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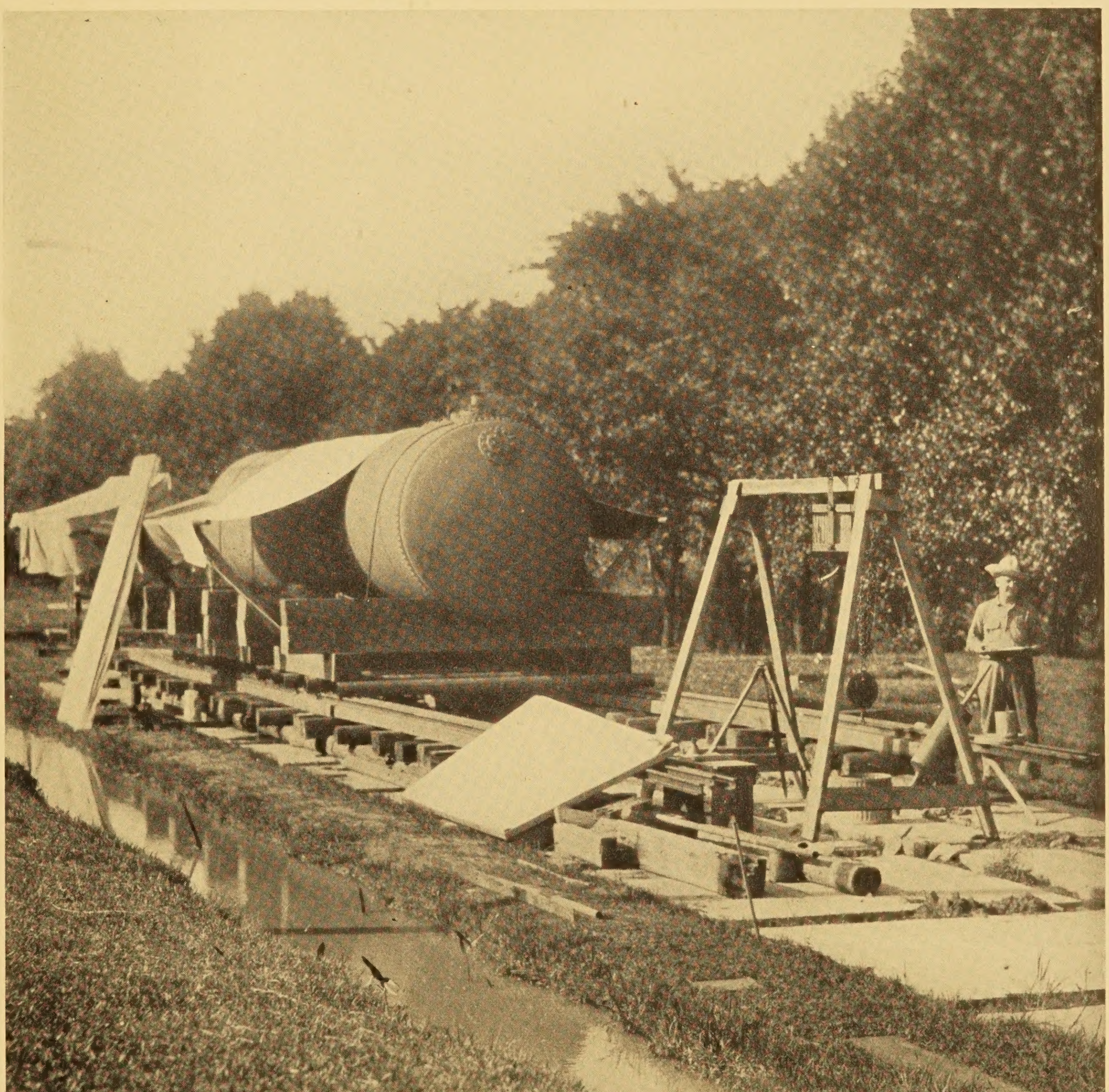

GENERAL VIEW OF APPARATUS FOR STATIC LOAD TESTS OF CONCRETE SLABS, ARLINGTON, VA.

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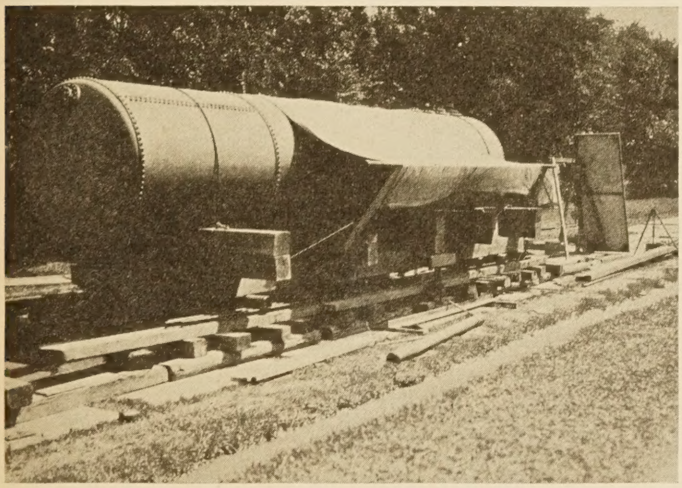
STATIC LOAD TESTS ON PAVEMENT SLABS

By J. T. THOMPSON, Highway Research Specialist, United States Bureau of Public Roads

FOUR years ago the Bureau of Public Roads began the testing of approximately 50 small typical road slabs under impact forces. The success of this early program led in the summer of 1921 to the construction of 124 larger slabs embracing a greater variation of type. These slabs were tested under impact during the summer of 1923 and the results of the test were fully reported in the article entitled "Impact tests on concrete pavement slabs," published in PUBLIC ROADS, volume 5, No. 2, April, 1924.

After these impact tests were concluded it was thought that a check on the impact results and additional information could be obtained by subjecting the slabs to tests under loads applied statically instead of dynamically. It is with these static tests, conducted during the summer of 1924, that the present report concerns itself.



The tank used in the static load tests, showing saddles and cribbing

SUMMARY OF CONCLUSIONS

1. The static resistance of both the corners and the edges of the rigid slabs is affected by the nature of the subgrade, the more resistant the subgrade to load the greater the resistance of the slab, and vice versa.
2. The resistance of the rigid slabs to static loads does not vary with the square of the depth but as some power greater than one and less than two. About 1.75 is the average value, the exponent being higher for slabs on the wet subgrade and lower for those on the dry subgrade.
3. The corners and edges of concrete slabs of the size and thickness tested offer about the same degree of resistance to static loads.
4. The presence of mesh reinforcement as employed in the slabs under consideration does not increase the load-carrying capacity of concrete slabs but does give rise to a tendency to hold together and resist complete failure after initial or elastic failure has taken place.
5. The bituminous topping laid on the rigid slabs does not increase the resistance of the slabs to static load.
6. At the ordinary summer temperatures encountered, bituminous slabs of the types tested show no slab strength.

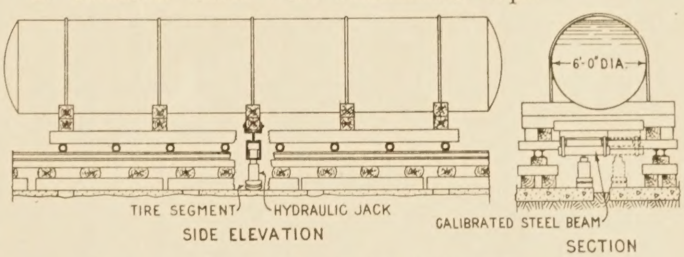
DESCRIPTION OF SLABS

Of the 124 slabs, 56 were placed on a carefully drained subgrade and 68 on a subgrade which was kept permanently saturated by water-filled ditches parallel to and on both sides of the line of slabs, the water standing level with the bottom of the slabs. The slabs were cast in duplicate and the more important types were laid on both the wet and the dry subgrades, which were carefully cut to the grade of the slab bottom to prevent the original structure of the soil from being disturbed.

In the mesh-reinforced slabs the reinforcement was placed uniformly 2 inches from the top, and where two layers were used they were placed in contact with each other.

The different types may be divided roughly into five groups:

1. Plain concrete.
2. Reinforced concrete.
   (a) Mesh-reinforced.
   (b) Rod-reinforced .[1]
3. Concrete bases with bituminous tops.



Arrangement of apparatus for static load tests

4. Bituminous bases with bituminous tops.
5. Macadam bases with bituminous tops.

A detailed description of the slabs is given in Table 1. For additional information relative to the construction of the slabs, the reader is referred to the article entitled "Impact tests on concrete pavement slabs," published in PUBLIC ROADS, volume 5, No. 2, April, 1924.

TABLE 1.—*Description of slabs—All slabs 7 feet square of material and thickness shown below—Series 200–267, on wet subgrade—Series 300–377, on dry subgrade*

PLAIN CONCRETE SLABS AND BASES

Slab No.	Base course		Binder course		Surface course	
	Thickness	Material	Thickness	Material	Thickness	Material
	Inches		*Inches*		*Inches*	
200	6	Macadam	4	Bituminous concrete.	2	Topeka.
201	6	do	4	do	2	Do.
204	4	do	3	do	2	Do.
205	4	do	3	do	2	Do.
208	4	do	2	do	2	Do.
209	4	do	2	do	2	Do.
212	6	do			2	Do.
213	6	do			2	Do.
214	9	do			2	Do.
215	9	do			2	Do.
216	12	do			2	Do.
217	12	do			2	Do.
218	6	Bituminous concrete.			2	Do.
219	6	do			2	Do.
220	4	do			2	Do.
221	4	do			2	Do.

[1] Not tested statically.

TABLE 1.—*Description of slabs—All slabs 7 feet square of material and thickness shown below—Series 200–267, on wet subgrade—Series 300–337, on dry subgrade*—Continued

PLAIN CONCRETE SLABS AND BASES—Continued

Slab No.	Base course		Binder course		Surface course	
	Thickness	Material	Thickness	Material	Thickness	Material
	Inches		*Inches*		*Inches*	
222	6	1:3:6 concrete	1½	Bituminous concrete.	1½	Sheet asphalt.
223	6	do	1½	do	1½	Do.
224	6	do			4	Coarse bituminous concrete.
225	6	do			4	Do.
226	6	do			2	Do.
227	6	do			2	Do.
228	4	do			2	Topeka.
229	4	do			2	Do.
230	4	1:1½:3 concrete			2	Do.
231	4	do			2	Do.
232	6	1:3:6 concrete			2	Do.
233	6	do			2	Do.
234	6	1:1½:3 concrete			2	Do.
235	6	do			2	Do.
236	8	1:3:6 concrete			2	Do.
237	8	do			2	Do.
238	8	1:1½:3 concrete			2	Do.
239	8	do			2	Do.
240					4	1:1½:3 concrete
241					4	Do.
242					6	Do.
243					6	Do.
244					6	1:3:6 concrete
245					6	Do.
246					8	1:1½:3 concrete
247					8	Do.
248					8	1:3:6 concrete
249					8	Do.
300	4	Macadam	2	Bituminous concrete.	2	Topeka
301	4	do	2	do	2	Do.
304	4	do			2	Do.
305	4	do			2	Do.
306	6	do			2	Do.
307	6	do			2	Do.
308	9	do			2	Do.
309	9	do			2	Do.
310	6	Bituminous concrete.			2	Do.
311	6	do			2	Do.
312	4	do			2	Do.
313	4	do			2	Do.
314	6	1:1½:3 concrete			2	Do.
315	6	do			2	Do.
316	6	1:3:6 concrete			2	Do.
317	6	do			2	Do.
318	4	1:1½:3 concrete			2	Do.
319	4	do			2	Do.
320	8	do			2	Do.
321	8	do			2	Do.
322					4	1:1½:3 concrete
323					4	Do.
324					6	Do.
325					6	Do.
326					6	1:3:6 concrete
327					6	Do.
328					8	1:1½:3 concrete
329					8	Do.

CONCRETE SLABS WITH MESH REINFORCING—WET SUBGRADE

Slab No.	Surface course			
	Thickness	Material	Reinforcement	
			Description	Lbs. per sq. ft.
	In.			
250	4	1:1½:3 concrete	1 layer No. 6	0.30
251	4	do	do	.30
252	4	do	2 layers No. 6	.60
253	4	do	do	.60
254	4	do	2 layers No. 8	.75
255	4	do	do	.75
256	4	do	1 layer No. 10	.46
257	4	do	do	.46
258	4	do	2 layers No. 10	.93
259	4	do	do	.93
260	6	do	1 layer No. 6	.30
261	6	do	do	.30
262	6	do	2 layers No. 6	.60
263	6	do	do	.60
264	6	do	2 layers No. 8	.75
265	6	do	do	.75
266	6	do	2 layers No. 10	.93
267	6	do	do	.93

CONCRETE SLABS WITH MESH REINFORCING—DRY SUBGRADE

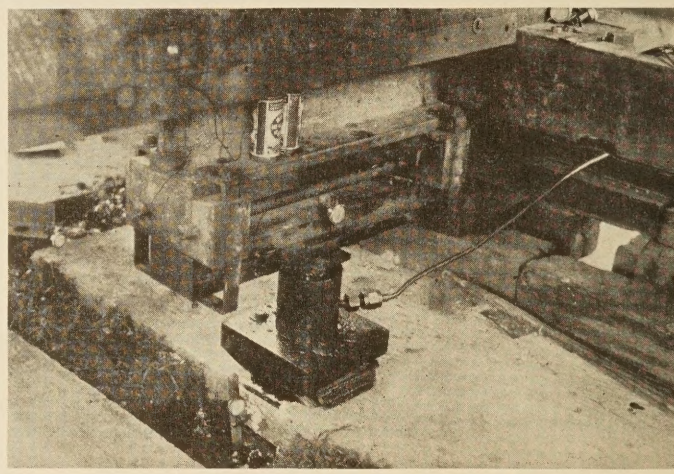
330	4	1:1½:3 concrete	1 layer No. 6	0.30
331	4	do	do	.30
332	4	do	1 layer No. 10	.46
333	4	do	do	.46
334	6	do	2 layers No. 6	.60
335	6	do	do	.60
336	6	do	2 layers No. 8	.75
337	6	do	do	.75

DESCRIPTION OF TEST METHODS AND APPARATUS

In the static tests the loads were applied to the slabs by a hydraulic jack through the medium of a segment of a solid rubber truck tire bolted to a cast-iron block. The necessary reaction for the jack was furnished by a large tank filled with water which the jack partially lifted as it applied load to the slab. This load was measured by a simply supported 4-inch by 6-inch chrome-nickel steel beam on a 30-inch span, the upward reaction of the jack loading this beam at the midpoint. The deflections of this beam, from which the loads were determined, were measured by an Ames dial, reading to ten-thousandths of an inch, which was mounted on the beam with its plunger resting on a one-half-inch square steel bar pivoted to the beam under the supporting knife edges at the neutral axis.

The deflections of the bituminous slabs were measured by engineers' scales set vertically on the tire block, the readings being made against horizontal arms secured to steel pins driven firmly into the subgrade. Two scales were employed and the average used to take account of the tilting of the tire block.

The deflections of the rigid slabs were measured by means of an Ames dial which recorded the movement



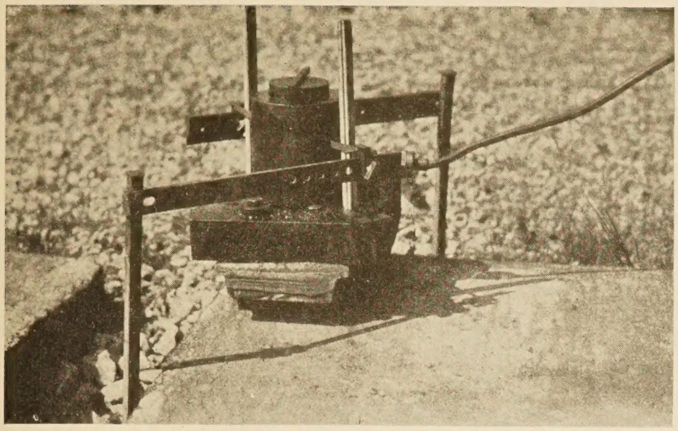
View of apparatus showing calibrated steel beam with ten-thousandths inch Ames dial measuring its deflection, hydraulic jack, tire block, slab deflection gauges at point of test and at corner, and graphic strain gauges in top and bottom of the slab at the edge

of a pin set into the corner or edge of the slabs, while the tilting of the slabs as a whole was recorded by other Ames dials mounted usually at the three corners of the slabs.

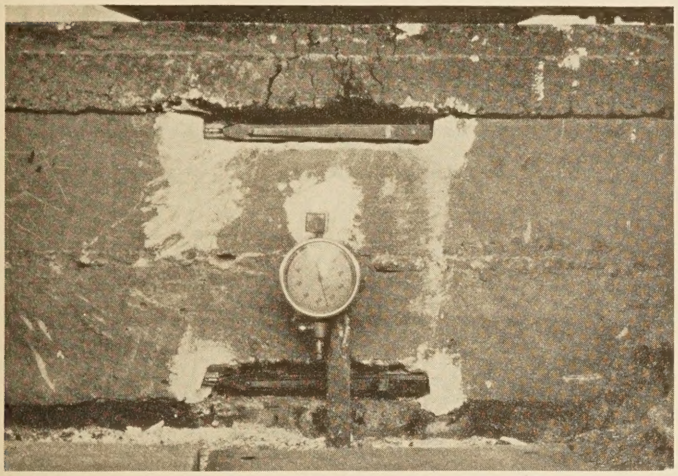
The fiber deformations produced were measured by means of graphic strain gauges of the type developed by the Bureau of Public Roads and described in Engineering News-Record, March 22, 1923, in an article entitled "A new impact strain gauge," by A. T. Goldbeck. In testing the edges such gauges were used in both the top and bottom of the slab. In testing the corners they were set along the diagonal on the top of the slab, one gauge overlapping its neighbor so as to insure at least one gauge catching the crack at failure and recording the maximum fiber stress.

In the edge tests the load was applied at the middle of the side of the slab and 5 inches from the edge. It was found that if the load were applied at a point closer to the edge the tire segment would overhang when expanded under load. In testing the corners the load was applied 7 inches from the corner measured along the diagonal of the slab.

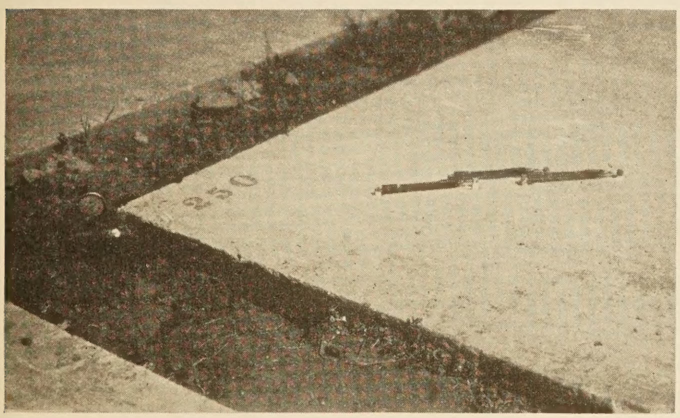
The subgrade bearing value was determined by the method described in PUBLIC ROADS, volume 4, No. 5,



Tire block and jack with engineers' scales for measuring slab deflection against stationary arms



Graphic strain gauges arranged to measure compressive and tensile stresses in edge of slab; Ames dial measures deflection

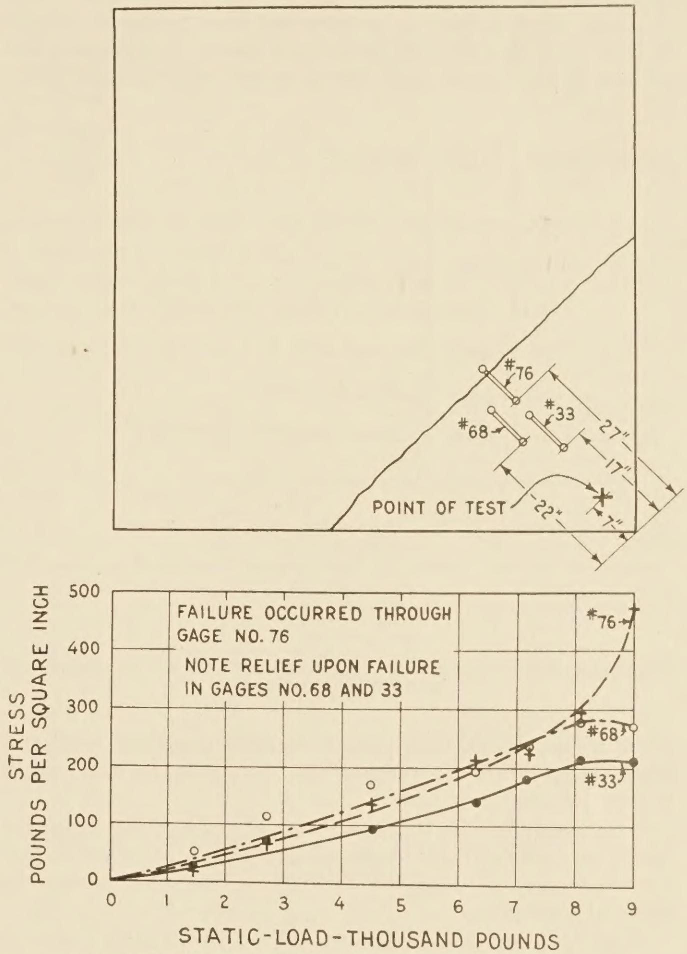


Three graphic strain gauges set along diagonal of slab, overlapping so as to catch maximum fiber stress

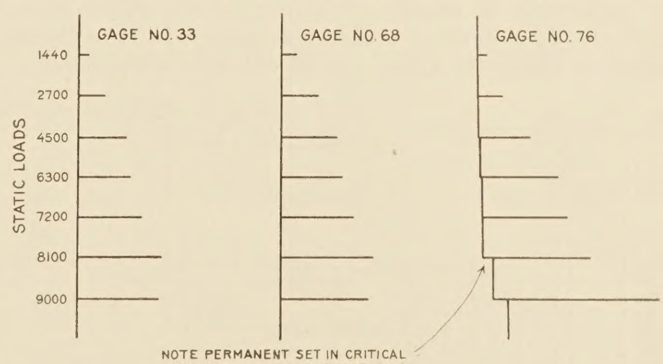
September, 1921, in the article entitled "Preliminary report on the Bates experimental road." The method of test was to apply a constantly increasing load to a small circular bearing block in contact with the scraped surface of the subgrade, and to measure the penetration of this foot into the subgrade at equal intervals of load.

DISCUSSION OF DATA

Before discussing the test data certain explanatory remarks are necessary. The concrete fiber stresses were measured in the following manner: Records of the fiber deformations for various static loads were inscribed by the graphic strain gauge upon the smoked-glass plate which is a part of the instrument. These plates were then fixed with varnish, placed in a projecting lantern, and the greatly magnified records were measured. The measurements of total fiber deformation were reduced to strain. The unit stresses corresponding to these strains were computed from the modulus of elasticity as determined from tests on 6 by 12-inch cylinders which were cast at the time the slabs were constructed (1921) and were tested for modulus of elasticity at the time of



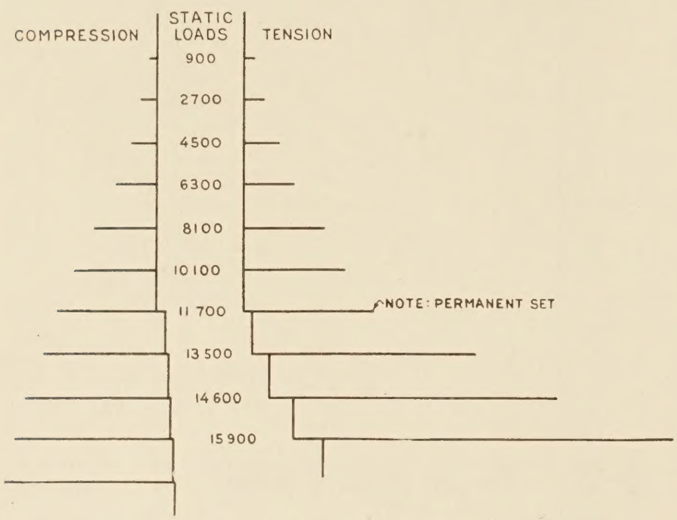
Corner test of slab No. 244, indicating static resistance of 8,100 pounds



Magnified graphic strain gauge records of corner test of slab No. 244, indicating a static resistance of 8,100 pounds

the impact tests (1923). Since they were two years old when the moduli were determined, it is felt that there was but little change during the ensuing year, and the 1923 values were therefore used without correction.

"Static load resistance" as used in this report is defined as that load which caused a tensile failure in the concrete. This tensile failure was detected by the graphic strain gauges. In the edge tests neutral axis plots were made and the load which caused the neutral axis to shift upward was taken as the "static load resistance." The shifting of the neutral axis was taken as indication that the point of elastic failure had been reached. A study of the strain gauge records to see where large initial sets accompanied by rapidly increasing deformations began to appear, together with a study of curves plotted between static loads and unit fiber stresses, also helped to determine this point of initial failure. In the case of the corner tests, no gauges were placed in the edges and therefore no neutral-axis plots



Magnified graphic strain gauge records of edge test of slab No. 242, indicating a static resistance of 11,700 pounds

were made, the strain gauge records together with the load-stress plots furnishing the evidence to determine where failure occurred.

The point of elastic failure is in reality the ultimate load, as subsequent loads of an equal or even lesser amount cause complete failure. This was noted in several instances.

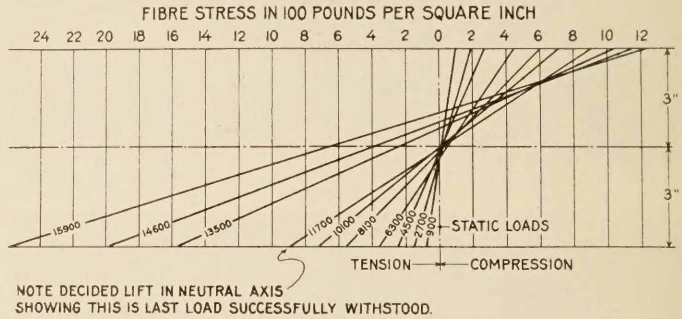
The data are somewhat restricted in quantity due to the fact that a number of the slabs were so badly broken by impact as to render them useless for static tests. This greatly interfered with the drawing of comparisons between duplicate types under different conditions.

EFFECT OF NATURE OF SUBGRADE ON STATIC RESISTANCE

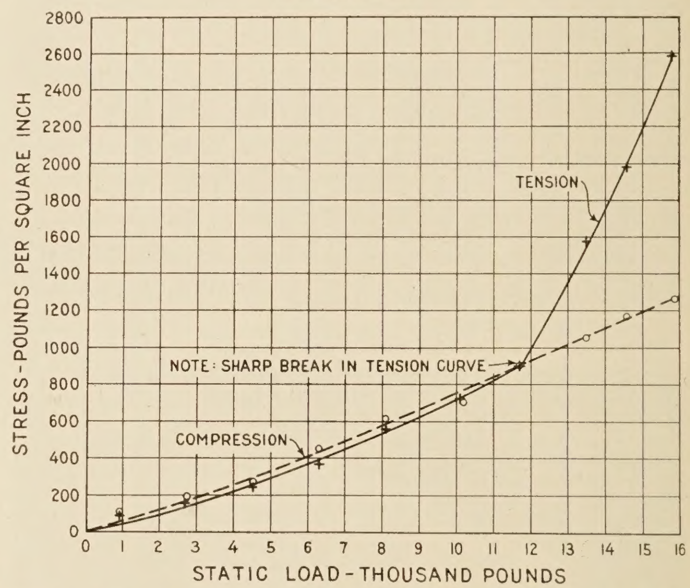
A study of Table 2 leads to the following conclusions:

1. That the slabs laid on a wet and yielding subgrade offer less resistance to statically applied loads than do those laid on a dry, firm subgrade.

2. That the resistance does not seem to vary in any definite manner with the subgrade bearing value as determined by the penetration test, the ratio of slab resistances being often high where the ratio of subgrade penetrations is low, and vice versa.



Stress distribution diagram for edge test of slab No. 242, indicating a static resistance of 11,700 pounds



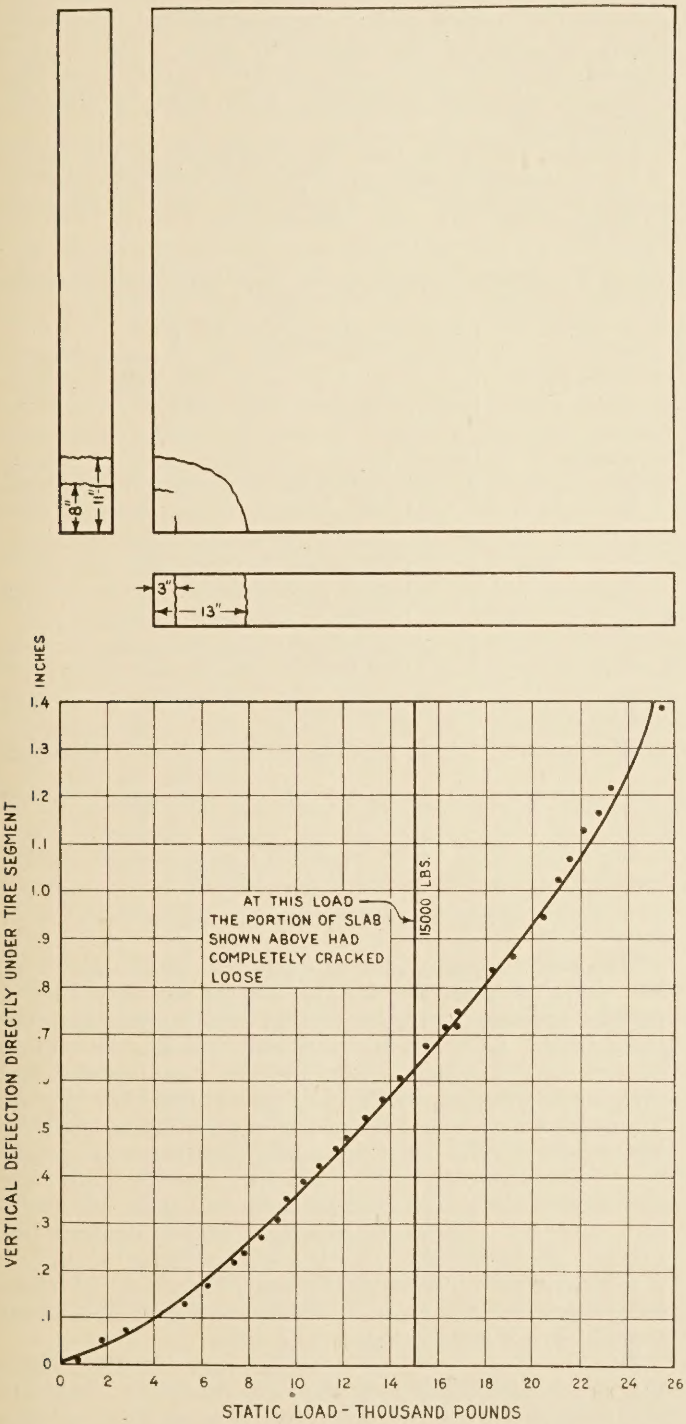
Load-stress diagram of edge test, slab No. 242, indicating static resistance of 11,700 pounds

TABLE 2.—*Effect of nature of subgrade on static resistance*

Slab No.	Description of slab: Thickness	Mix	Reinforcement	Top	Position of load	Static resistance: Dry subgrade	Wet subgrade	Ratio of resistance dry-wet	Subgrade penetration at 100-pound load: Dry	Wet
	Inches					*Pounds*	*Pounds*		*Inches*	*Inches*
331	4	1:1½:3	1 layer No. 6 (0.30 pound per sq. ft.)		Corner	7,200		1.33	0.017	
251	4	1:1½:3	do		do		5,400			0.048
330	4	1:1½:3	do		Edge	8,460		1.88	.016	
250	4	1:1½:3	do		do		4,500			.045
333	4	1:1½:3	1 layer No. 10 (0.46 pound per sq. ft.)		Corner	7,200		1.80	.005	
257	4	1:1½:3	do		do		4,000			.049
332	4	1:1½:3	do		Edge	7,380		1.52	.017	
256	4	1:1½:3	do		do		4,860			.045
314	6	1:1½:3		2-inch Topeka	Edge	12,000		1.80	.019	
234	6	1:1½:3		do	do		11,160			.075
326	6	1:3:6			Corner	10,400		1.29	.007	
244	6	1:3:6			do		8,100			.041
335	6	1:1½:3	2 layers No. 6 (0.60 pound per sq. ft.)		Corner	15,300		1.28	.017	
263	6	1:1½:3	do		do		12,000			.033
334	6	1:1½:3	do		Edge	15,480		1.55	.025	
262	6	1:1½:3	do		do		10,000			0.029
321	8	1:1½:3		2-inch Topeka	Corner	20,000		0.99	.014	
239	8	1:1½:3		do	do		20,200			.016
320	8	1:1½:3		do	Edge	28,600		1.79	.011	
238	8	1:1½:3		do	do		16,000			.041
329	8	1:1½:3			Corner	22,000		0.97	.018	
247	8	1:1½:3			do		22,800			.097
328	8	1:1½:3			Edge	17,000		0.68	.012	
246	8	1:1½:3			do		25,200			.062

VARIATION OF STATIC LOAD RESISTANCE WITH SLAB DEPTH

Table 3 shows that the load resistance varies as some power of the slab depth which is greater than one and less than two, the average value of the exponent being about 1.75. The influence of the subgrade resistance upon the exponent is quite marked, the value of the exponent being 1.92, or quite near the square, on the wet, yielding subgrade and 1.5 on the dry subgrade.



Corner test of slab No. 311, 6-inch bituminous base with 2-inch Topeka top. Air temperature 81° F., slab temperature 77° F. Note that there is no sharp break of the curve at failure

TABLE 3.—*Variation of static load resistance with slab depth*

Depth of slab (all types included)	Corner tests		Edge tests	
	Average static resistance	Power of depth with which resistance varies	Average static resistance	Power of depth with which resistance varies
Dry subgrade:	*Pounds*		*Pounds*	
4 inches	7,430		7,980	
6 inches	15,300	1.78	13,720	1.33
8 inches	21,000	1.50	22,800	1.52
Wet subgrade:				
4 inches	5,400		5,720	
6 inches	11,700	1.90	12,500	1.93
8 inches	21,500	2.00	20,600	1.85

COMPARISON OF EDGE AND CORNER STATIC LOAD RESISTANCE

Table 4 compares the static resistance of the corners and edges of duplicate slabs and shows that there is no decided difference between them.

TABLE 4.—*Comparison of edge and corner static load resistance*

Slab No.	Description of slab				Position of load	Static resistance
	Thickness	Mix	Reinforcement	Top		
Dry subgrade:	*Inches*					*Pounds*
319	4	1:1½:3		2-in. Topeka	Corner	7,900
318	4	1:1½:3		do	Edge	8,100
331	4	1:1½:3	1 layer No. 6 (0.30 pound per sq. ft.).		Corner	7,200
330	4	1:1½:3	do		Edge	8,460
333	4	1:1½:3	1 layer No. 10 (0.46 pound per sq. ft.).		Corner	7,200
332	4	1:1½:3	do		Edge	7,380
335	6	1:1½:3	2 layers No. 6 (0.60 pound per sq. ft.).		Corner	15,300
334	6	1:1½:3	do		Edge	15,480
321	8	1:1½:3		2-in. Topeka	Corner	20,000
320	8	1:1½:3		do	Edge	28,600
329	8	1:1½:3			Corner	22,000
328	8	1:1½:3			Edge	17,000
Wet subgrade:						
241	4	1:1½:3			Corner	6,900
240	4.	1:1½:3			Edge	8,100
251	4	1:1½:3	1 layer No. 6 (0.30 pound per sq. ft.).		Corner	5,400
250	4	1:1½:3	do		Edge	4,500
255	4	1:1½:3	2 layers No. 8 (0.75 pound per sq. ft.).		Corner	5,800
254	4	1:1½:3	do		Edge	6,120
257	4	1:1½:3	1 layer No. 10 (0.46 pound per sq. ft.).		Corner	4,000
256	4	1:1½:3	do		Edge	4,860
259	4	1:1½:3	2 layers No. 10 (0.93 pound per sq. ft.).		Corner	5,400
258	4	1:1½:3	do		Edge	5,040
235	6	1:1½:3		2-in. Topeka	Corner	9,900
234	6	1:1½:3		do	Edge	11,160
243	6	1:1½:3			Corner	11,900
242	6	1:1½:3			Edge	11,700
261	6	1:1½:3	1 layer No. 6 (0.30 pound per sq. ft.).		Corner	10,500
260	6	1:1½:3	do		Edge	13,320
263	6	1:1½:3	2 layers No. 6 (0.60 pound per sq. ft.).		Corner	12,000
262	6	1:1½:3	do		Edge	10,000
265	6	1:1½:3	2 layers No. 8 (0.75 pound per sq. ft.).		Corner	14,000
264	6	1:1½:3	do		Edge	14,400
267	6	1:1½:3	2 layers No. 10 (0.93 pound per sq. ft.).		Corner	12,000
266	6	1:1½:3	do		Edge	14,400
244	6	1:3:6			Corner	8,100
245	6	1:3:6			Edge	10,800
239	8	1:1½:3		2-in. Topeka	Corner	20,200
238	8	1:1½:3		do	Edge	16,000
247	8	1:1½:3			Corner	22,800
246	8	1:1½:3			Edge	25,200
237	8	1:3:6		2-in. Topeka	Corner	8,500
236	8	1:3:6		do	Edge	17,640

EFFECT OF QUANTITY OF MESH REINFORCEMENT ON STATIC LOAD RESISTANCE

It can be seen from Table 5 that the amount of mesh reinforcement employed in these slabs has apparently no influence upon either corner or edge static load resistance, slabs without reinforcement or with small amounts frequently developing greater resistances than those more heavily reinforced.

The mesh reinforcement did, however, tend to hold the slabs together after elastic failure had taken place and brought about a much less rapid failure when complete destruction occurred.

TABLE 5.—*Effect of quantity of mesh reinforcement on static load resistance*

Slab No.	Description of slab			Reinforcement	Position of load	Static resistance
	Thickness	Mix	Top			
Dry subgrade:	*Inches*					*Pounds*
319	4	1:1½:3	2-in. Topeka	None	Corner	7,900
331	4	1:1½:3		1 layer No. 6 (0.30 pound per sq. ft.).	do	7,200
333	4	1:1½:3		1 layer No. 10 (0.46 pound per sq. ft.).	do	7,200
318	4	1:1½:3	2-in. Topeka	None	Edge	8,100
330	4	1:1½:3		1 layer No. 6 (0.30 pound per sq. ft.).	do	8,460
332	4	1:1½:3		1 layer No. 10 (0.46 pound per sq. ft.).	do	7,380
314	6	1:1½:3	2-in. Topeka	None	Edge	12,000
334	6	1:1½:3		2 layers No. 6 (0.60 pound per sq. ft.).	do	15,480
Wet subgrade:						
241	4	1:1½:3		None	Corner	6,900
251	4	1:1½:3		1 layer No. 6 (0.30 pound per sq. ft.).	do	5,400
253	4	1:1½:3		2 layers No. 6 (0.60 pound per sq. ft.).	do	4,850
255	4	1:1½:3		2 layers No. 8 (0.75 pound per sq. ft.).	do	5,800
257	4	1:1½:3		1 layer No. 10 (0.46 pound per sq. ft.).	do	4,000
259	4	1:1½:3		2 layers No. 10 (0.93 pound per sq. ft.).	do	5,400
240	4	1:1½:3		None	Edge	8,100
250	4	1:1½:3		1 layer No. 6 (0.30 pound per sq. ft.).	do	4,500
254	4	1:1½:3		2 layers No. 8 (0.75 pound per sq. ft.).	do	6,120
256	4	1:1½:3		1 layer No. 10 (0.46 pound per sq. ft.).	do	4,860
258	4	1:1½:3		2 layers No. 10 (0.93 pound per sq. ft.).	do	5,040
243	6	1:1½:3		None	Corner	11,900
261	6	1:1½:3		1 layer No. 6 (0.30 pound per sq. ft.).	do	10,500
263	6	1:1½:3		2 layers No. 6 (0.60 pound per sq. ft.).	do	12,000
265	6	1:1½:3		2 layers No. 8 (0.75 pound per sq. ft.).	do	14,000
267	6	1:1½:3		2 layers No. 10 (0.93 pound per sq. ft.).	do	12,000
242	6	1:1½:3		None	Edge	11,700
260	6	1:1½:3		1 layer No. 6 (0.30 pound per sq. ft.).	do	13,320
262	6	1:1½:3		2 layers No. 6 (0.60 pound per sq. ft.).	do	10,000
264	6	1:1½ 3		2 layers No. 8 (0.75 pound per sq. ft.).	do	14,400
266	6	1:1½:3		2 layers No. 10 (0.93 pound per sq. ft.).	do	14,400

EFFECT OF TOPPING COURSE IN STATIC LOAD RESISTANCE

A comparison of the static load resistances of similar slabs with and without bituminous topping courses is shown in Table 6. The table brings out the fact that the addition of the topping course does not increase the strength. Indeed it might be said that the reverse is true in some instances. Certainly the 1:3:6 slabs with bituminous tops on the wet subgrade are badly disintegrated, while the uncovered 1:3:6 slabs on the same subgrade are in fair condition. Furthermore the covered 1:3:6 slabs on the dry subgrade are apparently nearly as good as the uncovered ones. The 1:1½:3 concrete in the covered slabs on both the wet and dry subgrade compares favorably with that in the uncovered slabs.

It seems probable that this weakness is the result of the saturated condition of the lean concrete, surface evaporation being prevented by the bituminous covering.

TABLE 6.—*Effect of topping course upon static load resistance*

Slab No.	Description of slab			Position of load	Static resistance
	Thickness	Mix	Top		
Dry subgrade:	*Inches*				*Pounds*
316	6	1:3:6	2-inch Topeka	Corner	8,100
317	6	1:3:6	do	do	7,000
326	6	1:3:6	None	do	10,440
321	8	1:1½:3	2-inch Topeka	do	20,000
329	8	1:1½:3	None	do	22,000
320	8	1:1½:3	2-inch Topeka	Edge	28,600
328	8	1:1½:3	None	do	17,000
Wet subgrade:					
235	6	1:1½:3	2-inch Topeka	Corner	9,900
243	6	1:1½:3	None	do	11,900
234	6	1:1½:3	2-inch Topeka	Edge	11,160
242	6	1:1½:3	None	do	11,700
239	8	1:1½:3	2-inch Topeka	Corner	20,200
247	8	1:1½:3	None	do	22,800
238	8	1:1½:3	2-inch Topeka	Edge	16,000
246	8	1:1½:3	None	do	25,200
237	8	1:3:6	2-inch Topeka	Corner	8,500
249	8	1:3:6	None	do	12,600

STATIC TESTS OF BITUMINOUS SLABS

The corners and edges of 12 bituminous slabs Nos. 300 and 301 and 304 to 313, inclusive, were tested. It was apparently impossible to determine when the slabs failed, as in no instance did the load-deflection curves show a sharp break, notwithstanding the fact that loads were applied and curves plotted far beyond the point where wide cracks had opened up around the tire segment. In some instances the test was carried to a point where the section of slab directly under the tire segment was completely detached from the main slab and yet the load-deflection curves did not indicate a sharp break. The test was nothing more than a soil-penetration determination. The effect of these slabs seems to be merely to distribute the loads to some extent over the subgrade.

In view of the apparent impossibility of telling when the slabs failed, the test data for these 12 slabs are not included in this report; but the writer concludes from his observation that these bituminous sections, at least at the temperature encountered, have an insignificant, if any, slab strength.

THE CONSTITUTIONALITY OF MOTOR VEHICLE LICENSE FEES AND THE GASOLINE TAX

By HENRY R. TRUMBOWER, Economist, United States Bureau of Public Roads

SOON after automobiles made their appearance on the highways and their numbers began to increase appreciably, State after State inaugurated systems of licensing motor vehicles and charging specific annual fees. The license fees in the beginning were nominal and generally were calculated only to cover the administrative expenses and the inspection costs necessary in the enforcement of all such regulatory laws. Nevertheless it was not long before the legality and constitutionality of these automobile registration and license laws were tested in a number of State court proceedings.

New Jersey was one of the first States to pass a motor vehicle registration law and soon after its passage its supreme court was invoked to pass upon the constitutionality of this enactment. The act was passed by the legislature in 1905 and was entitled "An act defining motor vehicles and providing for the registration of the same and uniform rules regulating the use and the speed thereof." It provided, in addition to certain traffic regulations, that the applicant for a license must make a written statement containing his name, address, description and character of automobile, name of maker, manufacturer's number, and horsepower, and pay a registry fee of $1.

The single question presented to the court was whether these provisions were constitutional. (Unwen *v.* State, 44 Vroom. (N. J.) 530.) In approaching this question the court stated that the manner in which public streets and highways should be used had been the subject of frequent legislation, that the control of such use had often been delegated by the legislature, and that such legislation was considered essential to the safety and comfort of those who use the public highway.

In developing its line of reasoning the court cited as precedents cases which dealt with regulations respecting the use of streets by street railway companies. (North Hudson County Railway *v.* Hoboken, 12 Vroom 71; Trenton Horse Railroad Company *v.* Trenton, 24 Vroom 132; Cape May Railroad Company *v.* Cape May, 30 Vroom 393.) Pedestrians, drivers, and occupants of horse-drawn vehicles using the same streets, the court said, were faced with new dangers upon the introduction of heavy cars propelled by electricity and capable of great speed. For the purpose of protecting the former users of the highway regulations were made which limited the speed of these cars among other things, and also required that licenses be obtained for each car. Such regulations were upheld by the courts and were regarded as legitimate extensions of the State's police power.

In turning from the electric street car to the automobile it was observed that motor vehicles operated over the highways of the State were being propelled, or capable of being propelled, at even greater speed than street cars. The menace of these machines, driven by reckless, inexperienced, and incompetent persons, to all persons using the highways was obvious to everyone. The court considered the right of the legislature to protect other users of the State's streets and roads against the dangers accruing from the operation of the automobile as much justified as those regulations which restricted the operation of the street car. Those provisions of the automobile law which limited the speed and which required the display of lights and the sounding of signals by automobile operators were considered necessary in order to protect the general public in its use of the highways.

These requirements, in the opinion of the court, would be useless if those violating them could not be detected and punished. The license and registration features were provided so as to aid to the identification of the vehicles and of those responsible for their operation. The law was attacked on the score that the required license fee of $1 was a tax upon the automobile and thus constituted a species of double taxation which was considered unconstitutional by the opponents of the law.

NEW JERSEY COURT HOLDS LICENSE FEE IS NOT A PROPERTY TAX

The court held that this license fee could not be regarded as a tax upon property. It was not imposed upon the vehicle as such but upon the use of the vehicle upon the public roads. It was a settled question, as pointed out by the court, that under the police power a license fee could be imposed which did not exceed the necessary expense of issuing the license and of carrying on the work and activities incidental to the inspection and regulation of motor-vehicle operation. In the eyes of the court this kind of automobile license legislation did not in any way conflict with the provisions of the Constitution of the State of New Jersey nor with any section of the Federal Constitution. It has been argued that legislation of this character by a State was an interference with interstate commerce and that it denied to nonresidents the equal protection of the laws. The court stated that the only question which the Federal courts would consider in dealing with legislation of this character was whether the regulations with respect to the operation of motor vehicles were within the legitimate exercise of a State's police power.

The Federal Supreme Court had taken a very decided stand on this question in the Slaughterhouse cases (16 Wall. 36). In other States where similar issues were presented to the courts the legality and constitutionality of automobile license laws were upheld as an exercise of the police power. The contestants in all of these cases were evidently satisfied with the views and findings of the State courts because the issue was not presented to the United States Supreme Court at this time even though in a number of instances nonresident automobile owners were protesting the legality of such license measures passed by the several States.

The nature of the evolution of automobile registration and regulatory statutes passed by many of the States, as the number of motor vehicles kept on increasing and the problems of highway development and maintenance began to emerge, is again illustrated by amendments made to the New Jersey law and by the opinion of the supreme court upholding its constitutionality and reasonableness. In 1908, three years after the first law was passed, New Jersey raised its annual registration fee to $3 for registering an automobile of less than 30 horsepower and $5 for each automobile of 30 horsepower or more, and fees were provided for licenses issued to drivers. This new legislation also provided that nonresidents would be required over their own signatures to designate the seretary of state as their agent within the State upon whom service could be made in case they were charged with a violation of any of the regulatory provisions of the act growing out of the operation of their cars over the streets and highways of the State.

Although the State's right to require the registration of motor vehicles and to exact a license fee had been upheld as an exercise of the police power, the validity of this new legislation was again attacked in the courts on the following grounds: First, because a tax was imposed upon automobiles not according to their true value but according to the horsepower of each automobile; second, that it was a system of double taxation in that the local assessor had already levied a tax upon this kind of property; third, that automobiles were singled out and put into a special class for purposes of taxation and that other kinds of property of similar character were excluded; and, fourth, that the requirement that nonresident owners and operators of motor vehicles must designate an agent upon whom legal processes could be served was a discrimination against citizens of other States and that the tax was a burden upon interstate commerce and a violation of the fourteenth amendment of the Federal Constitution. (Cleary *v.* Johnston, 50 Vroom (N. J.), 49.)

THE USE OF LICENSE FEES FOR ROAD MAINTENANCE QUESTIONED

It was contended by the objectors to this new act that its validity could not be sustained on the same grounds upon which the legality of the former act had been upheld because of the increase in the amount of the fees charged for registration, and that it had been transformed from a regulatory measure into a revenue measure for the reason that this revised enactment provided that the money thus collected and not needed in the administration of the law should be used as a fund for the repair of improved roads. The surplus funds were to be apportioned by the State treasurer among the counties of the State "according to the mileage of improved roads in each county, to be used for the repair of said roads." While the court did not definitely pass upon the power of the State to collect fees from automobiles which were to be used for highway purposes, it intimated that if such fees were imposed for revenue purposes the legislature had probably not exceeded its powers in that regard. The rules laid down in the previous case, in the opinion of the court, disposed of the constitutional objections raised against this act as a regulatory measure. The revenue aspects were considered more fully in a subsequent opinion where that issue was pressed more seriously. At the time when this case was decided the court suggested that the facts introduced into the record to show that the fees which were collected actually exceeded all of the costs incurred by the State and the local authorities in the administration of the law in all of its regulatory aspects were not sufficient to establish the fact.

So far as the objections were concerned which were urged by nonresidents, the court pointed out that, while the right of a nonresident to travel over the highways of the State was more than a privilege, the nonresident did not have an absolute right to the use of the highway. The restrictions in the law were largely safety measures, the court said, and applied to both residents and nonresidents alike. According to the court, the inherent speed of the automobile made it practically impossible to enforce the operating restrictions as to speed and mode of operation except through penalties imposed after infraction of such rules. The provision that nonresidents in taking out licenses for operating automobiles within the State give power of attorney to the secretary of state to accept legal service was a device for bringing nonresident violators of the State's automobile regulations before the courts of the State for trial in the same manner as residents of the State were tried for similar offenses. In the light of these facts it could not be considered that there was an interference with their constitutional rights. Both residents and nonresidents were placed upon the same plane of legal action.

THE USE OF LICENSE FEES FOR ROAD PURPOSES UPHELD

This pronouncement of the supreme court still did not satisfy the opponents of this particular law and they succeeded in bringing a second case involving the validity of the 1908 motor vehicle tax law, this time stressing the fact that the motor vehicle license tax yielded a very substantial sum over and above the administrative costs and claiming that on that account it was invalid and constituted in fact a burden upon interstate commerce in defiance of the Federal Constitution. The State supreme court upon further consideration of this question held that the imposition of license fees for revenue purposes was clearly within the sovereign power of the State. (Kane *v.* New Jersey, 81 (N. J.) 594.)

When it was shown in the record that the receipts derived from the automobile license taxes were so large that a considerable part of them were used for highway purposes the court took the position that since the State had spent large sums of money on improved highways, the facilities of interstate and intrastate commerce, it was entitled to make a charge and exact a remuneration for the maintenance of such public works. The theory of the automobile license tax as to its purpose was thus extended to include revenues for highway purposes in addition to a collection of funds barely sufficient to meet the expenses of administering regulations ordained and established in the beginning as a part of the State's police power. The license tax was thus made to serve a dual purpose.

In reviewing this matter, the court indicated that in former times the State had created agencies such as turnpike companies to construct and improve specified sections of highways and had given them authority to make certain charges for their use. What the State had done along these lines indirectly it could do directly, and the license tax could rightly be regarded as a fee for the use of the roads built wholly or in part by the State or by any of its political subdivisions. It had been observed that the rapidly moving motor vehicles brought about a rapid deterioration of the road surface and made necessary high maintenance expenditures. The motor vehicle tax law imposed upon the owners of all these vehicles driven over the roads a charge for the purpose of highway maintenance and upkeep. The court saw no objection to the State charging a lump sum for this use instead of a toll or mileage fee, and a classification of automobiles according to horsepower, in the opinion of the court, reflected to a certain degree the extent of the use and could be regarded as a reasonable classification. The legislature had prescribed a reasonable mode of measurement. The conclusions of the court are stated in the final paragraph:

> The imposition is a license or privilege tax charged in the nature of compensation for the damage done to the roads of the State by the driving of these machines over them, and is properly based not upon the value of the machine but upon the amount of destruction caused by it.

When Michigan attempted to add the revenue or tax feature to its motor vehicle registration law the supreme court refused to sustain the new legislation on constitutional grounds which were more or less technical in character. In 1913 the legislature passed an amendment to the motor vehicle administration act of 1909 which provided for a license fee graduated according to horsepower instead of a flat fee. It was estimated that under the new law the revenues per motor vehicle would average about $12; under the former law a flat fee of only $3 per vehicle was collected when the license was issued. The amendment also provided that the revenues accruing from these new license fees should be devoted to highway purposes and that automobiles should thereafter be exempted from all property tax assessments. The supreme court held that the new act was a revenue act and that the amount of fees derived under this licensing law was far in excess of the necessary expenses of registration and administration. While the police-power feature was still a part of this act, it was held that the tax feature had been introduced through the advance in the fees and that in doing so the title of the original act, which made no provision for the taxation of motor vehicles, had been retained by the amendatory act. On the ground that the legislative procedure had been irregular the new law was held invalid. (Vernor *v.* Secretary of State, 179 Michigan, 157.)

LICENSE FEES HELD TO BE PRIVILEGE TAXES—NOT PROPERTY TAXES

At the next session of the legislature (1915) the act was passed again, this time clearly indicating in the title that it was for the purpose of raising revenues as well as an exercise of the police power. This new act was promptly appealed to the supreme court but the schedule of license fees was duly upheld. (Jasnowski *v.* Board of Assessors, 191 Michigan, 287.) The title of the new act was as follows:

> An act to provide for the registration, * * * regulation of motor vehicles, * * * and to provide for levying specific taxes upon such vehicles, * * * and to provide for the disposition of such funds, * * * and to exempt from all other taxation such motor vehicles so specifically taxed * * *.

Among the objections to the act there was the contention that the title provided for both regulation and taxation, two distinct objects. The court stated that whether or not the act should be declared invalid depended upon the nature of the tax which this new law imposed. In settling this question it had to be determined whether the new tax was in the nature of a property tax or a privilege tax. If it could be regarded as a property tax the court intimated that the contention of the objectors was well founded. Granting that the legislature, in the exercise of the police power, could enact a regulatory statute in which regulation and taxation were so blended as to have but a single purpose, the court concluded this tax was intended as a privilege tax rather than a property tax and that the technical objection to the form and substance of the act was not well taken.

The contention was also made that the legislature exceeded its power when it exempted the automobiles operated on the highways from the regular ad valorem tax and substituted for it this new scale of motor vehicle license fees. Here the court admitted that it was within the province of the legislature to determine what class of property should be taxed and what class should not be taxed except where there was an interference with provisions of the Constitution. The legislature had exercised its discretionary power; the court could not say whether this was done wisely or justly.

The final objection that was made was that the act provided for the collection of money by taxation of owners of vehicles in cities and villages to be expended on the rural highways. The court, in answer to this, pointed out that under the constitution the State was authorized to engage in works of internal improvement. The construction and maintenance of highways were considered to be works of this class. This constitutional provision, or rather permission, therefore, furnished the basis for the action of the legislature in disbursing the fund collected from automobile operators; and the legislature had the power to determine which roads should be improved first, knowing that not all the streets and roads of the State could be improved at one and the same time.

It is interesting to note in this connection that the court refrained from advancing the toll-road theory in trying to justify the collection of fees from persons owing motor vehicles and residing in cities and villages which did not benefit directly in having any of these highway funds allocated for the improvement of their streets. The argument that these city dwellers used the rural highways probably as much as the rural population and could therefore be charged for such use was not presented. In other cases this reason is considered of great weight.

HIGH MOTOR VEHICLE FEES MUST BE PREDICATED ON NEED OF HIGHWAY REVENUE

That the legislature must clearly predicate high motor vehicle fees upon the theory that such revenues are desired for highway purposes and that in the passage of such an act the revenue feature must be clearly brought out is exemplified in Alabama's attempt to increase its motor vehicle fees from a nominal sum charged for licenses to rather substantial fees based on horsepower. The act passed in 1913 was presented to the supreme court for judicial review and was declared unconstitutional. (State *v.* Lawrence, 61 South. 975 (Alabama).) The attorney general in presenting his case to the court maintained that the statute was not a revenue measure but a police measure pure and simple; that the matter of taxation was not involved. The court held that the State had, without any doubt, the right to regulate the use of its highways and that in doing so it could compel the registration and numbering of automobiles; that it could impose fees which would compensate the State for the expenses and costs which such legistation entailed, but that such fees had to be reasonable and fair considering the object to be attained and all the surrounding facts. Inasmuch as the fees varied from $5 to $25 and the registration expense was estimated to be not over $1, the court concluded that the revenue feature of the law appeared to be all important, and that if it was the purpose of the legislature to exercise only the police power it had gone too far in adopting such a high scale of fees, the court ruled, therefore, that the statute was void in that it violated the due process clause of the State and Federal Constitutions.

California in 1913 passed a motor-vehicle act which provided for a scale of license fees based on horsepower. The law was contested in the courts and its constitutionality was passed upon by the supreme court in 1914. It was contended by those opposing the law that the classification of motor vehicles according to horsepower was illegal, but the court in upholding the law stated that it regarded this method of classification as "an attempt on the part of the legislature to apportion the license fees with some reference to the destructive or wearing power of each motor vehicle." (Ex parte Schuler, 167 Cal. 282.) While the horsepower basis might not be considered as an absolutely scientific method of determining road wear, the court could not say that it was an unjustified method. Automobiles of high power were usually heavier than automobiles of low power and the damage done to the road by the heavier vehicles was considered greater than that done by the lighter cars. Speed, which is another factor in road wear, was not mentioned by the court.

UNITED STATES SUPREME COURT DECLARES LAWS CONSTITUTIONAL

The constitutionality of legislation passed by States providing for a license tax upon automobiles to be paid by both residents and nonresidents was finally passed upon by the United States Supreme Court. The New Jersey case was appealed to the Federal courts and another case arose out of a similar enactment by Maryland. (Hendrick *v.* Maryland, 235 U. S. 610 (1915) Kane *v.* New Jersey, 242 U. S. 160 (1916). In unanimous opinions the Supreme Court held that the licensing of automobiles and of drivers and the charging of fees graduated according to horsepower was an exercise of the police power of a State and that its purpose was to preserve the health, safety, and comfort of its citizens. The revenue features of this character of legislation were also upheld by the Supreme Court on the grounds that when a State at its own expense furnished special facilities, such as improved highways, it might charge special compensation for their use whether the users were residents or nonresidents. After these decisions there was no longer any doubt as to the right of the States to charge motor vehicle license fees which were designed to produce highway revenues in addition to the amounts of money necessary to administer such licensing laws as a part of a State's police power. The fees paid could not be regarded as property taxes and the States were authorized to establish reasonable classifications upon which such charges could be based.

LITIGATION WITH RESPECT TO GASOLINE TAXES

When a number of the States began to pass laws providing for a tax upon gasoline a new phase of motor-vehicle taxation was developed. The courts were again invoked to determine whether or not such a tax could be considered valid upon constitutional grounds. The Supreme Court of Arkansas was called upon to review this question soon after the passage of an act of the legislature (1921) instituting a tax of 1 cent per gallon upon all gasoline sold within the State which was to be used in propelling motor vehicles. The law provided that all persons or corporations selling gasoline to be used in propelling motor vehicles over the highways of the State should collect from the purchaser of such gasoline 1 cent per gallon in addition to the regular price and remit the amount of money thus collected to the State, which in turn would distribute one-half to the general road fund of the county in which the tax was collected and one-half to the State highway improvement fund. Other sections of the act required wholesale distributors and retail dealers to file monthly reports showing the sales of gasoline used for such purposes.

The opponents of this new kind of tax contended that it constituted a property tax on gasoline and was therefore void because it violated the constitutional provision of uniformity. The question for the court to decide was whether or not the gasoline tax was a property tax, because it was conceded by all parties to the action that if it was there was a violation of the uniformity principle. (Standard Oil Co. *v.* Brodie, 239 S. W. 753 (Ark.).) The language of the act disclosed that it was neither the intention of the legislature to impose a tax upon gasoline nor upon its sale, nor even upon its use, but that the tax was essentially a tax upon the use of motor vehicles on the public highways. The extent of the use was measured by the amount of gasoline consumed which resulted in a tax on motor-vehicle operation in accordance with the use made of the highways. This interpretation disposed of the objection to the tax on the grounds that it was a property tax.

It was also argued by the objectors to this statute that it was a species of double taxation in that the legislature had already placed a tax upon the users of the highway in the form of an automobile license fee. The court disposed of this proposition in a rather ingenious fashion. It held that the license fee could be regarded as a tax upon the privilege of using the highways according to the capacity of the car, while the gasoline tax was an additional tax upon the privilege of using the highways according to the extent of the actual use. In adopting this point of view the court adopted the principle of charging for highway use which has been developed in the theory of public-utility rates and charges. Electric-power rates, for example, are based upon these same two factors—capacity and use; a flat readiness-to-serve charge is made, based on the consumer's capacity to use the service, and an additional charge is made for the current actually used. The former charge is designed to cover to a large extent the capacity costs or fixed charges and the latter charge covers the direct operating expenses. The gasoline tax in combination with an annual license fee follows the same principle.

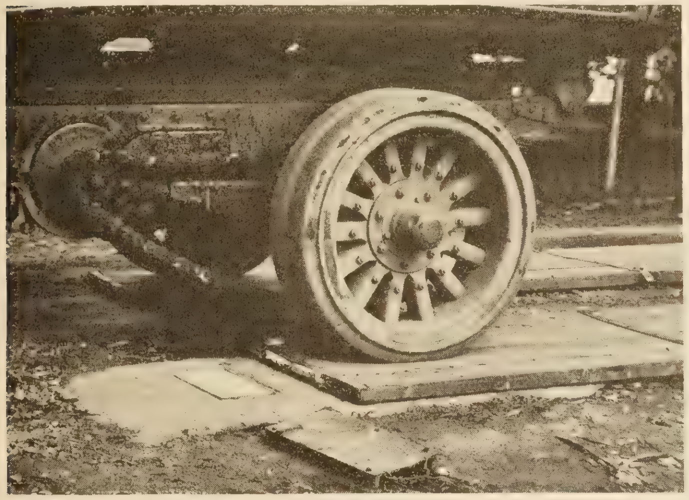
It was also brought to the attention of the court that the gasoline tax afforded means of evasion to those motor-vehicle operators who lived close to the borders of the State and who could purchase their supplies of gasoline in adjoining States which did not have a gasoline tax and that such a possibility of evasion constituted a discrimination against others who were compelled by their location to pay the tax. The court admitted the possibility of such an evasion of the gasoline tax, but held that it did not render the statute arbitrarily discriminatory in a legal sense.

(Continued on page 14.)

STATUS OF THE MOTOR TRUCK IMPACT TESTS OF THE BUREAU OF PUBLIC ROADS

By C. A. HOGENTOGLER, Associate Highway Engineer, United States Bureau of Public Roads

SIX years ago the Bureau of Public Roads undertook an investigation of motor-truck impact. The object of the research was two-fold—first, to determine the forces to which pavements are subjected, and, second, to determine the resistance to these forces of various types of road surfaces.



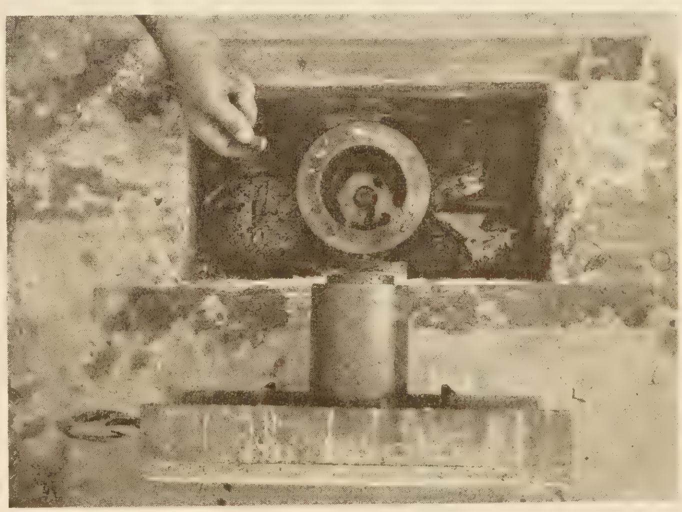
A truck wheel about to drop from a 2-inch elevation upon the piston head of the hydraulic jack used for transmission of the impact to the copper cylinders. The channel guard in the lower foreground was used to prevent recording the impact of the front wheels. It was pulled away in time for the passage of the rear wheels

From time to time reports of several phases of the investigation have been published in PUBLIC ROADS,[1] all of which have dealt with the measurement of impact forces and the effect of such forces on specimen slabs of pavement constructed at the Arlington Experimental Farm, Arlington, Va.

In the first stages of the investigation efforts were directed to the determination of the forces of impact delivered by moving trucks to road surfaces. The effect of the impact upon the surface was not considered. To determine the impact forces, motor trucks were driven over obstructions or drops placed in the roadway and the impact of the wheels on striking the obstruction or falling over the drop was received on the piston head of a hydraulic jack which transmitted the force of the blow to a small copper cylinder set between the piston and the bottom of the jack cylinder. The copper cylinders were calibrated under static pressures and their deformation by any given static force was known. It was assumed that an impact which caused deformation of the copper cylinders equal to that caused by a given static force would be equal to the static force. While these tests indicated that the impact of a motor truck wheel striking the surface of a road might be several times as great as the static load on the truck wheel, it was found that the impact force indicated was not as great as the maximum impact which would be delivered to the road without interposition of the copper cylinder, for two reasons: First, the copper cylinder itself, in deforming under the impact, to that extent cushioned the blow and, by reducing the deceleration, reduced the impact; second, the copper cylinder deformation was a measure of the work done upon the cylinder and not the maximum impact delivered to it. At the instant of contact of wheel and piston head the force of impact is zero. As deformation of the copper cylinder progresses the impact increases. The average force or resistance of the copper multiplied by the deformation or distance through which it acts is equal to the energy applied (heating and elastic effect neglected). This reasoning led to the conclusion that the force measured by the copper cylinder was the average force of impact and not the maximum.

THE TESTING OF SLABS BEGUN

The next phase of the investigation introduced the testing of sections or slabs of pavement of various kinds to ascertain their behavior under impact. To deliver the impact a machine was designed which, as shown by the illustration on page 12, consisted of a loaded box riding on a 5½-ton truck spring which, in turn, was supported by a loaded plunger on the bottom of which was a double 2-inch by 6-inch solid rubber tire. The box and plunger representing the sprung and unsprung weights, respectively, could be so loaded as to represent a truck of any size. By means of a motor, gears, and cam the plunger or unpsrung weight carrying the spring and sprung weight could be lifted and dropped from any height so that the effect would be identical with that of a truck wheel dropping from one level to another.



Looking down on the hydraulic jack used for transmission of impact to copper cylinders. The copper cylinder held in the hand is placed in the bottom of the jack cylinder. The blow of the truck wheel is delivered to it through the piston

[1] "The how and why of truck impact," Public Roads, volume 3, No. 31, November, 1920.
"Motor truck impact tests of the Bureau of Public Roads," Public Roads, volume 3, No. 35, March, 1921.
"Tests of impact on pavements by the Bureau of Public Roads," Public Roads volume 4, No. 6, October, 1921.
"Tests of impact on pavements by the Bureau of Public Roads," Public Roads, volume 4, No. 7, November, 1921.
"Motor truck impact tests of the Bureau of Public Roads," Public Roads, volume 4, No. 8, November, 1921.
"Impact tests on concrete pavement slabs," Public Roads, volume 5, No. 2, April, 1924.

Impacts delivered in this way were applied to a series of 7-foot square slabs of various paving materials. The problem of measuring the force of the blows delivered was met by the development of an autographic process for determining the maximum declaration of the falling load. Multiplying this deceleration by the mass of the

A general view of the first type of impact machine

plunger, spring, and loads gave as a result the impact in pounds corresponding to any drop of the machine. The autographic apparatus consisted of a strip of silicated paper which was moved horizontally over a 5-inch drum at a rate recorded by means of an instrument designed to break electrical contact every second and thus cause a movement of a time-recording point against the paper. Three other points attached, respectively, to the unsprung weight, the sprung weight, and the slab and bearing against the moving paper recorded the vertical movements of each when the plunger was dropped upon the slab. The graphs thus formed measured time by their horizontal distances and vertical movements by vertical distances. By mathematical analysis of them it was possible to derive the velocity of the falling load and the deceleration of the velocity from the instant when the rubber tire struck the slab until the downward velocity was reduced to zero. For the purpose of such analysis the autographic curves, a typical sample of which is reproduced on this page, were enlarged several times by means of an accurate pantograph.

Apparatus for recording space-time curves of motor truck impact

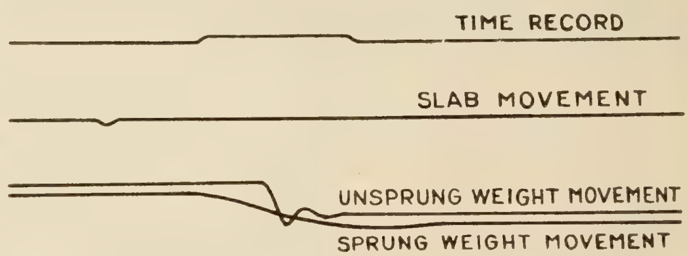
Impact forces delivered to the first series of experimental slabs were measured in this way and their effect on the slabs was determined by noting the height of fall and impact required to cause failure of the various slabs. Reports of this series of tests were published in Public Roads for October, November, and December, 1921.

THE TESTING OF THE SECOND SERIES OF SLABS

Upon the completion of these tests a new series of slabs was constructed including a wider range of designs, and work was begun on the construction of a new type of machine for delivering and measuring impact forces. The machine which was finally developed was far more compact and easier to move from slab to slab than the one used in the earlier tests; and for the measurement of the impact force the autographic space-time apparatus was supplanted by an accelerometer to measure the acceleration directly and reduce the time and labor required in the interpretation of the test results.

The work of developing and calibrating a type of accelerometer suitable for the purpose was one of the most difficult phases of the entire investigation. The problems involved were satisfactorily solved, however, and the perfected accelerometer was used in connection with the new impact machine for the testing of the second series of slabs, the results of which were published in Public Roads for April, 1924.

In the testing of the first series of slabs the behavior of the slabs could be determined only by observation of the occurrence of cracks and the deflection of the slabs following the blows delivered. No means were available for the measurement of the deformation of the slabs under the impact blows. Therefore the development of the graphic strain gauge which, when embedded



A typical space-time record of a single drop of the impact machine

in the slab, was found to give an accurate record of the deformation of the experimental section constituted one of the distinct advances of the second series of slab experiments.

In all the work up to this time the actual impact delivered by motor trucks to road surfaces was measured at one location on an actual road and corresponding impacts were then delivered to the experimental pavement slabs by means of the impact machines at another location.

THE CURRENT INVESTIGATIONS

The investigation has now entered a third stage in which the force of the impact delivered by an actual truck to an actual road is measured simultaneously with the effect of the blow on the road surface. Records of accelerometers mounted on the moving truck permit computations for the former, while graphic strain gauges inserted in the road surface indicate the stress produced in the slab, and thus show the latter.

In determining the magnitude of impacts found on ordinary roads, the current investigation goes further than those that preceded it in that it inquires into the causes of the impacts as well as their magnitudes. In this study the profile of the road surface as given by a 16-wheel profilometer is correlated with accelerometer records. This phase of the work in itself should be of special interest to the construction engineer since it opens up a means of determining whether or not a finished pavement has the proper degree of smoothness. If it should not have, records from these instruments will indicate the exact location of the troublesome areas or obnoxious bumps. It is not an extravagant prediction to say that in the very near future the acceptable degree of road smoothness will be determined by properly standardized instruments either mounted on a standard vehicle or towed behind it at specified speeds. The State highway departments of both New York and Illinois are now experimenting with apparatus of this character. New York uses the Vialog, an instrument which is attached to an automobile and which measures the deflection of the front spring, while in Illinois a 16-wheel profilometer is drawn by a truck and gives an accurate profile of the road.

Briefly stated, the present investigation was designed to secure definite information in regard to the wheel impacts as influenced by road roughness, vehicle design, load, speed, and tire equipment, and, as stated before, the resistance of the various pavement surfaces to these impacts.

PROCEDURE IN THE CURRENT INVESTIGATIONS

Procedure in this investigation is simple. First, representative sections of the various types of pavements commonly used, such as concrete, brick, granite block, and bituminous combinations are selected and marked off. A general indication of the roughness of these sections as compared with that of all available lengths of similar pavement is secured from an instrument similar to the Vialog which is mounted on a touring car. The actual profiles of the test sections are secured by means of a 16-wheel profilometer.

Over these selected sections of road are then run the test trucks, which range from 1 to 5 tons capacity. The truck variables include four speeds and three loadings—empty, capacity, and overload—and four kinds of tires—pneumatic, cushion, new and worn solid. By means of accelerometers attached to the trucks, records of the accelerations and the accompanying spring deflections and speed of travel will be obtained. With this information and a knowledge of the sprung and unsprung weights, a computation of the force of the blow is quickly made.

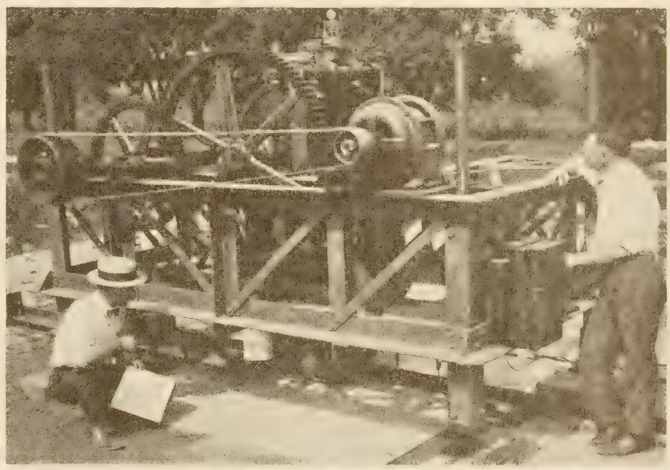
After the impacts occurring on normal roads have been determined, they will be reproduced on the experimental test road and their effects will be recorded by the graphic strain gauges which indicate the stress occurring in the concrete sections. This procedure has been made possible only because of the development of the graphic strain gauge and the accelerometers.

The development and calibration of the apparatus constitute the most difficult phase of the impact investigations. In the case of the graphic strain gauge it was essential to have a device which would accurately measure fiber deformations ranging from zero to several ten-thousandths of an inch and at the same time be so small as to be conveniently inserted in a road slab under a truck wheel. While several accelerometers are available commercially, none of them answered the test requirements, which were that the apparatus must be capable of measuring accelerations ranging from zero to 1,000 feet per second and at the same time be sturdy enough to function properly when subjected to the vibration caused by its being attached to a rapidly moving motor truck. In addition to the mechanical difficulties, we were faced by the fact that authorities disagreed as to the practicability of securing usable force values from accelerometer records.

THE ACCURACY OF THE ACCELEROMETER RECORDS

The feeling of doubt existing among engineers as to the practicability of determining impact forces from accelerometer records is expressed by C. D. Young, past president of the American Society for Testing Materials, in a discussion of a paper entitled "Accelerometer for measuring impact," presented before that body by E. B. Smith, of the Bureau of Public Roads Mr. Young is quoted as follows:

> The earliest testing of railway materials was largely by the impact method, namely, by drop testing. That is still the case in the testing of rails. At one time couplers, bolts, and a great deal of railroad material was tested by impact. Efforts were made to translate the results of those impact tests into force in pounds. I believe it was the consensus of opinion through 20 or 30 years' experience in that work that it was neither wise nor safe to draw too definite conclusions in the translation of the forces applied through acceleration into pounds loading equivalent to static. A great deal depends upon the character of the apparatus as to what the ratio factor should be in that translation. A great deal depends upon the mass back of the resistance, and, as I understand the paper, in this particular case it would be the mass of the vehicle carrying the instrument. In addition to that the character of the springs would be a determining factor in the translation of those forces into pounds, in the same way that the character of the spring bed supporting the anvil of a drop-testing machine has its effect upon the translation of the falling tup to the effect upon the metal and deflection of the metal. In other words, by changing springs in the anvil or the support of the piece deflected under accelerated drop test you can decidedly change the deflection for the same height of fall with the same material. So I feel that where data are obtained through accelerated movement, as in this instance, the attempt to translate into pounds of force should be made very cautiously.[2]



The latest type of impact machine

Happily, it can now be said that the calibration of the instruments has cleared away the doubts and has substantiated previous assumptions and shown conclusively that the instruments to be used in the current investigation accurately perform the work for which they were designed.

When all of the data from this investigation have finally been secured and analyzed, it is confidently hoped that it will be possible to say definitely just what types of vehicles, tires, and loads the various road surfaces can safely support. By correlating this information with that secured from traffic surveys, a simple mathematical calculation will suffice to determine the best combinations of road and vehicle for economic motor transport. Information of this character is of prime importance to the legislator as well as the engineer.

[2] Proceedings of the American Society for Testing Materials, vol. 23, 1923, Pt. II p. 633.

LEGISLATION SHOULD WAIT FOR TEST RESULTS

With the rapid development of motor vehicle transportation need for new laws and regulations arose, and in the absence of definite information many of them were based on more or less scientific guesses. For instance, many laws are based on total wheel load alone. They serve their purpose very well when the truck is not in motion, for a wheel at rest is a definite, tangible quantity which can exert no greater pressure than its static weight. The instant the wheel is set in motion, however, a different condition develops.

As the truck moves along a road surface variations, tire roughness, variations in rubber composition, etc., cause the wheels to mount vertically, after which the force of gravity and spring pressure cause them to return to the road, and make them capable of delivering forces ranging from their static weights to amounts eight or ten times as great. These forces are dependent upon the vertical velocities acquired and the time or distance in which these velocities are reduced to zero. That this change in velocity or deceleration as well as the accompanying force is due largely to the type of cushion existing between the falling body and stopping agency is shown by the following experiment:

A lead weigh of 9 pounds was dropped from the same height—one-half-inch—on five different springs and the resulting forces indicated by the spring deflections were recorded. These springs were previously calibrated under static loads and were found to have stiffness ranging from 31 to 400 pounds per inch deflection. The 9-pound weight when dropped on the 31-pound spring indicated a pressure of 50 pounds, when dropped on the 50-pound spring a pressure of 68 pounds was registered, on the 190-pound spring the force of the blow was 121 pounds, and when dropped on the 400-pound spring, a pressure of 173 pounds was recorded.

It will be remembered that the forces in the first impact tests were computed from a relation between the falling weight, the total fall, and the cushion or the distance in which the weight was brought to rest. Applying that same relation to a considerable number of drops from different heights of the 9-pound weight on the five different springs, a curve was secured which indicates that so long as an elastic cushion is used the maximum force of the blow is entirely dependent upon the percentage of cushion to total height of fall. This relation held with few exceptions, for the impacts delivered by the truck impact machine during the recent calibration work just as it did for the small springs.

Data available to date indicate that pressures delivered by the wheels of a moving motor truck vary just as much as those of the small weight cited above. Our previous tests have shown that a badly worn solid tire can deliver an impact seven times as great as the static wheel load. In one instance the difference in corner deflection caused by a 2,000-pound wheel load with new and very badly worn solid tires was 1,600 per cent. It is interesting to note in this case that the greatest deflection under the 2,000-pound wheel load was double the normal deflection under an 8,000-pound wheel load with a new solid tire. Pneumatic tires, on the other hand, seem to definitely limit the impact. In no case, using obstructions up to and as high as 4 inches, has it been possible to record pressures under pneumatic tires greater than double the static weight. Vehicle design also causes variation in wheel pressure. During the present tests we have indications that with one type of truck accelerations increase with both height of drop and speed, while with another a limiting impact seems to have been reached before maximum drop and speed have been reached.

When, as noted above, it is indicated that a 2,000-pound load can be more detrimental to a slab than one of 8,000 pounds, the fallacy of basing design and legislation on the wheel load is plainly seen. The above results, however, can be taken only as indications, since they are the result in some cases of questionable assumptions. We are now equipped with instruments and knowledge with which all of these questions can be quickly and definitely settled. That is the status of the impact tests at present. The most difficult part of the work, that of securing proper instruments of measurement and determining correct methods of interpreting results, has been completed. From this time it is expected that results from actual road tests will be secured rapidly.

(Continued from page 10)

UNITED STATES SUPREME COURT PASSES ON VALIDITY OF GASOLINE TAXES

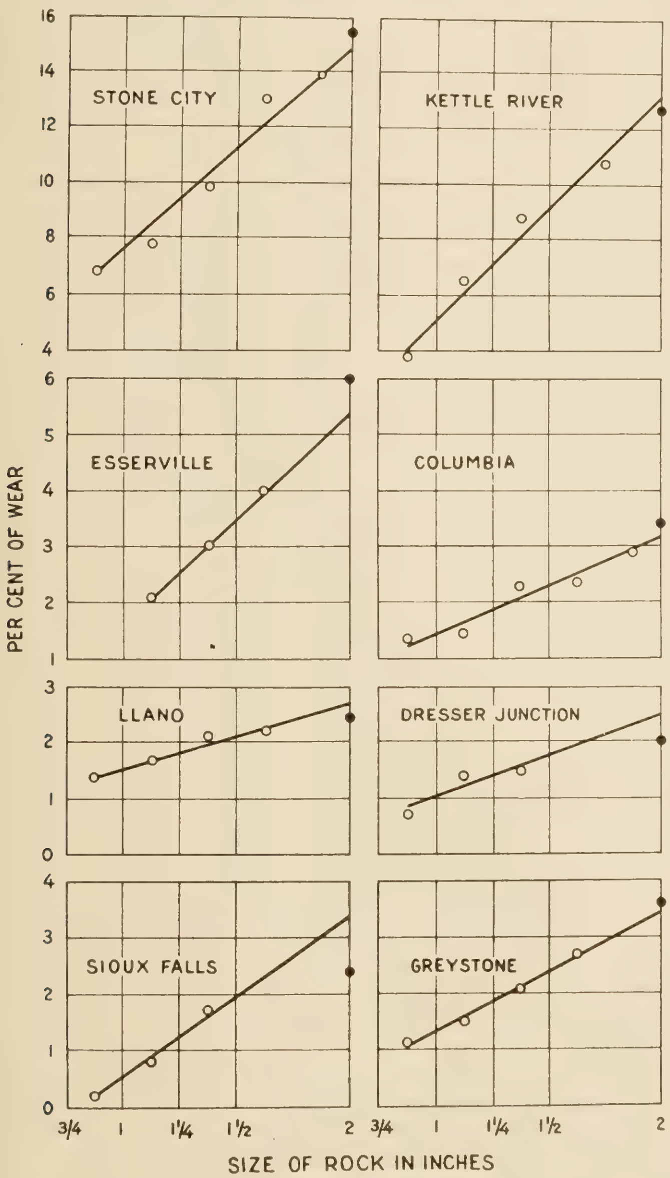
Although the State supreme court upheld the constitutionality of the gasoline tax statute passed by the Arkansas legislature, efforts were made by one of the large oil companies to have the law set aside as being in conflict with the Federal Constitution, and proceedings were brought in the district Federal court to enjoin the tax officials from the collection of the tax. The matter was finally appealed to the United States Supreme Court, which held that it did not come into conflict with the Federal Constitution. (Pierce Oil Corporation *v.* Luther Hopkins et al. (Decided Feb. 18, 1924).) It was claimed that the due-process clause of the Constitution was violated in that the tax was levied as a privilege tax for the use of the highways upon the purchasers of the gasoline but that the collection of the tax was imposed upon the distributors, who were obliged to make monthly payments and reports, and that this constituted an appreciable expense to them. The court refused to consider this a denial of any constitutional rights, and in doing so stated that a State had the power to regulate the business of selling gasoline and also the power to tax the privilege of carrying on that business and that the due process clause of the Federal Constitution did not prevent the State from imposing this incidental burden growing out of the collection of a gasoline tax.

This analysis of State and Federal court opinions indicates that the principle of licensing motor vehicles both for the purpose of police regulation and for highway revenues has been definitely approved by the courts as to its constitutionality. The gasoline tax likewise has been found to be not in conflict with any constitutional provisions except in so far as certain States have constitutions which definitely prohibit revenue measures of that kind. Where such situations exist they can and are being met by amendments submitted to the voters for their approval in cases where State legislatures contemplate the introduction of a gasoline tax to secure revenues for highway purposes.

ROAD MATERIAL TESTS AND INSPECTION NEWS

AN ABRASION TEST FOR CRUSHED STONE

THE Bureau of Public Roads wishes to call attention to a test for abrasion which may be applied to samples of crushed stone. As is well known, the present Deval abrasion test is only adapted to the testing of rock samples where the individual fragments are at least 2 inches in diameter. No method has as yet been adopted for testing crushed stone in the smaller sizes, such as ¾ inch, 1 inch or 1½ inches. The bureau has been endeavoring to develop a test of this nature for some time. Although the results so far secured are not sufficiently complete to warrant a recommendation for its general adoption it is believed that this method, which has so far given promising results, should be described for the benefit of others who may desire to work along the same line.



Abrasion loss by crushed stone particles of various sizes

The method of test is as follows: The sample as received is separated by means of screens with round openings into as many of the following sizes as its gradation will permit: ¾ to 1 inch, 1 to 1¼ inches, 1¼ to 1½ inches, 1½ to 2 inches. Samples for test are then secured by selecting 50 pieces of each size, which are tested for abrasion separately in accordance with the usual procedure. When a sample of crushed stone is tested in this manner and the abrasion losses compared as in the accompanying chart, an interesting relation is observed, which may be stated as follows: For a given sample of crushed stone the loss by abrasion for each size tested is proportional to the size of the pieces composing the test charge, provided that the same number of pieces are used in each case. This relationship is, of course, only approximately true. There are many factors which tend to impair it, the most important of which are variations in shape of the fragments, slight variations in size, etc. For this reason it is well whenever making tests of this nature to secure at least duplicate results for each size.

Assuming, however, that the relationship is approximately true, this method of test presents a means of estimating the probable percentage of wear by the standard method in cases where it is impossible to make this determination directly. Referring to the accompanying graph, it will be noted that the straight line averaging the various points for each sample is extended to the right until it intersects the ordinate for the 2-inch size. The solid circles on the 2-inch ordinates in each chart represent the percentage of loss by the standard Deval abrasion test. It will be observed that in only one of the eight cases plotted does the point where the straight line intersects the 2-inch ordinate differ more than 0.6 per cent from the standard test result. This is true in spite of the fact that the standard test results were secured upon hand-broken samples, whereas the other values were obtained by testing the product of the crusher. The discrepancies that appear are caused without doubt by this difference in the character of the test pieces.

CHECK TESTS OF MATERIALS

The system of check testing materials undertaken by the Bureau of Public Roads, in cooperation with laboratories located in various parts of the country, is continually yielding information of great interest to testing engineers.

It has been possible already to detect and correct many irregularities in laboratory procedure, most of which were found to be due either to the lack of standard equipment or to the failure of operators to appreciate the importance of details. The bureau desires to take this opportunity of thanking tne various laboratories for their cooperation in the conduct of this work.

In connection with the results of check tests of cement, Ct–5, it seems advisable to call attention at this time to a condition in regard to temperatures which appears to be quite common. The accompanying chart gives the temperatures of the laboratory air, mixing water, moist closet, and storage water which were reported by the 60 laboratories cooperating in this test. It will be observed that there is a general tendency to work at temperatures considerably above the standard of 70° F. set by the specifications. These tests were made during the latter part of July and the 1st of August, 1924, and the values are, of course, higher than they would be in the winter throughout the Northern States. The great bulk of cement testing, however, is done during the spring and summer months when temperatures are likely to be higher everywhere. Although the exact amount of variation from standard results that may be due to variations in temperature alone is open to question, there can be no doubt that efforts should be made to secure closer adherence to standard requirements than is here revealed. This is particularly true of both the mixing water and moist closet temperatures, both of which quite appreciably affect the test results.

Temperatures reported in check tests of cement sample Ct-5

In their inspection of laboratory conditions throughout the country, representatives of the Bureau of Public Roads have found in general that very little attempt is made to control this variable in the cement laboratory. This is due in almost all cases to the expense involved in the installation of the proper form of automatic temperature control apparatus. But, when one considers that the disposition of cement worth from $400 to $500 depends upon the result of a single test it appears highly desirable that every precaution possible be taken to insure compliance with every detail of the specification.

It is unfortunate that most of the apparatus which is adapted for controlling temperatures automatically is expensive. This is especially true of any automatic scheme for lowering temperatures. A complete refrigeration system is needed for best results, although conditions can be somewhat improved by the use of ice. Apparatus for raising temperatures to the standard, on the other hand, is quite reasonable in price and easy to install. For this reason it might be well to give consideration to the proposition of raising the standard temperature from 70° F. (21° C.) to 77° F. (25° C.) which is the standard for most laboratory operations. It is believed that compliance with the temperature requirements of the specification could be much more easily secured if this were done.

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publciation to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

DEPARTMENT BULLETINS

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*136. Highway Bonds. 20c.
220. Road Models.
257. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
*314. Methods for the Examination of Bituminous Road Materials. 10c.
*347. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
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*1077. Portland Cement Concrete Roads. 15c.
*1132. The Results of Physical Tests of Road-Building Rock from 1916 to 1921, Inclusive. 10c.
No. 1216. Tentative Standard Methods of Sampling and Testing Highway Materials, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.
1259. Standard Specifications for Steel Highway Bridges adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal aid road construction.

DEPARTMENT CIRCULAR

No. 94. TNT as a Blasting Explosive.

FARMERS' BULLETINS

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*505. Benefits of Improved Roads. 5c.

SEPARATE REPRINTS FROM THE YEARBOOK

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*739. Federal Aid to Highways, 1917. 5c.
*849. Roads. 5c.

OFFICE OF PUBLIC ROADS BULLETIN

No. *45. Data for Use in Designing Culverts and Short-span Bridges. (1913.) 15c.

OFFICE OF THE SECRETARY CIRCULARS

No. 49. Motor Vehicle Registrations and Revenues, 1914.
59. Automobile Registrations, Licenses, and Revenues in the United States, 1915.
63. State Highway Mileage and Expenditures to January 1, 1916.
*72. Width of Wagon Tires Recommended for Loads of Varying Magnitude on Earth and Gravel Roads. 5c.
73. Automobile Registrations, Licenses, and Revenues in the United States, 1916.
74. State Highway Mileage and Expenditures for the Calendar Year 1916.
161. Rules and Regulations of the Secretary of Agriculture for Carrying out the Federal Highway Act and Amendments Thereto.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

Vol. 5, No. 17, D-2. Effect of Controllable Variables Upon the Penetration Test for Asphalts and Asphalt Cements.
Vol. 5, No. 20, D-4. Apparatus for Measuring the Wear of Concrete Roads.
Vol. 5, No. 24, D-6. A New Penetration Needle for Use in Testing Bituminous Materials.
Vol. 10, No. 7, D-13. Toughness of Bituminous Aggregates.
Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

* Department supply exhausted.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

STATUS OF FEDERAL AID HIGHWAY CONSTRUCTION

AS OF

OCTOBER 31, 1924

GOVERNMENT PRINTING OFFICE

STATES	FISCAL YEARS 1917-1924: PROJECTS COMPLETED PRIOR TO JULY 1, 1924			FISCAL YEAR 1925: PROJECTS COMPLETED SINCE JUNE 30, 1924			FISCAL YEAR 1925: *PROJECTS UNDER CONSTRUCTION			FISCAL YEAR 1925: PROJECTS APPROVED FOR CONSTRUCTION			BALANCE OF FEDERAL AID FUND AVAILABLE FOR NEW PROJECTS	STATES
	TOTAL COST	FEDERAL AID	MILES	TOTAL COST	FEDERAL AID	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES		
Alabama	$ 4,598,721.63	$ 2,186,247.54	464.1	$ 575,007.24	$ 284,651.86	85.1	$15,530,308.90	$ 7,534,554.61	836.6	$ 79,416.15	$ 39,708.07	0.7	$ 1,207,800.92	Alabama
Arizona	8,338,365.41	4,287,683.98	527.8	713,173.97	406,825.70	37.5	1,730,194.41	1,048,007.14	150.4	387,292.14	236,674.21	40.7	1,516,510.07	Arizona
Arkansas	11,094,751.31	4,424,345.63	944.4	1,017,822.49	433,389.63	47.7	7,081,513.93	2,567,091.62	355.4	499,080.76	216,952.35	47.1	1,420,620.77	Arkansas
California	12,999,075.03	5,647,148.17	533.7	3,169,801.35	1,697,213.27	122.4	12,310,508.18	6,401,783.18	407.2	435,211.04	256,774.51	1.3	3,090,386.87	California
Colorado	8,108,070.31	4,029,898.97	502.6	724,284.07	374,740.49	39.3	5,385,426.62	2,920,403.94	204.6	62,667.99	35,168.34	5.1	2,199,669.26	Colorado
Connecticut	3,062,872.02	1,269,558.60	73.6	199,024.56	98,423.00	4.9	3,262,054.48	1,045,904.04	54.1				967,409.36	Connecticut
Delaware	3,056,832.22	1,007,714.83	72.5	462,969.09	197,825.92	13.9	1,196,267.49	449,231.10	29.4	122,520.75	55,950.00	3.7	29,758.25	Delaware
Florida	961,134.07	461,470.92	48.8	903,102.67	429,086.42	13.0	8,854,456.15	4,312,794.00	248.8	398,642.71	171,123.94	10.3	912,411.72	Florida
Georgia	17,167,373.32	7,955,805.20	1,214.2	719,629.54	357,915.42	61.1	10,970,229.25	5,404,189.33	823.9	935,377.74	372,029.44	31.3	359,957.61	Georgia
Idaho	8,181,697.92	4,092,395.52	506.8	243,867.57	139,962.62	18.7	2,491,389.16	1,496,692.89	170.5	63,387.46	36,764.71	5.0	911,906.26	Idaho
Illinois	26,964,706.06	12,279,546.33	804.7	1,355,788.15	670,702.08	40.5	15,741,331.50	7,820,073.10	538.8				2,666,170.49	Illinois
Indiana	7,577,444.16	3,655,540.97	225.7	1,202,211.53	590,703.25	41.5	16,162,550.11	7,975,195.57	517.4				2,190,952.21	Indiana
Iowa	23,195,778.19	9,237,031.86	1,682.9	282,803.25	113,620.08	20.2	8,764,648.61	4,071,449.47	637.7	1,125,849.69	505,300.00	52.4	1,408,735.69	Iowa
Kansas	17,084,136.48	6,043,176.90	502.7	4,996,700.82	1,901,478.91	146.0	14,890,306.54	5,962,371.64	616.5	1,900,933.68	877,366.80	108.7	514,894.85	Kansas
Kentucky	10,822,980.31	4,613,947.28	429.4	846,043.61	359,276.28	30.2	9,053,877.00	4,187,562.66	355.0	474,276.14	204,477.96	17.0	1,006,474.92	Kentucky
Louisiana	8,488,463.18	3,636,143.36	661.2	1,149,422.02	559,243.59	104.9	5,017,449.19	2,493,750.83	306.1	191,242.29	95,621.14	1.1	480,683.08	Louisiana
Maine	6,911,058.78	3,299,935.38	230.7	295,533.42	147,087.77	12.3	1,704,509.38	823,525.56	62.5	113,667.57	56,833.78	6.3	762,589.51	Maine
Maryland	6,760,044.42	3,213,321.78	243.2	358,411.02	179,205.49	16.4	2,566,937.34	1,097,755.29	77.8	414,509.32	154,670.00	11.6	13,997.44	Maryland
Massachusetts	10,191,202.02	4,105,727.22	232.8	88,434.91	28,760.00	1.4	6 480,878.47	2,091,214.34	106.9	466,585.01	137,365.00	7.2	1,556,713.44	Massachusetts
Michigan	13,434,135.07	6,060,612.23	494.5	85,790.03	41,110.20	7.3	15,726,921.72	7,492,390.61	534.4	227,396.68	89,025.00	6.0	2,196,633.96	Michigan
Minnesota	24,037,561.24	9,885,843.07	2,292.0	1,390,461.31	649,357.01	107.2	9,973,211.55	4,562,729.97	862.7	682,952.36	109,300.00	74.8	111,188.95	Minnesota
Mississippi	7,888,193.89	3,828,941.39	655.0	727,671.41	363,202.88	50.7	8,249,905.07	4,110,761.52	500.2	334,548.17	167,274.07	17.8	1,061,093.14	Mississippi
Missouri	11,352,027.70	5,245,899.18	803.5	1,317,280.96	650,328.61	100.6	19,418,957.57	9,240,113.31	794.3	2,110,864.83	1,031,504.24	125.2	1,772,342.66	Missouri
Montana	8,867,279.16	4,384,335.12	791.4	663,842.63	426,622.05	77.2	2,315,900.94	1,755,169.14	207.3	1,068,684.29	606,876.40	119.5	3,793,414.29	Montana
Nebraska	7,876,337.16	3,714,691.59	1,440.4	367,154.70	170,993.65	26.9	7,804,592.90	3,819,775.94	823.8	859,533.73	429,766.82	87.5	3,315,718.00	Nebraska
Nevada	3,460,245.52	1,853,624.98	225.6	600,051.46	522,268.72	43.4	4,919,310.57	4,122,474.82	423.5	89,227.46	77,824.18	8.5	314,128.30	Nevada
New Hampshire	3,076,750.19	1,487,867.58	171.3	39,658.20	19,277.89	1.8	1,692,652.32	798,211.95	56.5	23,510.71	11,755.35	0.3	117,851.23	New Hampshire
New Jersey	7,623,795.12	2,661,531.49	148.7	298,751.09	111,360.00	5.6	10,521,978.85	3,001,281.24	84.1				815,074.27	New Jersey
New Mexico	5,306,286.45	2,758,849.68	714.3	459,922.73	279,146.53	58.6	6,713,439.94	4,403,518.25	661.8	250,983.39	154,354.77	16.6	993,462.77	New Mexico
New York	18,962,742.49	8,257,844.44	572.7	601,393.18	258,083.36	19.2	30,084,966.96	11,306,316.72	668.5	6,378,094.00	1,790,545.00	115.9	5,095,358.48	New York
North Carolina	12,567,732.97	5,676,757.66	884.7	1,075,292.98	422,979.39	21.3	10,700,820.49	4,039,779.09	312.1	1,822,902.70	859,142.71	48.8	1,295,592.15	North Carolina
North Dakota	9,088,973.11	4,418,505.42	1,587.9	891,995.28	445,399.39	184.8	3,184,046.35	1,579,002.17	478.1	426,822.84	213,411.38	36.2	1,707,337.64	North Dakota
Ohio	33,122,751.43	11,879,917.99	962.5	1,772,058.39	693,050.64	44.6	13,962,924.71	5,175,506.01	382.9	914,126.13	363,246.62	37.6	2,028,442.74	Ohio
Oklahoma	12,986,865.26	5,888,852.03	497.3	1,193,003.76	575,235.49	52.9	8,943,018.46	4,280,990.91	380.1	1,735,045.71	755,679.93	89.4	1,035,944.64	Oklahoma
Oregon	12,082,873.17	5,819,093.79	655.6	808,472.48	468,237.85	68.6	3,127,155.01	1,845,453.31	167.6				373,374.05	Oregon
Pennsylvania	36,825,248.98	14,114,694.79	729.7	738,455.97	318,687.37	16.8	22,994,662.80	6,297,181.25	382.8	2,137,715.79	609,681.25	39.9	3,261,371.34	Pennsylvania
Rhode Island	1,774,397.25	779,227.96	46.0	486,927.24	210,938.14	11.2	869,747.59	286,169.30	17.1	380,178.15	92,700.00	6.2	564,105.60	Rhode Island
South Carolina	9,016,476.73	4,124,045.22	924.4	1,118,224.21	497,540.74	169.2	5,681,011.81	2,356,889.68	410.8	519,424.14	137,323.86	45.8	571,746.50	South Carolina
South Dakota	8,674,597.86	4,244,636.27	989.8	845,706.40	453,412.58	120.0	8,026,510.71	3,975,940.91	1084.6	87,989.45	40,895.15	14.3	3,795.09	South Dakota
Tennessee	6,805,683.35	3,313,936.07	259.6	2,919,375.46	1,434,944.87	101.3	12,933,199.49	5,798,648.30	411.4	1,173,785.49	577,049.19	63.6	900,058.57	Tennessee
Texas	42,341,998.56	16,190,624.91	3122.8	3,154,465.53	1,395,235.58	213.6	25,104,633.26	9,934,262.23	1572.9	3,008,806.31	1,170,852.26	141.8	3,033,238.02	Texas
Utah	3,304,423.75	1,895,805.92	219.0	719,066.79	390,456.24	91.2	4,691,270.78	3,136,607.08	278.0	179,027.65	114,931.00	13.0	578,672.76	Utah
Vermont	1,922,114.16	942,769.12	74.4				2,119,474.83	1,013,156.18	53.4	175,757.00	79,026.96	5.1	499,026.74	Vermont
Virginia	10,035,301.48	4,801.782.43	562.5	412,925.70	165,709.43	11.6	10,397,692.18	4,772,627.88	362.4	121,041.73	49,466.96	3.1	803,366.30	Virginia
Washington	11,384,615.67	5,290,895.45	457.0	232,694.93	109,880.09	23.4	4,172,116.91	1,912,300.00	153.8	76,148.13	38,000.00	5.2	535,602.46	Washington
West Virginia	5,489,747.95	2,365,041.53	255.6	1,030,538.46	465,662.95	31.3	4,786,142.71	2,150,604.61	166.5	44,213.40	16,800.00	1.1	756,022.91	West Virginia
Wisconsin	18,753,903.15	7,441,033.57	1,325.3	642,850.91	310,652.72	33.3	4,587,966.47	2,208,743.02	189.5	195,597.26	93,744.00	8.4	3,624,277.69	Wisconsin
Wyoming	6,127,625.61	3,078,098.70	687.6	811,510.31	471,419.85	92.7	4,405,501.88	2,784,637.92	307.1				353,194.53	Wyoming
Hawaii													365,625.00	Hawaii
TOTALS	$ 549,655,391.27	$ 237,852,399.82	32452.9	$ 44,709,573.68	$21,291,205.90	2643.1	$417,204,570.43	$187,753,733.63	19227.7	$ 32,695,037.94	$13,132,957.35	1481.0	$ 65,094,703.30	TOTALS

* Includes projects reported completed (final vouchers not yet paid) totaling: Estimated cost $ 84,083,419.11 Federal aid $ 37,909,951.69 Miles 3,689.4