	235,693.60
Illinois	4,431,348					1,153,986.41	1,153,986.41		21.1	25.3	1,794,460.74	22.1	1,482,900.85
Indiana	4,717,786					2,017,394.80	2,017,394.80		34.4	67.6	1,939,516.14	51.2	760,875.06
Iowa	5,027,830	722,781.94	721,500.00		31.6	4,229,352.32	3,985,230.00		31.1	222.1	263,250.00	15.3	57,850.00
Kansas	5,044,802	538,216.87	538,216.87		100.9	4,112,604.26	4,019,333.22		41.0	282.6	478,187.90	14.1	9,064.01
Kentucky	3,608,332	145,472.40	145,472.40		12.0	2,019,552.67	2,019,552.67		36.1	150.1	1,119,514.20	82.4	323,792.73
Louisiana	2,914,295	38,528.74	38,528.74		1.1	2,459,604.13	1,952,953.13		23.4	59.4	667,484.82	17.0	255,328.31
Maine	1,617,560					1,167,849.93	1,132,282.98		36.9	35.5	242,775.60	8.5	242,501.42
Maryland	1,782,263					801,143.78	791,495.03		10.7	14.8			990,767.97
Massachusetts	1,101,716	153,936.88	83,952.64	69,984.24	4.2	1,160,630.24	844,970.60	315,659.64	20.2	32.9	76,952.29	.7	95,840.47
Michigan	5,094,491	63,000.00	63,000.00		1.8	2,954,300.00	2,954,300.00		28.8	153.7	2,066,516.00	77.6	10,675.00
Minnesota	5,115,153	1,326,915.25	1,326,915.25		320.0	2,023,510.96	2,023,510.96		43.1	283.8	479,862.12	89.2	1,284,864.67
Mississippi	3,489,337	155,273.60	85,400.49	69,873.11	6.6	3,456,288.03	1,864,989.24	1,552,666.85	18.9	185.6	743,186.58	64.0	795,760.69
Missouri	5,237,532	434,210.86	313,743.92		26.3	3,828,655.67	3,510,383.45	50,048.60	37.2	129.6	807,776.07	27.7	605,628.56
Montana	4,463,849	516,749.40	516,749.40		51.5	3,836,697.68	3,430,212.16	326,485.52	35.6	275.0	351,272.88	19.7	165,614.56
Nebraska	3,914,481	380,431.98	255,420.54		144.8	4,003,829.48	3,117,540.42	108,538.00	45.3	181.4	368,365.57	52.1	173,154.47
Nevada	2,909,387	272,235.60	272,235.60		60.2	1,739,088.95	1,739,088.95		42.3	144.8	812,650.99	54.5	85,411.46
New Hampshire	725,739					573,516.95	567,831.95		30.6	9.8	68,469.25	1.0	89,437.80
New Jersey	3,065,137	12,742.75	12,742.75		.2	1,921,643.33	1,914,689.53		7.2	23.7	819,081.25	10.9	318,623.47
New Mexico	2,896,467	1,314,311.91	1,314,311.91		150.6	1,627,684.20	1,491,324.72	102,921.33	10.7	126.7	44,621.19	1.7	46,209.18
New York	10,182,526	117,100.00	117,100.00		3.8	10,765,060.68	9,514,585.68	358,000.00	23.3	224.5	214,428.00	9.4	336,412.32
North Carolina	4,761,147	572,881.72	326,298.27	246,583.45	44.0	2,038,136.42	1,732,712.15	305,424.27	30.9	248.4	1,479,976.39	248.5	1,222,160.19
North Dakota	2,902,224	510,757.38	510,753.87		265.8	864,806.47	864,806.47		17.1	221.4	1,337,731.83	428.9	188,931.83
Ohio	7,277,758	293,134.35	292,290.00		5.9	6,193,130.00	6,010,380.00		33.6	161.1	665,396.00	17.3	309,692.00
Oklahoma	4,608,399	228,526.20	228,417.12		15.9	3,536,333.90	3,536,333.90		45.9	232.7	469,867.08	49.1	373,780.90
Oregon	3,053,448	350,457.26	322,563.76		40.4	2,646,150.29	2,406,493.59	58,505.67	34.5	133.9	222,423.08	8.3	101,967.57
Pennsylvania	6,691,194	12,791.10	12,791.10		.2	4,747,625.05	4,737,013.20		13.6	111.8	1,008,173.70	11.3	933,216.00
Rhode Island	999,354	18,144.13	18,144.13		.5	969,153.21	969,153.21		27.4	20.0	10,468.37		1,588.29
South Carolina	2,729,583	4,168.89	4,168.89			2,000,712.21	1,997,982.59	2,729.62	37.3	184.1	91,205.37	5.2	636,226.15
South Dakota	3,005,739	625,764.57	619,848.08	5,916.49	111.6	1,385,345.41	1,353,321.12	32,024.29	29.8	220.4	621,056.85	100.5	411,512.95
Tennessee	4,246,309	190,117.74	104,645.13	85,472.61	5.8	3,295,717.47	2,805,172.70	490,544.77	29.1	118.8	1,080,392.51	60.7	256,098.66
Texas	12,122,012	1,125,876.08	834,168.39		256.3	8,194,186.45	7,361,257.55		35.3	578.3	1,712,385.24	157.7	2,214,200.82
Utah	2,374,205	854,854.43	854,854.43		101.6	1,203,715.06	1,203,320.16		35.2	87.8	99,127.09	3.9	216,903.32
Vermont	928,184	47,983.81	47,983.81		6.1	735,351.85	707,198.60		36.3	34.7	41,604.99	.7	131,396.60
Virginia	3,708,379	190,180.06	172,607.08	17,572.98	11.1	2,431,083.30	2,430,670.99	412.31	30.1	78.9	1,041,215.55	43.1	63,885.38
Washington	3,057,934	212,292.13	212,271.76		14.1	2,269,656.45	2,266,299.63	3,356.82	33.0	76.8	279,529.44	9.1	299,833.17
West Virginia	2,013,405	194,881.82	194,881.82		6.4	1,545,942.71	1,539,942.71		37.1	63.6	198,870.69	2.2	79,709.78
Wisconsin	4,362,441	298,477.25	288,174.42	1,190.00	15.7	2,596,412.90	2,574,313.37	21,500.00	37.9	99.7	1,165,779.17	79.0	834,174.04
Wyoming	2,250,663	912,725.90	797,131.00	78,000.00	163.8	1,332,768.88	1,207,700.00		12.8	279.9	77,182.61	11.7	168,649.39
District of Columbia													
Hawaii	1,683,956	26,001.46	12,994.33	12,994.32	.9	1,417,975.35	1,186,148.24	181,827.36	19.6	28.6	218,720.78	3.3	266,092.65
TOTALS	185,363,396	15,599,556.97	14,189,756.37	701,829.79	2,134.0	134,296,971.85	119,760,065.57	7,584,063.28	32.3	6,926.4	29,239,670.19	2,109.1	22,173,903.87

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 MARCH 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	$ 2,092,533	$ 29,479.63	$ 29,479.63		0.8	$ 333,928.98	$ 333,928.98		37.7	9.6	$ 564,330.82	19.3	$ 1,164,793.57
Arizona	781,794	22,538.90	22,538.90		.7	176,373.73	174,932.85		13.1	4.5	42,811.39	1.8	541,510.86
Arkansas	1,687,084	17,506.70	15,826.70	$ 1,680.00	.3	572,028.98	501,813.77	$ 70,215.21	41.1	15.3	351,702.85	13.2	817,740.68
California	3,901,839	311,486.74	279,811.54		7.5	2,293,433.76	2,059,163.96		22.0	26.3	907,013.20	10.9	655,850.30
Colorado	1,718,633	170,834.51	170,834.51		4.1	587,891.32	587,891.32		17.9	10.4	521,226.86	12.4	438,680.31
Connecticut	802,407	52,696.86	52,696.86		.5	430,230.83	430,230.83		30.9	6.9	314,554.72	2.8	4,924.59
Delaware	454,772	75,309.50	75,309.50		.8	149,600.00	149,600.00		5.3	1.1	50,710.00	.8	179,152.50
Florida	1,307,959	39,165.31	21,653.41	17,511.90	.2	1,090,654.13	870,400.82	220,253.31	28.7	11.7	415,904.77	5.5	
Georgia	2,724,620	42,177.96	42,177.96		1.9	555,745.71	555,745.71		41.4	20.8	401,909.10	17.6	1,724,787.23
Idaho	1,197,829	22,257.32	22,049.37		1.7	390,958.61	386,923.81		22.2	6.8	125,969.87	5.8	662,885.95
Illinois	6,877,199	58,782.38	58,782.38		.8	3,993,623.20	3,993,623.20		13.4	42.7	2,715,562.10	26.4	109,231.32
Indiana	4,818,165	24,698.54	24,698.54		.4	24,810.85	24,810.85		64.5	.7	2,672,231.73	52.9	2,096,423.88
Iowa	2,815,585	244,176.37	242,350.00		8.6	929,855.23	877,645.00		13.6	17.7	634,650.00	18.5	1,060,940.00
Kansas	2,522,401	51,160.15	51,160.15		3.9	2,115,902.73	1,966,094.48		17.6	26.0	505,146.37	7.2	
Kentucky	2,029,687	13,307.85	13,307.85		.2	236,014.61	236,014.61		5.9	4.3	546,527.52	14.8	1,233,837.02
Louisiana	1,457,148	136,863.72	136,863.72		1.7	293,810.51	293,810.51		49.7	9.2	518,138.50	14.3	508,335.27
Maine	909,878	79,296.57	79,296.57		1.6	350,433.41	350,433.41		36.8	8.6	404,607.03	6.6	75,540.99
Maryland	891,132					16,788.76	12,638.76		99.0	.6			878,493.24
Massachusetts	5,007,199	53,896.49	30,896.49	23,000.00	1.5	3,942,858.28	3,928,758.28	14,100.00	13.7	12.7	250,293.28	1.0	797,250.95
Michigan	4,457,679	180,700.00	180,700.00		2.2	1,890,766.00	1,888,616.00		10.1	21.1	866,600.00	12.9	1,521,763.00
Minnesota	3,410,102	553,219.79	553,219.79		35.9	818,509.75	818,509.75		45.7	33.8	609,126.87	16.4	1,429,245.59
Mississippi	1,744,669	67,501.63	63,751.37	3,750.26	2.2	366,991.49	354,820.99	12,170.50	9.9	14.7	371,733.66	13.1	954,362.98
Missouri	4,019,501	64,021.79	61,736.26		1.4	1,349,266.90	1,213,835.93		30.3	20.2	752,786.25	16.2	1,991,142.56
Montana	1,115,962	2,878.39	2,878.39		.2	414,751.32	414,751.32		30.1	11.7	311,702.73	12.2	386,629.56
Nebraska	1,957,240	29,236.64	28,547.35		3.6	1,096,489.00	1,096,489.00		26.4	17.9	752,405.13	12.7	79,798.52
Nevada	500,051	50,304.27	50,304.27		1.2						45,899.24	1.2	403,847.49
New Hampshire	706,640					538,459.54	538,459.54		9.7	12.9	168,180.46	3.6	
New Jersey	3,217,442	90,163.28	90,163.28		1.4	2,030,463.11	2,030,463.11		26.1	13.2	683,985.71	6.6	412,829.90
New Mexico	1,448,234	47,286.70	47,286.70		2.6	454,094.59	454,094.59		40.7	7.8	732,356.41	16.6	214,496.30
New York	8,530,099	130,131.30	129,750.00		2.2	6,478,477.60	6,030,045.00	39,000.00	17.7	49.3	1,404,822.70	9.9	965,481.30
North Carolina	2,380,573	70,938.35	70,938.35		5.2	477,343.92	477,343.92		22.4	17.7	522,055.69	26.6	1,310,235.04
North Dakota	1,451,112	2,153.29	2,153.29		1.0	49,955.24	49,955.24		52.0	6.2	504,199.80	16.0	894,803.67
Ohio	4,335,686	65,638.97	58,083.75		2.0	1,717,269.43	1,589,281.93		20.8	18.7	2,531,834.00	36.6	156,486.32
Oklahoma	2,304,200	30,917.97	30,901.44		1.9	756,212.40	756,212.40		26.6	16.9	1,115,202.51	21.8	401,883.65
Oregon	1,526,724	99,566.50	99,566.50		2.0	685,410.91	671,095.18	14,315.73	10.6	13.4	453,496.34	9.4	302,565.98
Pennsylvania	4,854,988	120,743.33	119,911.49		4.4	1,538,276.00	1,524,328.93		19.9	27.3	1,895,123.26	22.1	1,315,624.32
Rhode Island	499,677					155,048.79	155,048.79		5.2	2.4	196,041.23	2.9	148,586.98
South Carolina	1,364,791	24,919.48	24,919.48		1.7	431,999.17	431,594.16	405.01	17.8	20.3	16,261.22	1.6	892,016.14
South Dakota	1,502,870	50,799.37	50,799.37		3.3	183,622.25	183,622.25		28.3	7.3	385,589.28	14.8	882,859.10
Tennessee	2,123,155	19,992.06	19,992.06		1.1	661,918.74	661,918.74		27.8	9.0	553,285.01	9.0	887,959.19
Texas	6,061,006	263,679.90	228,684.40		14.8	2,455,126.02	2,303,020.87		24.4	64.7	1,322,392.22	24.6	2,206,908.51
Utah	771,826	372,211.41	372,134.41		8.9	214,492.36	212,733.98		41.4	6.0	60,000.00	1.8	126,957.61
Vermont	500,509	3,854.07	3,854.07		.6	298,777.26	297,549.64		23.5	8.2	199,105.29	5.8	
Virginia	1,854,189	69,060.24	59,408.36	9,651.88	2.8	1,222,522.42	1,018,883.11		19.1	11.5	653,134.71	12.8	122,762.82
Washington	1,877,571	212,091.88	207,347.42		5.5	1,611,609.74	1,611,609.74		12.7	25.8	19,460.21	.9	39,153.63
West Virginia	1,342,270	15,323.43	15,323.43		.4	380,702.34	356,356.60		25.0	6.3	614,456.44	10.7	356,133.53
Wisconsin	2,431,220	151,529.60	151,529.60		4.8	644,150.05	644,150.05		41.9	15.3	847,375.57	21.3	788,164.78
Wyoming	1,125,332	53,504.69	53,004.69		1.1	500,617.97	500,615.69		16.8	11.5	306,077.57	4.9	265,634.05
District of Columbia	959,235	295,510.62	295,510.62		2.4	672,000.45	663,650.15		20.3	2.3			74.23
Hawaii													
TOTALS	114,372,417	4,583,514.45	4,442,134.22	55,594.04	154.0	48,580,268.39	46,683,517.75	370,459.76	20.9	729.3	30,837,979.62	596.8	32,408,785.41

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 MARCH 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	$ 2,092,533				$ 93,143.79	$ 93,143.79	40.8	5.0	$ 564,197.75	42.2	$ 1,435,191.46	Alabama
Arizona	625,435				412,835.88	400,873.89	34.4	32.2	25,520.12	.8	199,040.99	Arizona
Arkansas	1,687,084	$ 11,141.83	$ 11,141.83	.2	439,188.26	439,188.26	12.8	38.1	283,783.39	48.9	952,970.52	Arkansas
California	3,901,838	122,219.50	85,059.65	1.7	2,487,099.97	2,071,106.89	22.6	125.1	243,556.40	17.8	1,502,115.06	California
Colorado	1,718,632	90,000.00	90,000.00	19.3	1,004,759.98	1,004,759.98	57.7	132.8	269,062.39	17.7	354,809.63	Colorado
Connecticut	659,120				664,915.58	659,120.00	3.5	14.5				Connecticut
Delaware	454,772				161,554.00	161,554.00		1.8	21,360.00	7.3	271,858.00	Delaware
Florida	1,307,958	72,057.40	72,057.40	8.5	1,144,714.00	1,144,714.00	42.0	59.9	21,345.28	.1	69,841.32	Florida
Georgia	2,320,973				453,343.74	453,343.74	32.9	27.7	462,810.30	36.8	1,404,818.96	Georgia
Idaho	1,121,562	67,404.64	63,302.38	7.0	889,511.02	841,142.00	56.1	117.7	64,000.00	7.4	153,117.62	Idaho
Illinois	6,262,223	78,787.21	78,787.21	19.3	2,779,413.23	2,779,413.23	13.7	182.3	2,121,892.27	110.7	1,282,130.29	Illinois
Indiana	501,892				189,508.90	189,508.90	17.9	42.4	244,793.75	22.1	67,589.35	Indiana
Iowa	2,212,245	85,897.35	83,000.00	27.3	725,443.41	690,700.00	32.4	71.5	589,100.00	69.7	849,445.00	Iowa
Kansas	2,522,401	11,865.47	11,865.47	3.7	1,810,190.29	1,810,190.29	16.5	133.7	689,713.59	26.8	10,631.65	Kansas
Kentucky	1,879,340	52,828.05	52,828.05	16.1	1,480,016.42	1,480,016.42	27.6	172.2	321,679.44	30.9	24,816.09	Kentucky
Louisiana	1,457,148	61,627.65	61,627.65	2.2	468,932.69	468,932.69	4.9	21.6	460,748.64	21.3	465,839.02	Louisiana
Maine	842,479	489,078.07	488,198.56	54.5	403,386.85	337,221.58	86.0	36.6	8,989.70	.2	8,069.16	Maine
Maryland	891,132				240,544.07	240,544.07	21.2	18.6	497,081.30	34.6	153,506.63	Maryland
Massachusetts	488,185				469,741.41	469,741.41	37.0	15.2			18,443.59	Massachusetts
Michigan	3,184,057	88,500.00	88,500.00	7.4	1,880,350.00	1,880,350.00	10.2	146.1	889,350.00	71.1	325,857.00	Michigan
Minnesota	2,131,314	45,666.23	45,666.23	34.6	1,438,466.76	1,358,035.76	37.6	200.0	313,308.15	32.7	414,303.86	Minnesota
Mississippi	1,744,669				459,999.99	459,999.99	47.6	54.6	282,216.49	28.3	1,002,452.52	Mississippi
Missouri	2,923,273	18,488.65	18,488.65	4.0	2,550,256.61	2,550,256.61	41.8	458.3	162,026.53	23.9	192,501.21	Missouri
Montana	1,859,937	105,097.67	105,097.67	16.0	1,016,863.81	1,016,863.81	9.7	109.3	637,706.80	85.0	100,268.72	Montana
Nebraska	1,957,240				1,823,129.74	1,821,267.42	30.7	253.0	134,179.61	30.9	1,792.97	Nebraska
Nevada	1,136,479	24,880.52	24,880.52	.4	965,151.01	965,151.01	45.5	96.6			146,447.47	Nevada
New Hampshire	477,460				518,207.67	477,383.82	36.4	25.7			76.18	New Hampshire
New Jersey	63,460				56,550.52	56,550.52	14.1	.5			6,909.48	New Jersey
New Mexico	1,448,234	8,500.00	8,500.00	1.6	951,500.00	951,500.00	58.2	343.5			488,234.00	New Mexico
New York	3,617,476	143,946.51	143,946.51	4.6	3,809,913.19	3,378,488.19	19.9	93.1	85,975.00	1.9	9,066.30	New York
North Carolina	2,380,573	145,298.61	145,298.61	18.4	1,103,591.71	1,103,591.71	45.6	98.9	106,946.10	15.9	1,024,736.58	North Carolina
North Dakota	1,451,112								106,552.87	18.2	1,344,559.13	North Dakota
Ohio	3,871,148	190,100.00	190,100.00	68.5	2,610,880.00	2,470,244.90	25.9	207.7	1,036,450.00	28.7	174,353.10	Ohio
Oklahoma	2,304,199				285,063.50	285,063.50	4.9	28.8	1,508,329.88	205.3	510,805.62	Oklahoma
Oregon	1,526,724				968,962.59	924,636.75	24.2	30.3	602,087.25	78.2		Oregon
Pennsylvania	7,344,822	39,596.00	39,596.00	4.9	6,387,324.88	6,312,722.68	25.3	590.9	508,432.19	46.6	484,071.13	Pennsylvania
Rhode Island	499,677				226,847.63	226,847.63	2.6	20.9	185,162.59	12.3	87,666.78	Rhode Island
South Carolina	1,364,791				1,174,986.08	1,174,986.08	35.8	133.8			189,804.92	South Carolina
South Dakota	1,502,870	53,493.81	53,493.81	19.9	78,013.63	78,013.63	52.6	27.0	318,183.34	117.4	1,053,179.22	South Dakota
Tennessee	2,123,155				996,285.00	996,285.00	17.9	83.7	199,796.07	13.2	927,073.93	Tennessee
Texas	6,061,006	391,183.38	297,245.50	76.8	5,080,782.70	4,279,989.90	40.7	587.6	715,464.54	98.9	768,306.06	Texas
Utah	1,048,677	218,991.79	216,610.42	45.2	669,084.56	658,411.65	36.3	111.0	68,967.69	5.8	104,687.24	Utah
Vermont	438,880				336,541.00	318,237.70	23.9	29.2	120,642.30	7.3		Vermont
Virginia	1,854,189	73,918.51	65,000.72	32.1	1,401,482.85	1,316,727.79	39.9	172.9	472,460.49	10.8		Virginia
Washington	1,180,362	90,437.72	90,437.72	13.3	897,127.37	887,127.37	21.0	45.6	111,723.58	8.4	91,073.33	Washington
West Virginia	1,118,559				523,473.59	523,473.59	17.6	28.1	495,404.64	31.7	99,680.77	West Virginia
Wisconsin	2,431,220	223,248.44	223,248.44	7.8	1,263,471.40	1,224,036.68	12.3	87.7	706,770.47	54.1	277,164.41	Wisconsin
Wyoming	1,125,332	237,058.12	231,300.00	28.7	556,290.81	546,155.20	27.5	87.2	269,716.19	33.5	78,160.61	Wyoming
District of Columbia	959,234	110,674.64	110,674.64	2.0	748,207.37	748,207.37	20.8	5.1	100,201.99	.6	150.00	District of Columbia
Hawaii	187,106								177,717.69	4.9	9,388.31	Hawaii
TOTALS	94,264,187	3,351,987.77	3,195,953.64	546.0	57,097,049.46	54,725,821.40	28.7	5,406.0	17,205,406.77	1,560.9	19,137,005.19	TOTALS