

## PUMPING OF RIGID PAVEMENTS UNDER WAR-TIME TRAFFIC

Tilton E. Shelburne, Research Engineer,  
Joint Highway Research Project,  
Purdue University

During the present emergency much attention is being directed to the careful inspection and maintenance of our existing transportation equipment. These precautions are necessary so that the largest volume of war materials may be transported with the least possible drain on production facilities and critical materials. Special inspections are now required both for trucks and passenger cars. These regular inspections aim at the conservation of all critical materials and, more particularly, tires.

The life of automobiles and trucks, and especially the tires, may be as much dependent upon the condition of the pavements over which they travel as upon periodic inspections. This places added responsibilities on the highway engineer. He must keep essential war-time traffic moving and at the same time maintain the existing highways through the war period in as good a riding condition as possible. These duties are expected in spite of limitations on time, money, labor, equipment, and the use of critical materials.

Since the construction of new pavements during the present emergency is at a minimum except for military purposes, the maintenance of existing highways is of major importance. Many of our highways, which are now carrying more and heavier traffic (because of the war effort) than was anticipated when they were constructed, are now showing signs of distress. On concrete pavements carrying heavy truck traffic, distress has been noted in the form of pumping at transverse cracks and joints. While pumping of rigid pavement slabs was observed before the war, increased traffic and heavier loads have aggravated the situation in many defense areas. In fact, this is one of the problems confronting the highway engineer that appears to be of major importance.

This problem is not confined to Indiana but is of concern to many states<sup>1</sup>, Ohio, Illinois, Iowa, Missouri, Oklahoma, Kansas and others. Illinois<sup>2</sup> conducted extensive field experiments in 1939 with methods of correcting pumping on some of her heavily traveled highways. Since that time, many other states have become concerned and have tried corrective procedures. With increased traffic and heavier loads the pumping problem may be expected to become more serious. In order

<sup>1</sup> "Maintenance Methods for Preventing and Correcting the Pumping Action of Concrete Slabs," Wartime Road Problems No. 4, Highway Research Board, October, 1942.

<sup>2</sup> Paul J. Kunzer—"Subgrade Treatment by Mud-Jacking and Filling," *Roads and Streets*, November, 1940, and December, 1940.

that we may more clearly understand the problem, let us consider what is meant by pumping.

**Explanation of Pumping.** The deflection of pavement slabs under repeated heavy loads, when the subgrade is in a saturated condition, causes a displacement of the soil and results in the ejection of muddy water. This action is termed "pumping," and with continued repetition it removes sufficient subgrade material to permit settlement of the pavement. It is evidenced by discoloration at joints or cracks and by mud spots along the pavement edge. With a decrease in subgrade support under a portion of the slab and repeated displacement, excessive stresses are set up in the slab, causing it to crack. Pumping is closely associated with the direction of traffic. It has been observed that the receiving end of a slab (the end just past the joint or crack) is the portion from which the subgrade material is first removed. This removal may extend only a short distance at first and is responsible for the faulting or settlement at the joint or crack. Once the slab cracks, usually six to twelve feet ahead of the joint, the crack is likewise susceptible to pumping. Thus, once pumping starts, the rate of deterioration appears to be fairly rapid, assuming no change in traffic conditions.

#### EXTENT OF PUMPING IN INDIANA

While no complete survey has been made of all state highways, several have been inspected for evidences of pumping. Those roads on which pumping has been observed are listed in Table I. It is believed that this list is by no means complete and that pumping is more extensive than is indicated by the table. The table merely emphasizes the fact that at all locations where pumping has been observed, the subgrade soil is susceptible to pumping and that these roads carry relatively large volumes of heavy truck traffic. Several roads on which subgrade soil conditions are favorable to pumping have been inspected with no evidences of pumping. Reference to traffic surveys indicated that these roads did not carry a large volume of truck traffic.

It is generally recognized that the axle load passing over a crack or joint on a rigid slab governs the amount of deflection regardless of the number or size of tires. With increases in axle loads and frequency of application, the problem of pumping may be expected to become more critical.

#### PERFORMANCE SURVEYS

The Joint Highway Research Project has been interested in the pumping problem for some time, and during the past two years we have made performance surveys on some of

TABLE I  
SECTIONS OF INDIANA HIGHWAYS OBSERVED TO BE PUMPING  
(Incomplete)

Road No.	County	Approx. Length (miles)	Soil Area	Predominating Soils	Commercial Vehicle Traffic Volume 24 Hours
U. S. 12	Porter	1	Lacustrine	Lucas	500-1000
U. S. 20	Porter	6	Lacustrine and Wisconsin Drift	Homer, St. Clair, Nappanee	500-1000*
U. S. 6	Lake and Porter	20	Lacustrine and Wisconsin Drift	Homer, St. Clair, Nappanee	500-1000, 250-500
U. S. 30	Lake and Porter	24	Wisconsin Drift	Miami, Carrington	500-1000
U. S. 41	Lake and Newton	20	Wisconsin Drift	Miami, Carrington	500-1000
U. S. 52	Tippecanoe, Boone, Hendricks, and Marion	6	Wisconsin Drift	Miami, Crosby, Brookston	500-1000
S. R. 67	Marion and Hancock	4	Wisconsin Drift	Miami, Crosby, Brookston	500-1000
†S. R. 67	Morgan	?	Wisconsin Drift	Russell, Fincastle	?
‡U. S. 40	Putnam	?	Illinoian Drift (Bedrock)	Gibson, Cincinnati	500-1000

\* Trucks over 3 tons routed over U. S. 12 about Nov., 1941; since then pumping ceased.

† Reported by subdistrict superintendent. (No survey made.)

‡ Reported by district engineer. (No survey made.)

these roads. These surveys have been for the purpose of determining the extent, causes, and correlation of drainage and subgrade soil types with pumping. Two of these surveys will be discussed briefly.

**U. S. 20 in Porter County.** The area covered by the survey may be divided into four classes based upon topography and soils (Table II). These topographic subdivisions will be discussed in order of their importance with respect to the distressed pavement. Serious failures were confined to areas in Class II and III.

TABLE II  
CORRELATION OF TOPOGRAPHY, SOIL TYPE, AND PERFORMANCE

Class	Topographic Features and Soil Types	Performance
I	Sand west of Salt Creek (Plainfield Sand)	No failure—short crack interval
II	Low, flat terrain extending from Salt Creek to the Calumet River (Soil types—Homer-Lucas, and Maumee)	Pumping failures, except two miles placed on sandy fill material—long crack interval
III	Morainic hills (St. Clair)	Pumping and failures localized in cuts
IV	Elevated flats (Nappanee)	Localized pumping

*Low Flat Terrain.* This area extends from Salt Creek to the Calumet River, being a portion of old Lake Chicago. The three soils encountered are Homer, Lucas, and Maumee, in order of their extensiveness. These soils are directly related—each varying from the other only in minor respects. A general description of this group of soils would be this: a thin layer of top soil underlain by a layer of highly plastic silty clay a few feet (4'-6') in thickness. Beneath this silty clay is a layer of clean sand approximately 10 feet in thickness. The west one and one-half miles of this three and one-half mile section were in poor condition, showing considerable distress. The remaining two miles were in good condition. This better condition was attributed to the fact that a slightly higher level profile was used and a better subgrade material (more sand) was employed on this portion.

*Hilly Terrain (Class II).* This portion, extending from the Calumet River to the Porter Road, is in a category entirely different from that of the lowland. In this area failures occur principally in cuts, with some in fills. The predominating soil is Lucas, which is derived from the weathering of plastic, water-laid clays.

*Elevated Flats* (Class IV). The flat lands between Porter Road and State Road No. 49 are in the same drainage category as the lowland soils, although they are elevated flats and have an entirely different origin. No sand is present in this area.

*Sand* (Class I). From Salt Creek west, Plainfield sand is encountered. This is a wind-blown, water-worn sand and represents dune sand more or less stabilized by grass or forest cover. Only one failure was observed in this area and that occurred in a cut approaching Salt Creek at the approximate elevation of the glacial drift.

Results of the performance survey are given in Table III. It is significant to note that pumping was almost entirely confined to the two outside lanes, with the south lane much worse than the north. Inspection indicated that the relation between distressed pavement and distressed berm or widening strip was direct. Further examination indicated that the porous nature of the berm was at least a contributing factor to the condition causing pumping.

Shortly after the survey, heavy truck traffic was detoured over state roads 49 and U. S. 12. Since the rerouting of heavy truck traffic, pumping has stopped; however, some portions were in such a condition that the road is being rebuilt. The survey emphasized the importance of subgrade soil type and drainage as they affect the performance of pavement subjected to large amounts of heavy traffic.

TABLE III  
RESULTS OF PERFORMANCE SURVEY ON U. S. 20

	West Bound	East Bound	Total or Average
Patch, Lin. Ft. ....	351	2700	3051
Patch, Percentage ....	0.57	4.5	2.5
Pumping, Lin. Ft. ....	12800	16800	29600
Pumping, Percentage ....	21 (2 lanes)	28 (2 lanes)	24 (4 lanes)
Number Cracks ....	1401	1487	1444
Crack Interval. .... (Clay Subgrade)	18.1	17.2	17.7
Crack Interval. .... (Sand Subgrade)	14.5	11.8	13.2

**U. S. 30 in Lake and Porter Counties.** The portion of U. S. 30 surveyed includes all the four-lane divided pavement in Lake and Porter Counties extending from U. S. 41 east to the old 18-foot pavement southeast of Valparaiso, a distance of approximately 24 miles. All the pavement sections have been constructed since 1937. The 200-foot right-of-way accommodates two 22-foot slabs which are separated by a 44-foot center strip. The individual 22-foot slabs are of standard 9-7-9-inch sections, reinforced with wire mesh and designed

with expansion and contraction joints. The road follows fairly level to gently rolling topography and crosses the Valparaiso moraine.

This portion of U. S. 30 carries a relatively large amount of traffic, about 20 per cent of which is trucks. The 24-hour annual average traffic on April 1, 1941, ranged from 3,050 vehicles near State Road 2 to 5,550 near State Road 41. Many of the trucks appeared to be heavily loaded. This is especially true of some of the trucks carrying steel from the Chicago area. In addition to the heavy truck traffic, a large portion of the road was used as a test track for 28.5-ton tanks which were assembled in Hammond.

Since a considerable portion of this road was pumping, a performance survey was made last spring (1942) of the entire portion of the divided-lane pavement. Each joint was inspected to determine if there were evidences of pumping, and, if so, rated according to the degree of pumping. This involved the logging of some 6,600 joints covering a distance of 24 miles (an equivalent of 48 miles of two-lane pavement). The joints were classified in three groups, according to the degree of pumping, as slight, moderate, or severe. In addition, a survey was made to determine subgrade soil types. In general, two distinctly different soil types were encountered.

Pumping of the joints was extensive, with approximately 19 miles out of 24 (80%) showing distress. On the portion not pumping, the subgrade was predominately sand. Of the 6,662 joints inspected in the 24 miles, 2,172 (33%) showed evidence of pumping. Various degrees of pumping were found. For example, on the sections which were pumping (silty-clay subgrade) 1,528 joints (28%) were logged as slight, 441 joints (8%) as moderate, and 177 (3%) as severe at the time of survey. Both sides of this divided four-lane pavement were pumping; however, pumping was confined to the outer 11-foot lanes, which carry the major portion of traffic, and was negligible on the inside or passing lane.

It was observed that pumping was more pronounced on those slabs where the joints had not been "poured" for one or more years. Some sections of the road were surveyed before the maintenance crews had poured the joints and cracks with bituminous materials, while others were surveyed afterwards. While the value of pouring joints and cracks on rigid pavements has been a controversial subject for some time, these observations indicated that this maintenance operation is well worthwhile, particularly when pavements are resting on soils susceptible to pumping action.

On one portion of U. S. 30 (Contract R-1474) experimental subgrade sections were constructed in 1937 to eliminate curling of the pavement at the joints. Seven types of treatments were employed, including saturating the subgrade with water, treating with bituminous materials (AES-1, TC, and

MC-1), and replacing with granular materials (sand, limestone screenings, and stabilization). While it is not known how effective these treatments have been in preventing curling of the joints, most of them have been effective in minimizing or eliminating pumping. It is indeed fortunate that these treatments were placed on U. S. 30, since they give a partial answer to the problem of how to prevent pumping on new construction.

No pumping joints were found on either the 6-inch sand backfill or the 3-inch stone stabilization sections, while the joints in the untreated sections both adjacent to and opposite the sections were pumping considerably. The three bituminous materials (tar TC, liquid asphalt MC-1, and emulsified asphalt AES-1) and limestone dust were effective in minimizing the severity of pumping. The water-saturated section was much worse than any of the untreated sections, since 45 (67%) of the 67 joints were pumping.

#### CAUSES OF PUMPING

From these performance surveys it was found that pumping was prevalent during periods of rainfall on heavily traveled pavements supported by silty-clay subgrades. The pumping action of rigid slabs at joints or cracks and along pavement edges is dependent upon three factors, namely: (1) subgrade soil type; (2) free water; and (3) the amount and weight of traffic. Each of the three factors will be discussed.

Our surveys in Indiana show that the *subgrade soil type* where pumping occurs consists of soils containing a predominance of silts and clays. No pumping has been observed where the subgrade soil was sand or gravel. Analysis of mud pumped on the slab showed about equal amounts of silt and clay. More factual information is needed regarding the type of soil susceptible to pumping. The permeability or drainability of the soil is undoubtedly an important characteristic as regards its susceptibility to pumping.

*Free water* must be available for pumping to occur. Therefore, this action is more pronounced during periods of prolonged rainfall such as normally occur during the spring and fall seasons. The source of free water, contributing to pumping, is largely surface infiltration to joints, cracks, and along the edge of the pavement, but may be from water-bearing strata. During the spring "break-up" subgrade soils usually contain enough water for pumping. It has been observed that the amount of water necessary for a joint to start pumping is small, probably in most instances only a gallon or so.

A *large number of heavily loaded vehicles* in combination with a susceptible soil type and free water is the third and most important factor producing pumping. Experience on U. S. 20 in Porter County substantiates this statement. On

a portion of this highway, where pumping was severe, truck traffic was rerouted to another parallel highway. Pumping ceased on this highway but started on the other one where the subgrade soil type was susceptible. Instances have been observed where passenger cars passing over a joint caused a slight pumping and a heavy truck squirted mud four or five feet in the air. While more information is needed concerning the number of heavy vehicles which produce pumping, our data indicate that this may be as low as 500 per day.

### CORRECTIVE MEASURES

Since pumping is a serious problem confronting highway engineers, particularly during the war period, let us consider ways and means of prevention or correction. There is, no doubt, much that can be done to eliminate pumping in the original design and construction of the pavement; but much study and research will be required before a final solution is reached. Our studies to date indicate, however, that careful consideration should be given immediately to such features as joints, load transfer devices, the thickened edge, trench construction, high-level profile, drainage, and, most important, the selection of suitable subgrade materials. This may involve either insulation courses or subgrade treatments. The problem of preventing pumping has not been given sufficient consideration in the past. More factual data are needed concerning the type of soil susceptible to pumping as well as the amount of heavy truck traffic required to cause pumping.

**Pavements in Place.** Many of our highways are now carrying more and heavier traffic than was anticipated at the time of construction, and because of this some of them are pumping at transverse joints and cracks. The correction of this condition is a difficult problem. At least two solutions have been attempted. The first consists of draining the water accumulated under the slab. Various types of drains have been employed, including pipe and French drains. Since each location presents an individual problem, the solution varies. In some locations where porous strata are encountered below the subgrade, the use of vertical drains appears feasible. Perhaps the most commonly employed method of draining pumping joints is French drains. In the past, highway engineers have not been agreed upon the proper size or gradation of aggregate. In some cases large-sized, open-graded aggregate is used, while in other cases dense-graded aggregate is employed. A determination of the best gradation of aggregate for French drains is needed, since it is reported that they soon become clogged. Some investigators claim that French drains are not satisfactory except as temporary preventive measures. Undoubtedly the sealing of joints and cracks



against the infiltration of water to the subgrade would be a preventative measure against pumping.

Another method of treatment consists of forcing a suitable mixture under the slab. This method, called "mud-jacking," has been employed by several states. With this procedure water is forced from under the slab and the void between the pavement and subgrade is filled with a soil-cement or soil-cement-bituminous mixture. Settled or faulted slabs may also be raised to proper elevation by this operation. Holes, sometimes called void-filling holes and lifting holes, are drilled in the pavement. Their location is very important so as to get the maximum amount of void space filled and also to raise the slab without cracking it. Much experimenting has been done on the handling and placing of these mixtures.

Various mixtures of soil, cement, bituminous material, limestone dust, and water have been used. While many combinations of the above materials have been tried by various states, it appears that much more information is needed concerning the design of a satisfactory mud-jacking mixture.

#### DESIGN OF MUD-JACKING MIXTURES

In view of this fact, we have been experimenting with various mud-jacking mixtures both in the field and in the laboratory to determine the most suitable combination. While we do not have the final answer, some of our findings may be of interest. Such a mixture must be of such a consistency that it can be forced into all the voids. It must "set up" readily and be durable under the climatic conditions to which it is exposed. Let us examine the individual constituents comprising the mixture and consider their function and desirable characteristics.

**Soil.** Since soil is usually the largest single ingredient, we will consider it first. The type of soil used in mud-jacking mixtures must of necessity vary with the location in which it is being done. There are, however, certain soil characteristics which should be considered essential for efficient use with the mud-jack. The soil should be of such a composition that it slakes readily in water to form a uniform slurry, and it should be reasonably free of organic material. It should contain no rocks and not too much clay or colloidal material and have a relatively low shrinkage. A soil which we have found to be satisfactory is composed of the following: sand, 46 per cent; silt, 34 per cent; and clay, 20 per cent. This soil has a liquid limit of 29.3 and a plastic limit of 22.2. This sand content may be fairly high; however, it happens to be a fine sand which is slightly larger in grain size than silt. While some sand is desirable to reduce volumetric shrinkage and add stability, too much coarse sand results in a harsh mixture difficult to pump. An excessive amount of clay in the soil

would result in detrimental shrinkage and require more water for proper consistency; however, clay up to about 20 per cent appears to be beneficial in that it forms a smooth-flowing paste preventing the sand from settling too rapidly. Further research is needed to determine the variations in soil characteristics that may be used in mud-jack mixtures.

**Portland Cement.** Portland cement is used in the mixture to accelerate the set, to increase stability, to absorb excess water, and to reduce detrimental shrinkage. Various amounts have been employed by different states, ranging from practically none to five bags per cubic yard. In some cases limestone dust has been substituted for a portion of the cement to reduce the cost. It is claimed that the limestone dust performs a similar function to that of the cement but that its action is much slower.

**Bituminous Materials.** Bituminous materials are added for waterproofing and also to retard the setting of the cement. Various types and grades have been employed, including slow-curing, medium-curing, and rapid-curing liquid asphalts, as well as tars. The slow-curing liquid asphalts have been more commonly employed than the others; but since they are now unobtainable, the tendency appears to be toward the use of medium-curing, cut-back asphalt. The bituminous materials have been employed in quantities varying from 8 to 25 per cent by volume. Ohio reports the use of a 50-50 mixture of SC-2 and powdered asphalt giving satisfactory performance as a mud-jacking material.

The final mixture of soil and cement or soil-bituminous material and cement must have low shrinkage when dried and must flow at a relatively heavy consistency. The proportions of the materials varies with the type of soil and the consistency of the mixture desired. Usually a stiffer mixture may be required for lifting the slab back to proper grade than is required for filling voids.

The manner of incorporating the materials into the mixture has a great deal to do with its performance. Best results have been obtained by first mixing the soil and water to form a slurry. Then the bituminous material is added and mixed to secure thorough distribution, and finally the cement is added, together with additional water if necessary for obtaining proper consistency. The consistency of the mixture is a very important feature for proper handling in the mud-jack.

**Consistency Tests.** Since consistency of the mixture is important for efficient use in the mud-jack, some means of measuring consistency was desired. The first method tried was that of measuring the time required for a definite quantity of the mixture to flow through a funnel. This method did not prove satisfactory, since too sloppy a mixture was required

before any flow was secured through the funnel. The next method tried was the flow table<sup>3</sup>. This method appears to have considerable merit since it can be used in the field for controlling consistency. It is a rapid method capable of measuring consistencies of mud-jacking mixtures within the range in which they can be used in the field. Typical mixtures of varying moisture contents were prepared and tested for consistency. Based upon the weight of other ingredients, the water content in these mixtures varied from 25 to 37½ per cent, while the percentage flow ranged from 25 to 147. (See Fig. 1.) From field experience, mixtures ranging from 80 to 110 per cent flow work best in the mud-jack. The flow table can be used for controlling the consistency of mud-jack mixtures in much the same manner that the slump cone is used to control the consistency of fresh concrete.

Several batches of mud-jack mixtures have been prepared in the laboratory and molded into 2-inch cubes. In preparing these mixtures the soil described previously has been combined with varying amounts of water, bituminous material, and cement. Twenty-four hours after molding the cubes are removed from the molds, stored in a moist room for 7 days, and immersed in water afterward. It is believed that such a curing procedure represents as nearly as possible average field conditions. These cubes are then tested for compressive strength at varying ages up to and including 28 days. At the end of 28 days' curing, cubes from each batch are tested for

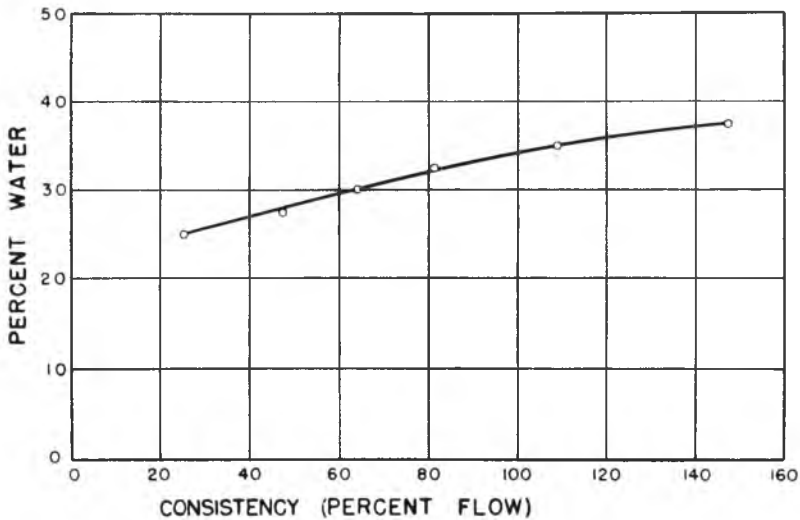


Fig. 1. Effect of water on consistency of mixture.

<sup>3</sup> Flow Test, Masonry Cement, Tent. Spec. for (C91-38T), *Proceedings, A.S.T.M.*, Vol. 33, I, p. 731.

durability. This test consists of 10 alternate cycles of freezing (8 hours) and thawing (16 hours). While all of the series of tests contemplated are not complete, some of the results will be discussed.

The effect of varying the water content is shown by Fig. 2. It will be noted that the compressive strength of the mixture varies considerably with the age and water content. It appears that the strength of the mixture is dependent upon the water-cement ratio. As previously mentioned, the batches containing 32.5 and 35 per cent water are within the range of consistency found to work satisfactorily in the mud-jack.

Fig. 3 shows the effect of varying the percentage of bituminous material, in this case RC-3. It appears that varying amounts of bituminous materials do affect the strength of the mixture; however, not as much as variations in water content. It was found that increases in bitumen content also reduced the consistency somewhat. For example, 3 per cent RC-3 gave a flow of 109 per cent, while 15 per cent reduced the flow to 73 per cent. Despite the slight reduction in strength with increased bitumen content, results of freezing and thawing tests indicated that the higher bitumen contents were desirable from a durability standpoint. While not enough tests have been completed to give definite quantities, it is indicated that

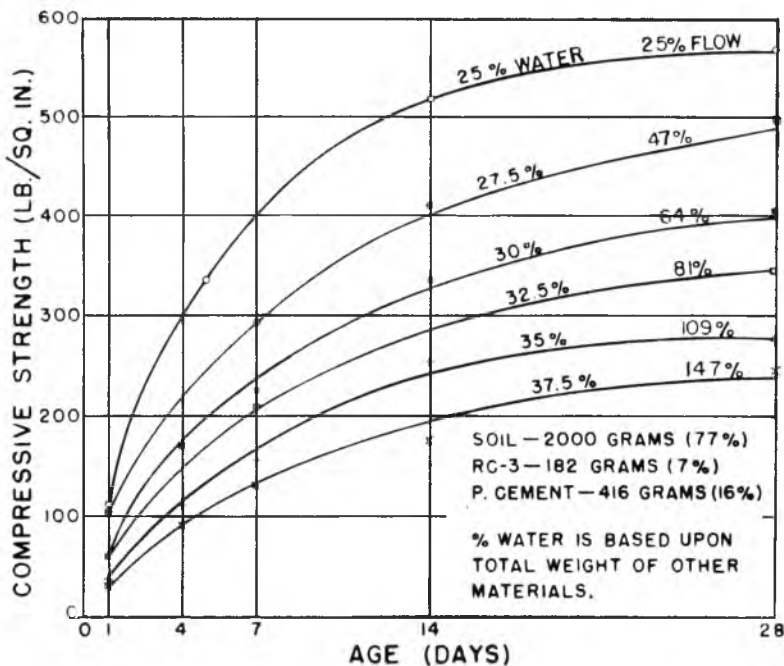


Fig. 2. Effect of varying water content.

with 16 per cent cement the quantity of bituminous material should be as high as 10 or 12 per cent.

In another series, tests were molded with cement contents varying from 11 to 20 per cent. Results of the strength tests on these specimens are shown in Fig. 4. The higher cement contents gave greater strengths at all ages. The consistency of the 20 per cent cement specimens was 81 per cent, while that of the 11 per cent batch was 112 per cent flow. This range of consistency is within that which can be handled by the mud-jack; however, in this series the difference in strength is partially due to the change in water-cement ratio. It is planned to test another series of specimens in which the cement content will be varied, but the water-cement ratio held constant. Durability tests should indicate the range of cement content which can be used for mud-jacking mixtures.

It is planned to extend these tests of mud-jacking mixtures. Various types of bituminous materials will be employed as well as types of soil. It is hoped that the results of these tests will give further information about the combinations of materials that can be used successfully for mud-jacking mixtures.

In conclusion, the more important points stressed in the paper may be summarized as follows:

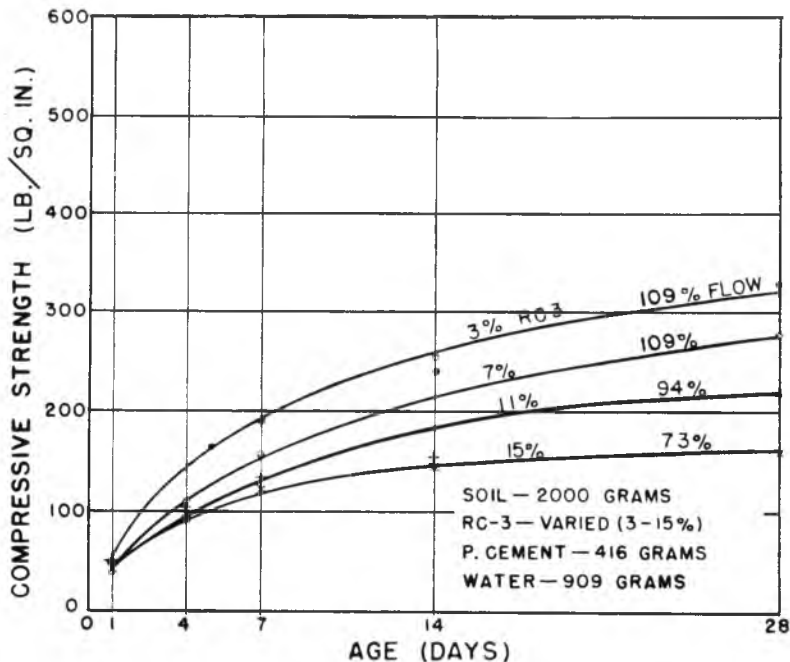


Fig. 3. Effect of varying bitumen content.

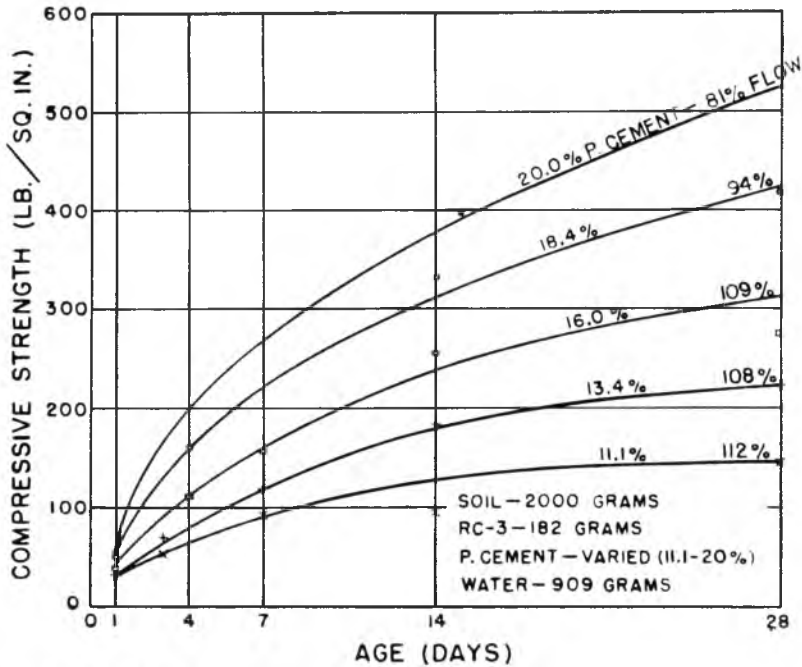


Fig. 4. Effect of varying cement content.

- (1) Pumping of rigid slabs on silty-clay subgrades is extensive on roads which carry a large volume of heavy traffic.
- (2) It is not confined to the older pavements but is prevalent on some pavements constructed during the past five years.
- (3) With increases in heavily loaded vehicles, the problem of pumping may be expected to become more critical.
- (4) There is much that can be done to eliminate pumping in the original design and construction of the pavement. Our studies indicate a careful consideration of such features as joints, load-transfer devices, the thickened edge, trench construction, high-level profile, drainage, and, most important, the selection of subgrade materials.
- (5) Since new construction is at a minimum during the present emergency, the correction of pumping on existing pavements is of immediate concern.
- (6) The type of soil for use in the mud-jack is of primary importance both for ease of manipulation and for correcting the pumping condition.

- (7) Consistency of the mixture is important not only as it affects ease of handling in the mud-jack but also as it affects the performance.
- (8) The flow-table appears to be a satisfactory method for determining consistency of the mixture for field control.
- (9) The water-cement ratio influences the strength of mud-jack mixtures.
- (10) Traffic should be kept off treated joints for at least two days to permit the mud-jack mixture to "set".
- (11) Using durability tests as criteria, it is indicated that relatively high percentages of admixtures may be required. While this may make the mixture fairly expensive, it should be emphasized that the materials involved are a relatively small amount of the total expense and that the most durable mixture would be the cheapest over a period of years.

#### DISCUSSION OF "PUMPING OF RIGID PAVEMENTS UNDER WARTIME TRAFFIC"

R. F. Berns, Engineer of Construction,  
State Highway Commission of Indiana

Mr. Shelburne's excellent paper on "Traffic Pumping of Pavements" deals with a highway problem that has been in existence to some extent as long as we have had pavements. However, it did not develop to a point of extreme concern to the highway official until recent years and did not appear to warrant much excitement until the advent of modern, heavy motor truck transportation. Since the advent of this type of traffic, particularly during the present war emergency when it is not in the public interest to enforce load limits rigidly, this thing called "pumping of pavements" has indeed become a bogeyman to many of us. It was, therefore, timely and fortunate that the Purdue Joint Highway Research Project, an organization that has become one of the nation's leaders in highway research, selected this problem for detailed study.

Mr. Shelburne has indicated to you the three principal factors causing this ravaging action that is taking place at so many places on our street and highway systems. They are, namely, poor subgrade soil, presence of free water, and heavy commercial truck traffic. These same factors are the primary cause of a large percentage of all of our various types of pavement failures.

He has indicated also that our problem is two-fold. First, there is the question of what to do about existing pavements