

Commonwealth of Kentucky
Department of Highways

Discussion and Outline
of

A PROPOSED STUDY OF SOILS
AS RELATED TO THE PUMPING OF RIGID PAVEMENTS

by

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Pumping has been described as, "The process of ejecting the water-suspended subgrade soil from joints, cracks, and the edges of pavement caused by the deflection of the pavement slab under the action of traffic"(4)*. Obviously, the action is limited to rigid or semi-rigid pavements. Hence, the problem is largely concerned with soil and is almost entirely dependent upon properties of the subgrade. During the past five or six years pumping has become the most discussed if not the most important element of highway soils engineering largely because of the increase in heavily loaded vehicles resulting from wartime traffic requirements.

PAST INVESTIGATIONS

Although the matter has been given much consideration in recent years, opinions relative to the specific causes and corrections of pumping are not accordant. There has been general agreement among all engineers to the effect that there are three basic factors necessary to cause pumping. These are: heavy loads, soil properties conducive to the action (principally fine-grained soils), and a supply of free water entering the subgrade from the surface. Aside from these principal points, there is general disagreement as to how fine the soil must be, whether joints promote or retard the action, what types of subgrade treatments or insulation courses prevent slab deflections, whether insulation courses should be extended through the shoulders or limited to the width of the pavement, and other questions of similar nature.

As a result of widespread concern over the situation, the Highway Research Board in 1942 initiated a subcommittee to deal with the specific problem and, in addition, several states conducted field experiments such as those reported from Ohio (1),(6), Missouri (13), New Jersey (11), Indiana (3), (16), and Tennessee (10).

*Refer to references, pages 11 and 12.

From these, several general conclusions were obtained not all of which were compatible. Some of the most significant observations were: that the crack (or joint) interval had a definite relation to slab pumping; that the amount of material ejected from a pumping joint was appreciable (average amount of mud-jack material required to fill cavities beneath joints on one project was 8.7 cu. ft.); that granular subgrades were effective in preventing pumping; that compaction with control of water content was of considerable value; that soils having more than 55 percent retained on the No. 270 sieve did not pump in locations where drainage was reasonable (in Tennessee); and that some stabilized soil subgrades having no more than three inches depth moderated the action despite excessive volumes and weights of traffic (16).

PREVENTIVE AND REMEDIAL MEASURES

Methods of coping with the problem may be divided into the three general categories of maintenance, design, and soil research. The first of these consists of procedures for correcting the action once it has started; by realigning the slabs and filling the void spaces with an appropriate material or, by the installation of drains in an attempt to secure a rapid flow of water from the openings in the pavement.

Maintenance

Realignment of slabs has been done by mud-jack using a slurry of soil with a cement and bituminous admixture or more recently by a bituminous jack whereby low penetration asphalts were pumped beneath the pavement at high temperatures and relatively high pressures. Still more recently, a mechanical method of raising the slabs has been tried (4) in order to insure good distribution of the bituminous material beneath the pavement and to reduce the pressures that were formerly required in the bituminous jack. Drainage methods generally consisted of laterals along the edges of the pavement or French drains through the shoulders supplemented by the rigid maintenance on the shoulders and ditches to secure the best run-off possible. Prompt and careful sealing of joints and cracks has been regarded universally as good practice, and in one instance (13) large scale use of a "substantial bituminous surface or upper deck not less than one inch in thickness" was recommended where pavements were cracked extensively*.

Design

In the category of design, emphasis has been placed on the role of joints as a means of providing accessibility of water to the subgrade. The trend in thought has been toward the elimination of expansion joints, at least from the standpoint of this problem. However, there are some who recommend heavy load-transfer devices (11) and the retention of expansion joints properly maintained. Other design procedures have been directed toward subgrade insulation courses principally of granular material, the doubtful feature being one of suitable depth and grading for the material.

*"The degree of failure necessary to require upper-decking can best be described as that condition where the slab pumping has progressed to such a point that the riding surface of the pavement has been definitely impaired" - Whitton (13).

From one point of view an open gradation is desirable since it promotes drainage downward and laterally, and in addition the base contains no particles small enough to be susceptible to pumping. On the other hand, these coarse materials may be forced into the underlying soil by pressure from above; if so, the soil will fill voids in the insulation course and result in subsidence beneath the slab. Should this continue to a point where fine soil particles from below reach the upper level of the granular base a situation conducive to pumping would be created. The minimum of damage in such a case would be a badly faulted* joint.

Engineers in New Jersey, by using nine inches of 2-1/2 inch crushed stone beneath a rigid pavement (11, p. 92) as early as 1932, found that the pavement did settle under heavy loads. Observations showed that the crushed stone had been pressed into the clayey subgrade, and subsequent laboratory experiments corroborated these observations. Other laboratory experiments with sand as the insulation course showed no clay particles mixed in the voids of the sand.

If the point of view is reversed and close-graded or compact bases are analyzed critically some good as well as detrimental features are apparent. Such a material can be compacted without a great amount of difficulty so that possibilities of further compaction under load are reduced. Fine material from the underlying soil could hardly enter the base course or reach the surface. However, fines in the well-graded base could be pumped out if movement of the slab could be started. Also, the close-graded material is not as free draining as the open-graded aggregate.

The final factor in insulation or base course design is the section to be used. Those who advocate an insulation course extended through the shoulders claim an advantage in drainage which offsets construction difficulties and difficulties in maintaining turf on the shoulders. Others who prefer a trench section or one in which the insulation is limited to the width of the pavement (or extended slightly beyond) are interested in simplified construction procedures and costs of base material. The principal point in question is the possibility of trapping water beneath the pavement even if outlets through the shoulders are provided by French drains or similar installations at certain intervals.

Continuously reinforced pavements without joints, recently proposed and now being tried in some states, may have merit as a protection against pumping. Besides having no intentional openings in the surface, this type of pavement would possess structural qualities that should resist localized and differential deflections necessary to start the action. Regardless of subgrade weaknesses, such a slab, if it remained intact, could pump only at the edges and then to a limited extent because of the rigidity of the steel.

This situation to some extent would be comparable with a concrete mat foundation "floated" on a weak soil, the combination having strength by virtue

*Faulting, as opposed to pumping, may be described as misalignment of adjacent slabs due to settlement in the subgrade without removal of subgrade-soil onto the road surface.

of the slabs ability to receive large concentrated loads and transmit them to the underlying soil as low, uniform pressures. Thus, as in the case of a floating foundation, "the obvious advantage -- is that if uneven settlement occurs, which is rendered less probable by this type of foundation, serious injury to the structure does not result." In this instance the pavement would be both structure and foundation, and, of course, the analogy would be valid only so long as the slab remained essentially unbroken.

At the other extreme, one of the oldest means of highway construction - traffic bound materials - should not be excluded from considerations relative to pumping. Since prevention of initial deflections is one of the main items of concern, a traffic bound base is theoretically outstanding as a foundation material thoroughly acclimated to the conditions under which it must exist after the concrete pavement has been built. Probably exposure would be more severe before the surface was built than after, and of course, rigorous maintenance would be required during this preliminary period. Without strict maintenance including almost daily care, the purpose would be defeated. Densities obtained by compaction under traffic exceed those obtained by rolling with any method. If large quantities of material are required in final shaping of the base, or if the traffic bound material is disturbed in grading, then the advantage of natural compaction is largely vitiated.

Research

Research on soils as related to the problem of pumping has been somewhat varied with most of the effort being concentrated on performance surveys, field experimental projects, and the development of tests such as the so-called California bearing method for determining the type and amount of insulation practicable in given situations. Also, the principles of soil origin as well as compilations of data on soil properties have been used advantageously to locate probable sources of trouble on proposed construction sites. However, information of this nature has been reported only to a limited extent, the most comprehensive group of data being that compiled by the Highway Research Board and recently circulated to its subcommittee members but not yet formally published.

According to this set of results (obtained through inquiries made to several highway departments) and a map prepared therefrom, the soil groups that have produced the greatest amount of pumping situations are about as follows:

1. Residual soils derived from limestones, limestones and shales, and shales. These are predominantly fine-grained, plastic and cohesive soils often located in situations where groundwater tables are high. Outstanding locations reported - Appalachian valleys of northern Alabama and Georgia; Highland Rim of Tennessee, and Ozark plateaus in Missouri.
2. Residual soils derived from igneous and metamorphic rocks. Outstanding locations reported - Piedmont sections of Alabama, Georgia and the Carolinas.
3. Glacial soils; including old drift weathered to great depths, and young drift. Outstanding locations reported - all sections in old drift in Missouri and Iowa and limited areas in Indiana. Principally shallow cuts in young drift of northern Indiana and Ohio.

In addition, soils of four other groups were found - either through the survey or through information obtained in other ways - to be susceptible to pumping. These groups are:

4. Loessial soils or windblown materials having more than fifty percent of grains in silt size. Outstanding locations reported - western Tennessee; otherwise found to be free from pumping. Note: There is a possibility that this material was not recognized in other states of the Mississippi and Missouri River valleys.
5. Lacustrine soils found in the beds of extinct lakes. These are almost invariably silts or clays, the ground is level, and the water tables are high. Outstanding locations reported - northern Ohio, Indiana and Iowa.
6. Alluvial soils. These were generally ignored because they are limited to stream valleys. Known pumping locations (many not reported) from Louisiana northward to Illinois as well as other widely scattered locations.
7. Soils of the coastal plain. Clays and sand-clays in states bordering the Gulf of Mexico and in New Jersey are known to pump.

It is evident that by these generalizations about the only materials excluded from the "pumping" category are granular soils. Such was not the intention of the survey nor the situation in the field, however, for probably there are within these major groups just a few types of subgroups of soil which do pump. At the most, only a fraction of the total mileage of pavement located in any soil region is pumping regardless of variations in soil groups.

These observations are not intended to be critical of the method of soil classification nor to detract from the survey. On the contrary, the classification is a logical approach but to be effective it must be done in greater detail.

CONDITIONS IN KENTUCKY

Only groups 1, 4 and 6 are represented extensively in the state of Kentucky yet soils of these descriptions cover much more than one-half of the area of the state and those of group 1 are predominant. Even on the basis of generalizations then, it is apparent that the potential for pumping pavements in Kentucky is high. A considerable portion of the potential has actually become effective according to the most recent data available.

Results of the observations made during the 1945-46 survey by the Division of Design showed pumping in sections of pavement totalling about 81 miles in length (about 7 percent of total mileage of concrete pavements in the state) although of course, only certain portions of those sections are pumping. On the other hand, pumping was only a minor factor hardly within the scope of the survey so the results were not intended to show all the pavement affected. Table I is a summary of these field observations pertinent to

TABLE I - TABULATION OF PUMPING PAVEMENTS IN KENTUCKY AS DETERMINED BY RECENT SURVEY OF CONCRETE PAVEMENT PERFORMANCE

Highway Number	Road	Description	Length Miles	Year Constructed	Joints	Section	Traffic Count (trucks)	Soil Description	Soil Group (Origin)
US 42	Florence - Warsaw	From: Jct. US 25 To: Union	5.374	1929	None	9-6-9	300-784	yellow clay	Glacial Till & Residuum
		From: 0.5 mi north Beaver Lick To: Union	4.518	1929	None	9-6-9	320-812	red clay	Interbedded
		From: Gallatin Co. Line To: 0.5 mi north Beaver Lick	5.523	1930	None	9-6.5-9	360-616	yellow clay	Shales & Limestones
		From: E.C.L. Warsaw To: Boone Co. Line	9.581	1930	None	9-6.5-9	250-342	yellow clay	
US 60	Louisville - Shelbyville	From: West end Middletown To: 200' East of Shelby Co. Line	7.926	1934	Exp. 90 Cont. 30	9-6.5-9	560-640	yellow clay	Shallow Limestone Residuum
		From: W.C.L. Shelbyville To: Near Jefferson Co. Line	9.644	1938	Exp. 90 Cont. 30	9-6.5-9	1000	A-7-6 A-7-4	Limestone Residuum
	Shelbyville - Frankfort	From: E.C.L. Shelbyville To: Near Franklin Co. Line	11.718	1942	Exp. 120 Cont. 60	9-7-9	644	A-7 A-7-4	Limestone Residuum
		From: 2nd St. in Frankfort To: Near Shelby Co. Line	7.830	1941	Exp. 120 Cont. 60	9-7-9	600	A-7-4 A-7-6	Residuum from Interbedded Shales & Limestones
US 25	Mt. Vernon - London	From: Courthouse in Mt. Vernon To: Toward London	6.259	1942	Exp. 120 Cont. 60	9-7-9	560	A-4 A-6-7	Limestone Residuum
		From: Rockcastle - Laurel Co. Line To: 1/2 mi north of Victory	5.250	1925	None	9-8-9	350-616	Sandy clay	Sandstone Residuum
US 31W	Elizabethtown - Munfordville	From: C.L. Elizabethtown To: 1/2 mi north of Nolin River	7.264	1942	Exp. 120 Cont. 60	9-8-9	535	A-6	Limestone Residuum

Total Miles Pumping = 80.887

pumping. The soils involved were predominantly of three types within group 1 as outlined above and only one - sandy clay or sandstone residuum - was not within the seven groups set forth as outstanding producers of pumping pavement.

Where results of soil tests were available the data agreed with conclusions from the Tennessee survey. There it was noted that "pumping was found in the A-7, A-6, A-5-7, and A-4 (PRA) soil groups. It was also found in the A-2-4 and A-2-6 borderline groups having near the minimum sand content in the soil mortar for those soils.

"No pumping was encountered in soils of the A-2 and A-3 groups nor on any of the borderline A-2-4 and A-2-7 groups containing near maximum sand and gravel content for those groups."

Although there is a possibility that pumping will become more wide spread and more intense under conditions that may be anticipated in the future, the volume and weight of truck traffic that prevailed during the war may not be exceeded to a great degree. If that is so, the mileage of pumping pavements now in service should not increase materially; accordingly, the maintenance phase of the problem should remain secondary to design and soil research. Research in turn should be directed toward information usable in design.

PROPOSED RESEARCH

Such is the research proposed for this project with the objectives being a critical comparison of soils from pumping and non-pumping locations, explicit determination of the range of soil properties within which pumping is likely to occur, and a study of subgrade treatments practicable for locations where soils are found to be subject to pumping. The last of these three includes the location of sources for borrow, subgrade stabilization, relative costs, and methods for ascertaining the amount of depth of treatment necessary to insure stable subgrade conditions.

Soil Properties Involved

Before a study of materials so variable as soils is undertaken, it is well to analyze properties of the material which have a bearing on the problem and also the actions developed in the different stages of progress for either pumping or faulting. First there must be some amount of subsidence in the base in order to permit even a slight deflection of the slab. This may occur in either granular or fine-grained materials depending upon their original condition, and the loads placed upon them. Original deflection, then, may be termed the initial stage.

Once a void space has been created beneath the crack or joint, there is a possibility that pumping will develop provided free water becomes available and the soil particles are fine enough or so light in weight that they may be eroded from the base and transported to the road surface by agitation of water in the void. The limit to which this action may progress is dependent upon the amount of soil that can be washed away and the amount of deflection permitted by the structural qualities of the slab. If the void space becomes great enough and the slab is stressed to the point where it will no longer

support the loads placed upon it, it will crack - usually about eight to ten feet from the joint - and the broken portion will act almost as a free body to permit greater pumping action. This may be called the intermediate stage. Ultimately, the pounding of traffic will result in disintegration of the broken portion of the slab, a condition that is conveniently described as the ultimate or final stage.

Methods of coping with the problem in its various stages can be separated so that research and design would be directed toward the initial stage in order to eliminate conditions by which pumping could start (protective maintenance is a minor factor in this stage because sealing of joints and cracks and shoulder maintenance is beneficial).

The intermediate stage can be combatted only through protective maintenance designed to protect the slabs from permanent damage. After the action has progressed to the final stage, corrective maintenance consisting of extensive repairs - i.e. bituminous surfacing, removal of broken slabs replaced by new concrete, etc. - is the only recourse.

The soil properties relative to the various stages of pumping and the soil tests that may be applied in determining these properties are summarized in Table II. Naturally, the properties and tests cannot be segregated strictly in accordance with different phases of the action. Nevertheless, they can be considered as fundamental to some stages and only incidental to others.

Initial Stage - As pointed out above, the subgrade must be compressed in order to permit deflection of the slabs. Consequently, the compressibility of the soils determined by consolidation tests as well as the bearing value determined by some loading tests are pertinent to the resistance of the soil to loads placed upon it. If the bearing value of the soil is great enough and subgrade deflection under load is insignificant then no void can be created and pumping cannot start.

On the other hand, it is possible for deflection to occur not accompanied by pumping if water does not enter the subgrade or if the soil is so permeable that free water does not remain. Some soils are permeable because of their granular composition and others at least semi-permeable because of their structure despite a large amount of fine particles. Soils of the latter class are mainly those of windblown origin or those derived from limestones. This feature is dependent upon their condition in place as to whether they have the structure given them by nature or whether they have been recompacted. Hence, observations of structural characteristics and tests for compaction are significant in the determination of probable resistance or lack of resistance to initial compression.

Many fine-grained soils are expansive in nature. It is conceivable, then, that such materials upon receiving free water would expand a small amount or upon drying shrink to such an extent that a small void would be created regardless of the amount of load placed upon the pavement. Thus, shrinkage tests and tests for chemical and mineralogical constituents of the clay are relevant since some clay minerals are more susceptible to shrinkage and expansion than are others.

TABLE II - Pavement-Subgrade Actions and Soil Properties and Tests Involved in the Three Stages of Pumping

<u>Stage</u>	<u>Action</u>	<u>Soil Property</u>	<u>Tests</u>
Initial	Deflection of Pavement (Subsidence of subgrade)	Compressibility	Consolidation;
		(volume change under load)	strength or load resistance (bearing value)
		Structure	Observation
		Compaction	Compaction for moisture-density relations
Intermediate	Movement of slabs & Erosion of Subgrade	Volume change (independent of load)	Expansion and shrinkage; mineralogical and chemical
		Erodability	Grain-size distribution, plasticity cohesion
Final	Breaking of slabs & Disintegration of concrete	Permeability	Permeability
		Same as intermediate stage	Same as intermediate stage

Intermediate Stage - When a cavity has formed beneath a joint and the slabs are free to deflect under load, then characteristics of the subgrade alone determine whether pumping will progress (assuming a supply of free water and heavy loads). If the soil particles are to be removed to the surface, the soil as a mass must be erodible. This quality could be evaluated in a general way by tests for grain-size distribution supplemented by tests for plasticity and cohesion. This is so since the particle size would determine the ability of water under pressure to move the material and in turn plasticity and cohesion are somewhat dependent upon the fineness of the soil.

Similarly, tests for permeability would be pertinent to this stage because a soil which did not retain water for an appreciable length of time could hardly be eroded by pumping action. The limits on permeability values that would separate the erodible from non-erodible materials in a given situation are completely indefinite at present. For that reason, reliable tests for the rate of percolation would be of great importance in the analysis.

Final Stage - Actually soil analyses are of little value after pumping has progressed to the point where the concrete surface has disintegrated. Nevertheless, the action at this stage is made possible only by the removal of so much soil from the subgrade that support for the slabs is almost completely lacking. The soil tests applicable to the intermediate stage then are at least related to the final stage. Probably the greatest value to be received from soil investigation at this point would be through a determination of a subgrade treatment where portions of the surface were to be replaced.

Procedures

The methods proposed for this investigation are equally applicable to the field and laboratory. Not only will the field work consist of locating materials representative of pumping and non-pumping situations but also some field tests are desirable such as bearing tests on soils and base courses immediately beneath the pavements.

In general, the procedures will consist of:

- (1) Sampling soils of widely varying characteristics and subjecting them to the tests outlined in Table II, the objective being to determine why soils having certain properties pump while others of a similar nature do not.
- (2) Study subgrade treatments in the field and in the laboratory through bearing tests and other means thought to be pertinent in order to determine desirable types and depths of treatments for given localities and soil groups. This will include laboratory investigations for strength, durability and similar properties for some types of stabilization that have not been thoroughly investigated heretofore.
- (3) Analyze completely a proposed right-of-way relocation for one or more projects in an area where soils are known to be susceptible to pumping. The end point in this case would be a group of recommendations for construction materials and procedures which are found to give best protection against pumping.

Equipment

The soils section of the Research Laboratory is in the process of being equipped for a large variety of tests both routine and investigational. Aside from minor apparatus, several major pieces of equipment must be obtained or built. These include a testing machine (now on order), the construction of devices for consolidation and permeability tests, and also means for performing field bearing tests beneath existing pavements. The last of these can probably be combined with equipment which has been developed for coring and testing bituminous pavements in the field.

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