CORRECTION OF PAVEMENT PUMPING BY MUDJACKING, UNDERSEALING, CONCRETE REPLACEMENT, CRACK SEALING AND SUBSEQUENT RESURFACING[1]

LEON W. CORDER, *Senior Maintenance Engineer, Missouri State Highway Department*

SYNOPSIS

In an effort to prevent the destruction of concrete highways by causes directly traceable to the pumping action of concrete slabs, field maintenancemen and engineers have waged a long and at times heart breaking battle. From early days, when the only known safeguard was a traffic "slow order," down to the present time, when numerous preventive and corrective processes are correlated to produce a controlling result, the conflict has been continuous. This every day difficulty has, in fact, been the major factor affecting pavement life expectancy.

First of the corrective processes developed was pavement patching, which included the removal and replacement of broken concrete. Next came mudjacking, the now well known method of pumping a soil cement slurry under the pavement to provide support. Following these two corrective processes came crack sealing, whereby surface cracks of the broken pavement were poured with an asphaltic compound to prevent the entrance of surface water. Asphaltic undersealing, which followed the general mechanics of mudjacking, but which made use of a heavy penetration asphalt for pumping under the pavement, was the next great development. In so far as this process provided both support and sealing action it was not only corrective, but also preventive. All of these, plus pavement resurfacing with bituminous surface courses, now provide the means by which the longevity of serviceable concrete pavement may be increased.

Any history of the ever continuing battle of man against the elements certainly should include a chapter on the long effort to control slab pumping. So dependent is this country on hard surfaced roads for transport, that if methods had not been perfected to prolong the serviceability of our concrete pavements at reasonable expense, certain phases of the nation's economy might have been affected. Slab pumping appears to be the most basic cause of pavement failure; therefore, its prevention and partial correction surely are technical achievements of the first rank.

Probably there has been no phase of highway maintenance so lacking in dramatic appeal as this sloppy, dirty, only partially evident work of pumping-slab correction and prevention. Very little of the results show on the surface. If the roadway is smooth, usually no thought is given by the casual traveler to the subgrade support, which has been so carefully placed. In spite of the fact that these processes have had a great deal to do with the stretching of the taxpayer's dollar, so far no adequate way has been devised to show him just how it was done.

"Slab Pumping" of portland cement concrete pavements is being satisfactorily controlled on the Missouri highway system by the cumulative results obtained from mudjacking, undersealing, concrete replacement, bituminous upper decking, crack pouring and proper shoulder and drainage maintenance. An adequate definition, provided by the Committee on Maintenance of Concrete Pavements as Related to the Pumping Action of Slabs of the Highway Research Board, describes "slab pumping" as the ejection of water, carrying soil particles in suspension, through cracks or

[1] Prepared by Leon W. Corder, Senior Engineer; G. B. Major, Division Maintenance Engineer; J. L. Maynard, Division Maintenance Engineer; P. G. Parrish, Division Maintenance Engineer; O. I. Steele, Assistant Maintenance Engineer; Rex M. Whitton, Engineer of Maintenance; and George Wolf, Division Maintenance Engineer, Missouri State Highway Department

joints in the pavement, or along the edges of the pavement, caused by the movement of the slabs under heavy axle loads.

So dependent is this country on hard surfaced roads for transport, that if methods had not been developed to prolong the serviceability of our concrete pavements at reasonable expense, certain phases of the nation's economy might have been affected. Slab pumping appears to be the most basic cause of pavement failure; therefore, its prevention and partial correction surely are technical achievements of the first rank.

Slab pumping, like many other concealed factors affecting pavement life, has not always been easy to diagnose in its initial stages. Some of the early indications or results of this physical action in Missouri were, in fact, noticed long before it was realized that their ultimate result would be the failure of the pavement. As early as 1933, and possibly as early as 1931, the ejection of water through cracks or joints in the pavement under heavy axle loads was noted. This was particularly apparent during and immediately following periods of rainfall, and resulted in a muddy film on the roadway surface. The only known objection to this condition at the time was the skidding hazard it presented to traffic, and the unpleasing appearance of the mud on the pavement.

Slab pumping developed in intensity and spread geographically in direct proportion to the increase of heavily loaded vehicles on the highway. Even before it was realized that certain types of pavement failure, such as small corner breaks along the centerline and additional transverse cracks, were the direct result of slab pumping, it became necessary to repair these pavement failures with full depth concrete or surface bituminous patches.

By the fall of 1932, a section of pavement on U S 40 had broken up so badly that it was found advisable to upperdeck some portions to restore the riding surface. At the time the cause of the failure was attributed to thin pavement and bad aggregate, but now it is thought that the primary cause was slab pumping. This resurfacing work was experimental in purpose, and consisted of both bituminous and concrete decking. No attempt was made to stabilize the rocking slabs before placing the upperdecking, and as a result the bituminous section was soon a complete failure. After a short period of service, it had to be entirely removed from the old pavement.

It is thought now that by 1937, slab pumping had become prevalent in several State Highway Department divisions. This was especially true on Routes 40 and 66, both of which carried large volumes of traffic with heavy axle loads. With the spread of this condition geographically, the knowledge gradually developed that slab pumping was causing voids under the pavement, and that this condition was resulting in pavement failure. It became fairly well established that the removal of soil from beneath the pavement was caused not only by the flow of water along the subgrade, but also by the vertical ejection of soil bearing water through the cracks and joints in the pavement. Both of these actions were the direct result of pavement deflection under heavy axle loads. Since pavement failure as a result of slab pumping was occurring simultaneously in several highway department divisions, it was natural that individual thinking and initiative would develop different methods of attempting to control the difficulty, and different theories about the best ways to repair the resulting pavement failures.

It was recognized at an early date that the presence of water under pavement was one of the basic contributing factors to slab pumping, and due to the fact that it was possibly the factor most readily controlled by the maintenanceman, probably the first efforts to prevent pumping made use of various types of drains, consisting of rock drains, farm tile, perforated corrugated pipe, and a special metal arch type with cover. One of the early attempts at drainage provided a trench along the pavement edge, excavated to a depth slightly below the bottom of the pavement, and backfilled with crushed stone or gravel; laterals being provided at intervals leading through the shoulder. Tile and pipe were employed in approximately the same manner. Since the pumping was confined almost entirely to cracks and joints, drainage work was in some instances concentrated at these points. A method of boring through the subgrade under the crack or joint was developed and in this hole a special metal arch type drain, which extended laterally through the shoulder to the side ditch, was inserted. All of these drainage methods gave some temporary relief, but in

a short time they usually became clogged, so it was soon determined that slab pumping could not be controlled in this manner.

In 1937, one of the highway divisions used a mudjack to pump a semi-stiff mixture of water, cement and soil under some pumping slabs to fill the voids, force out the free water, stabilize the subgrade, and reduce the pumping. This mudjack method of controlling pumping slabs was continued during the following three or four years in this and other divisions of the Department with moderate success. It was found that a rather large percentage of the cracks and joints that had been mudjacked would resume pumping, but the mudjacking did provide a degree of control that was better than any other method so far developed. However, throughout all of this early period of effort to control slab pumping, it was considered necessary to replace the completely failed areas with full depth patches of portland cement concrete, because of the impossibility of stabilizing pavement broken in small pieces with a mudjack.

Due to the enormous increase in number and frequency of vehicles with maximum loaded axles in the early 1940's, the damage to concrete pavement by slab pumping became widespread and extremely critical. There was one section of pavement on Route 66 where a 24-hr. watch was maintained in order to prevent traffic accidents. Such occurrences forced the realization that methods for controlling slab pumping in use up to that time were inadequate to cope with the conditions created by the enormous increase in heavy traffic.

In 1940 and 1941, bituminous decks were again brought into use in a further attempt to cope with the slab pumping problem. It was thought that these bituminous decks or mats would not only strengthen and smooth the pavement affected by pumping slabs, but would also have a tendency to water-proof the surface and prevent the entrance of more water into the subgrade. Pavement condition showed definite initial improvement after the placing of bituminous decks, but it was soon found impossible to keep the cracks in the deck surface sealed. The voids, which had developed under the pavement cracks and joints, were so large that deflection and rocking of the slabs under traffic opened the joints faster than they could be filled. This proved to be more than the decks could stand, and quickly resulted in a recurrence of slab pumping, with evidence of squirting through the cracks in the bituminous decks.

The failure of bituminous decks alone to control pumping led to the use in combination of mudjacking, full depth concrete replacement, and bituminous decking. When this correlated system was started a marked improvement in the control of pumping slabs was noted. Even with this overall process, however, a small percentage of joints or cracks would frequently resume pumping, and would require additional mudjack work or bituminous patching, or both.

The investigations of a committee of the Maintenance Department of the Highway Research Board, appointed in 1942 for the purpose of making a study of the proper maintenance methods for preventing and correcting the pumping of concrete pavement slabs, brought out a great amount of information and experience from many State highway departments. At one of the first meetings of the committee, information was given concerning the experience of the Ohio State Highway Department with the use of a low penetration asphalt, which was pumped under the pavement affected as a method of filling the voids and undersealing the pavement in one operation.

In the fall of 1944, after studying the experience of Ohio and other States, a limited amount of asphalt undersealing was started in Missouri in the hope that pumping slabs might be controlled. Continued and increased use of asphalt underseal, sometimes in conjunction with mudjacking, full depth concrete replacement, and subsequent bituminuous surfacing, has resulted in the control of slab pumping to a very satisfactory degree. Of course, crack pouring, and adequate shoulder and surfaace drainage maintenance must be added to the foregoing operations. As a result of at least 15 years experience in Missouri, therefore, the present established methods of controlling slab pumping in concrete pavements are mudjacking, undersealing, full depth concrete replacement, bituminous resurfacing, crack pouring, and adequate shoulder and drainage maintenance.

Under this procedure, mudjacking is the first process used in connection with the controlling of pumping slabs where voids under the pavement are known or suspected to be

large. This is because the mudjack operation has been found to be cheaper per cubic yard of material in place under the slab than asphalt underseal.

The first step in mudjacking, after determining that such work should be done, is the location of the holes through which the slurry is to be pumped. They should be located by one who has a thorough knowledge of the problem. It is the present practice in Missouri to drill these holes in the pavement 10 to 12 in. from the longitudinal center joint, and 10 to 12 in. beyond the transverse crack or joint, in the direction of traffiic. Sometimes it is advisable to drill holes in each of the corners near the centerline, so that the greatest amount of slurry can be pumped under the pavement. Also, it has often been found necessary to drill holes along the outside edge of the pavement to obtain adequate coverage. When this is done the holes should be drilled approximately 30 in. from the edge of the pavement, and 30 in. beyone the transverse crack or joint, in direction of traffic. The holes, which are usually 1½ in. in diameter, are usually drilled by one man using an air compressor and a jackhammer. One man can ordinarily drill as many as 400 holes per day, depending upon the thickness and condition of the pavement, the number of necessary holes per mile, and the type of coarse aggregate in the concrete. The number of holes necessary per mile will range from 200 to 400, and the cost per hole for drilling has averaged from 7 to 10 cents.

The mudjacking is performed by an eight-man crew, consisting of a foreman, mudjack operator, a skilled nozzle man, a laborer to shovel the soil and cement from a truck to the pug mill of the mudjack, a truck driver who operates the two trucks (one truck being filled at the pit while the other is being emptied at the mudjack), a laborer who plugs the holes and cleans the surface of the pavement after jacking, a laborer at the soil pit, and a flagman.

The most suitable mix so far developed in Missouri is a slurry of the consistency of whipping cream, composed of top loam soil (preferable), cement and water. The proportion of the ingredients, four sacks of cement to the cubic yard of soil mixed with 50 to 55 percent water by volume, was developed after considerable research and experimentation. It is still apparent, however, that additional research is desirable on the composition of this slurry.

The pumping of the mix under the pavement is continued until all the voids have been filled that can be reached through the one particular hole that is being pumped. The ability of the nozzle operator to determine this condition is the result of training, experience, and careful attention to the work. When sufficient slurry has been pumped through a hole, the hole is temporarily stopped with a tapered wooden plug, and later plugged with a dry mix of soil and cement. Enough moisture seeps through from below to provide the necessary dampness and set this final plug.

The amount of soil cement slurry pumped under the pavement varies, of course, according to the condition of the pavement, but will average as high as 28 to 30 cu. yd. per mile. The cost will average approximately $9.00 per cu. yd., exclusive of hole drilling, under present conditions. This expense which amounts to approximately seven cents per hole, must be added to the above cost to obtain the total cost of mudjacking slurry in place.

With the evaporation, or draining off of the water from the slurry during the setting-up process, and due to the action of the slab under traffic before the mixture has taken its initial set, thin voids are again created under the pavement. This condition leads to the second operation in the process of controlling pumping slabs. Before the development of asphalt underseal, it was necessary to repeat the mudjack operation at varying intervals, but the use of undersealing has to date given very satisfactory and lasting results when used to supplement the initial mudjack operation in the filling of these smaller voids.

When slab pumping has been allowed to continue until large voids have developed under the pavement and the mudjack slurry method has been used to fill these voids, it is advisable to allow some three weeks to elapse before starting the asphalt underseal operation. This allows enough time for the setting of the slurry mix and the formation of the resulting smaller voids following this process. It is now considered to be far better policy to use asphalt underseal for this follow-up work. Following this line of thought further, it might also be said that for new pavements, or pavements in the early stages of

slab pumping, where mudjacking, full depth concrete replacement or bituminous resurfacing are not as yet required, it has been definitely established in Missouri that asphalt undersealing alone will control the problem in a very effectual manner.

Asphalt undersealing is accomplished by pumping an asphalt heated to a temperature of 425 to 450 deg. F. under the pavement through holes spaced and drilled in the same manner as for mudjacking. Generally speaking, the asphalt underseal has 30–45 penetration at 77 deg. F., and a softening point ranging from 167 to 185 deg. F. More specifically, the asphalt used meets the specification for oil-asphalt filler, AASHO Designation M-18-42A.

As stated earlier, the first information obtained in Missouri on the use of asphalt underseal for concrete pavement was furnished by personnel of the Ohio State Highway Department. Shortly thereafter, however, additional details of field operations were obtained through observations of working methods used by the Texas Highway Department. Since this process was first started in Missouri, the quantity of material pumped under the pavement has increased steadily. This can best be illustrated by quoting the quantities of asphalt pumped during each year. In 1944, only about 15,000 gal. were used due to a start late in the year. In the following years, 72,500 gal. were pumped in 1945, 207,500 gal. in 1946, 450,000 gal. in 1947, and in 1948, up to November 15, 471,250 gal. have been pumped. The total to date, therefore, adds up to approximately 1,216,250 gal. of asphalt underseal that has been placed under concrete pavements in Missouri.

The extremely high temperatures to which this asphalt must be heated in order to produce the desired results, makes undersealing a potentially hazardous operation, and great care must be taken to adequately safeguard the men. However, over a million gallons of hot asphalt have been pumped under concrete pavements, and the number of men burned or otherwise injured in connection with undersealing operations, has not exceeded the number injured while engaged in other types of comparable on-the-road maintenance work. This statement should not be construed to mean that the undersealing operation is not potentially dangerous, but it does mean that if proper precautions are taken, accidents to the workers can be held to a minimum.

When asphalt undersealing was first started in Missouri, the asphalt was received by rail, in 100-lb. paper bags. It was heated in stationary tanks, transferred to and pumped under the pavement by truck type or trailer type bituminous distributors. The removal of the paper covering from the asphalt before heating proved to be a costly and tedious operation, and so the following year, underseal asphalt was secured in cardboard cartons. The removal of this cardboard packaging material was somewhat easier and accordingly cheaper, but it was still a slow and costly procedure. In order to speed up the work and reduce the cost still further, a large proportion of the asphalt has recently been received in tank cars or tank trucks. This method of shipment eliminates the removal of the paper or cardboard covering, the manual handling, and the heating in specially designed units. With shipments by tank car or tank truck, the asphalt can be heated by standard asphalt heaters. When obtained hot at the refinery in tank trucks, the asphalt can be heated to final application temperature by the bituminous distributor which pumps the asphalt under the pavement.

The reduction in cost created by shipping in tank cars or tank trucks as compared with shipping in cardboard or paper cartons can best be shown by giving the cost records of the undersealing crew of one of the divisions. During the first three months of 1948, when it was thought that it was too cold to handle asphalt shipped in tank cars, 66,000 gal. were received in cardboard cartons. The material cost 15 cents per gallon f.o.b. destination, plus 16 cents per gallon to remove the cardboard covering, heat, haul, drill holes, and pump the asphalt under the pavement, or a total cost of 31 cents per gallon of asphalt underseal complete in place.

Beginning with the month of April, 1948, the asphalt for underseal in this same division was ordered in insulated tank cars, and 72,700 gal. were used by this same crew prior to June 1. The cost of the material was 13.5 cents per gallon f.o.b. destination in the cars. This, when added to the operation cost of 5.2 cents per gallon for heating, unloading, hauling, drilling holes and pumping, gave a total cost of 18.7 cents per gallon of asphalt under-

seal complete in place. For this particular crew, a net saving of 12.3 cents per gallon was gained by ordering in tank cars instead of purchasing the material in paper or cardboard cartons. It must be remembered, however, that shipments in tank cars necessitate the using of asphalt in large quantities, and before tank car shipments are made, the proper organization of crew and equipment should be accomplished. Failure to do so might cause demurrage costs to mount up, and other additional expenses might accrue due to delayed handling of the asphalt. As an example of the amount of underseal material that can be handled in one day with regular maintenance equipment, one division crew heated and unloaded from a tank car, hauled and pumped under the pavement a total of 10,000 gal. The personnel of a typical underseal crew for handling asphalt shipped in tank cars consists of 6 to 10 men: a foreman in charge of the work, operators for the jack hammer, distributor, pump nozzle, and tank car heater, plus laborers to plug holes and do clean-up work, and flagmen. Asphalt underseal pumped by a crew of this size has cost approximately $1700 per mile of pavement during 1948.

The necessity for good judgment in determining the limits of the area of pavement to be undersealed and the location of the points to drill holes is highly important. The location of the drilled holes with respect to the longitudinal center joint, transverse cracks and joints, and the edge of the pavement is approximately the same as for the holes used in mudjacking. There is, however, some difference of opinion as to the number of holes to be drilled. Some think that the holes should be drilled on each side of the transverse cracks or joints, on both sides of the centerline and along the edges. It does seem wise to err on the side of too many holes rather than too few. With too many holes, it very often happens that it is not necessary to pump asphalt through all, but all the holes do serve as points of inspection to assure that adequate coverage of the subgrade is obtained.

Underseal asphalt shipped in insulated tank cars usually arrives at the destination at temperatures ranging from 225 to 280 deg. F., and is then heated in the cars by a booster heater, or some other type of heater, to a temperature of about 450 deg. F. A bituminous truck distributor is used to transport the hot asphalt from the railroad to the point of work on the highway and to pump it under the pavement. Again, as in mudjack work, the nozzle operator must be highly trained and skilled by experience in order to know when the voids are filled. The surface of the pavement around the hole is wetted with water in order to prevent the overflow asphalt from sticking to the pavement surface. A three-way cutoff valve is used in the hose line just back of the nozzle, to permit frequent circulation of the hot asphalt thru the line and thus prevent "freezing". As soon as the void under the pavement has been filled, and the nozzle removed, the hole is temporarily plugged with a tapered wooden pin. This pin remains in place until the asphalt has chilled and hardened sufficiently so that it will not flow back out of the hole. It is important that a permanent plug be placed later, because it has been found that the asphalt underseal will occasionally flow up through the hole during the summer. The most satisfactory type of permanent plug that has been used to date is one of soft wood, or thoroughly tamped stone chips. Soft wood plugs are generally believed to give the best results.

It can be stated that there is still much to be learned about asphalt undersealing of concrete pavements. Results to date, including the fifth year of experience in Missouri, are entirely satisfactory. Asphalt undersealing seems to have considerable advantage over mudjacking as a preventive for slab pumping, except in the matter of cost per cubic yard of void filling material in place under the pavement. The asphalt not only seems to fill the voids better than the mud slurry, but it also tends to seal a large number of the cracks and joints in the pavement from the bottom side. It thus stops surface water from reaching the subgrade from the surface of the pavement, and conversely, prevents the extrusion of mud and water upward through the crack or joint.

It has been definitely established that if underseal is placed before physical action has advanced beyond the initial stage, or before breakage of pavement has started, excellent results can be accomplished in stopping, or at least controlling the deteriorating action in concrete pavements due to slab pumping. This can be substantiated by giving a definite example. On a five mile section of concrete

on U.S. 71, in Platte County, Missouri, a pavement which was constructed with expansion joints at 40-ft. intervals, slab pumping was, in 1944, occurring at many of the joints. During that same year, these joints were treated with the mudjack method. By the spring of 1946, most of the joints that had been treated with the slurry were again working, and in addition, a considerable number of the remaining joints had started pumping. In April, 1946, about three hundred of these pumping joints were undersealed with asphalt. It was later estimated that pumping had been completely stopped at 95 percent of the joints. Those which continued pumping were undersealed again in the fall of 1946, and for the past two years there has been no perceptible slab movement on this 5-mile section. Similar experiences have occurred on other routes in other sections of the State.

When pavement failure caused by slab pumping has progressed so far that the slab has broken into small pieces, with the greater dimension approximately five feet or less, it has usually been found impossible to stabilize these rocking blocks by either the mudjack or underseal method. It then becomes advisable, and usually a necessity to replace these badly broken areas with full depth portland cement concrete patches. Before concrete replacement, however, it is desirable to underseal, or mudjack and underseal, the pavement immediately adjacent to the area of patch, in order to support or stabilize the old pavement that is to be left in place.

In concrete replacement, it is again extremely important that good judgment, gained by training and experience, be used in locating the limits and determining the size and shape of the full depth patch of portland cement concrete. From the most successful concrete patching practices in Missouri, it appears that the area to receive new concrete can take on a very odd and irregular shape, depending of course on existing cracks. In general, the new patch should not have any corner angles of less than 60 deg., nor any horizontal dimension less than 3 ft. No longitudinal joint between the new patch and the old pavement should ever be placed directly in line with the wheel track.

The thickness of the patch is usually 1 in. greater than the existing pavement, and in the case of plug patches whose greater horizontal dimension is 5 ft. or less, this additional thickness may be 2 in. Underpinning of the old pavement by the new patch is not generally considered necessary, but may be desirable under certain conditions. With small plug patches, there is some thought that the additional thickness serves a more useful purpose than underpinning.

Improvement of subgrade through the use of graded granular material has seemed to pay dividends in minimizing the danger of a quick return to slab pumping conditions. In some instances new patches have failed within the first 12 months after placement. Where this has occurred the new breakage has generally been attributed to lack of support for the adjacent old pavement, which could have been provided by mudjacking or undersealing or both, and failure to adequately prepare the subgrade under the new patch by adding suitable supporting material.

Tie bars and other reinforcing steel are not, as a rule, reused unless they are in excellent condition. Some new wire mesh is used on longer patches of narrow width. Expansion joints are not used in new patches except at bridge ends. Longitudinal center joints, if affected, are maintained through or along the new patch. Material proportions of 1:1.53:2.70 for standard portland cement, and 1:1.95:3.20 for high early strength cement are determined by weight.

Although several different methods of operation in concrete replacement have been and are being used in Missouri, no effort to standardize has been attempted as yet. The methods vary by divisions. Some divisions make use of truck mixers which operate from a central material storage site, and deliver the mixed concrete to the point of replacement on the road. Other divisions use a central mixing plant, and haul a wet batch to the patch location in dump trucks. Still other divisions use a portable concrete mixer, haul a dry batch, and mix at the point of repair. Most of the divisions purchase mixed concrete, delivered on the road from commercial plants, when available at prices considered to be reasonable. In all cases, however, except for the commercial mixed concrete delivered on the road, the concrete patching crew is substantially the same. A general foreman supervises all operations. He is assisted by a sub-foreman, a concrete finisher, 4 or 5 pave-

ment breaker operators, 1 or 2 flagmen, and 1 or 2 night watchmen. In addition, the regular maintenance crew for the section is generally assigned the responsibility for disposing of the old concrete, an operation which usually requires two trucks with drivers, and two laborers. The cost of labor and equipment for concrete replacement may be roughly broken down by percentages as follows:

	percent
Removing and stockpiling old concrete	30
Setting forms and subgrading	9
Mixing and hauling concrete	21
Finishing concrete	10
Night watchmen, signs, barricades, etc.	12
Moving and unloading material	10
Supervision	8
	100

Labor and equipment costs usually approximate 56 percent of the total and material costs account for the remaining 44 percent. On a unit basis, recent costs have ranged from approximately $5.50 to $7.00 per sq. yd. of portland cement concrete patch complete in place.

In cases where uncorrected slab pumping has progressed to the stage where the riding surface of the pavement has become permanently impaired, or if the surface has undesirable qualities for other reasons, it can be restored to a satisfactory condition with a new bituminous topping. This bituminous resurfacing will not only restore the riding surface to the desired degree of smoothness, but will also provide the additional service of waterproofing the old pavement. This water repellant feature can provide additional and still better protection if the resurfacing is carried beyond the outside edges of the pavement, so that it will shed the run off of moisture well out on the shoulder.

The general idea of placing a bituminous upper-deck on concrete pavements as a part of the overall method of controlling slab pumping, was developed and put into practice by the Maintenance Bureau of the Department. All of the initial work of constructing such decks was carried out by maintenance crews. After actual usage had proven the success of this method, however, both the Design and Construction Bureaus began to include bituminous decks of the hot mix type in the construction program. As a result, it is now a well established Department policy to construct decks with both its own maintenance crews, and by contract. In either case, however, it is the duty and responsibility of the Maintenance Bureau to first place the old pavement in a proper condition. If a bituminous deck is to provide satisfactory service it is essential that the old pavement be adequately stabilized by prior treatment with one or all of the previously described methods of mudjacking, undersealing, or concrete replacement.

Bituminous decks built by the maintenance organization do not usually exceed 10 cu. yd. of aggregate per hundred feet, which results in a rolled thickness of about 1¼ in. It is the general practice to use about 18 to 20 gal. of MC-3 or MC-4 cutback asphalt to the cubic yard of aggregate. The aggregate, meeting predetermined specifications, is usually locally produced, and can be stream gravel, hill gravel, crushed limestone, chats (a by-product of lead and zinc mining), or any other aggregates that have been found by experience to give desirable results. The aggregate and asphaltic material is usually mixed on a side road with motor graders and then loaded and hauled by truck to the pavement that is to be resurfaced. Motor graders are again used to spread and lay the deck on the pavement. Both pneumatic tired and flat steel wheeled rollers are used for compaction. Present costs of maintenance-built 1¼-in. bituminous decks range from $2500.00 to $3500.00 per mile. The wide range is due mainly to a variation in the cost of aggregate. On many sections of highway, the single 1¼-in. deck has not been thick enough to give satisfactory results, and where necessary, it has been and is the policy to build additional decks over the top of the old. In some areas as many as three 1¼-in. decks have been built before sufficient thickness was obtained to withstand the pounding of traffic.

The practice of building hot plant-mix bituminous decks by contract as a part of the slab pumping control procedure was started in 1945. The thickness of these hot-mix decks has varied, for experimental purposes, from 2½ to 4-in., and the width has ranged from 2 to 6 ft. wider than the old pavement. The question of thickness of the bituminous deck has been a subject for experimentation

for some time. On contract hot plant mix work, it is the present policy to build the decks in two courses, with a total thickness of 2¾ in. The bottom course is 1½ in. thick, with 1-in. maximum size aggregate; and the top course 1¼ in. thick, with ½-in. maximum size aggregate. In the case of lip type pavements, where the height of the lip is 3 in., the bottom course of the deck is increased to 1¾ in., thus making the total thickness 3 in. This completely fills the space all the way across the pavement to full lip height. The percentage of asphalt in the mix will average from 4½ to 5 by weight in the base course, and 5½ to 6 in the top course. The present average cost of a 3-in. hot plant mix 22 ft. wide is $14,000 per mile.

Viewed solely from the standpoint of slab pumping control, both the road mix decks constructed by state maintenance crews, and the hot plant-mix decks constructed by contract, have proven highly satisfactory. In addition to this advantage, the decks will restore the riding surface and also provide additional width if desired.

Experience in Missouri indicates that a great majority of the cracks in the old concrete pavement will also show up on the surface of the bituminous deck. The percentage of cracks coming through will vary with the the thickness of the deck. Regardless of whether a concrete pavement has been treated by any or all of the foregoing methods of pumping prevention or correction, the cracks and joints should always be kept sealed as completely as possible. This is also true of the cracks which appear on the surface of an upper-deck. A material should be used that is sufficiently fluid to penetrate and seal even the smallest cracks. After application it should increase in consistency to a point where it will resist flow and extrusion. It should also be ductile and highly adhesive, in order to form a permanent seal.

Ease and simplicity of application, as well as cost, are important factors to consider in selecting materials for crack sealing. RC-3 cutback asphalt, blotted with sand or sawdust, is most generally used in Missouri at the present time. Crews for this work usually consist of 6 men and 1 flagman. One man moves the truck and the trailing portable heating kettle, usually a 400-to 600-gal. trailer distributor. Two men pour cracks with cone shaped pouring pots. Two men cover the freshly poured asphalt with sand, sawdust or dirt, which is hauled by the same truck pulling the kettle. One man brooms cracks ahead of the crew and a flagman is used for protection from traffic. Such a crew can cover an average of from 2½ to 3 miles per day, but where the pavement is excessively broken, this mileage may be reduced to ½ mile per day. Likewise when the pavement is in an unusually good condition, the distance covered may range as high as 8 to 10 miles. Depending upon the general condition of pavement, the width of cracks, etc., the cost of crack pouring will usually average about $23 per mile, including labor, material and equipment operation.

Other preventive and corrective practices that should be followed to avoid slab pumping, regardless of whether any or all of the foregoing methods have been used, are proper maintenance of shoulders along the pavement, and adequate provision for both surface and subgrade drainage. Shoulders should be kept smooth, at proper elevation at the pavement edge but sloping down and away from the pavement at all times. Ruts and depressions appearing in the shoulder adjacent to the pavement should be filled immediately, for if the water is allowed to collect and stand in them it will tend to seep or flow under the pavement, and contribute to slab pumping. Only nonporous material, which is fairly impervious to water, should be used for backfilling such depressions. Side ditches should be kept open to a depth which will permit the free flow of water away from the pavement, and provide adequate subgrade drainage. Good and proper drainage makes a very definite contribution to the control of slab pumping.

In summarizing, it may be said again that the Missouri methods of controlling pavement pumping still include those same six tried and proven operations of mudjacking, undersealing, concrete replacement, bituminous resurfacing, crack sealing, and proper maintenance of shoulders and drainage. However, maintenance engineers and field men are still surveying the problem, and seeking for ways to improve each operation. Attention is currently being concentrated on a study to determine the approximate stage in the growth and progress of a pumping joint, when the various corrective measures should be started.

It is known, of course, that an early start will usually give better and cheaper results. Present thinking in Missouri indicates that an earlier use of asphalt underseal following the first signs of initial slab movement, will result in control of slab pumping at the lowest cost. Early use of the other methods of control will pay dividends in the cost of maintenance and the life of the pavement. Especially is this true if the use of bituminous decking is indicated, because the early use of decking will certainly help to hold down the cost of preliminary mudjacking, undersealing, and full depth concrete replacement. It will, in addition, result in a better and longer lasting road surface. It should be added, of course that proper shoulder and drainage maintenance should always be practiced, regardless of the presence of other corrective or preventive operations.

The problem discussed in this paper has been approached from the maintenance point of view. All tools and processes described have been developed to provide corrective or preventive relief. The opportunity should not be passed, however, without giving due credit to the design, construction, and material engineers, who have steadily altered and modernized their designs and methods, to take advantage of maintenance findings. Improved subgrade material gradation and compaction, the elimination of joints, better shoulder design and more adequate drainage, to mention only a few, all illustrate the good that can come from close cooperation between all branches of highway engineering. Such shoulder-to-shoulder efforts cannot help but make the maintenance load lighter. While it is not anticipated that slab pumping will ever be ruled out completely, it now appears that its occurrence will be less general, and its effects less expensive to correct. When that happens, however, the maintenance engineer will still have plenty of other needy projects upon which to spend the money saved.

DEPARTMENT OF TRAFFIC AND OPERATIONS

WILBUR S. SMITH, *Chairman*

THE EFFECT OF BUILDING SPACE USAGE ON TRAFFIC GENERATION AND PARKING DEMAND

J. TRUEMAN THOMPSON AND JOSEPH T. STEGMAIER, *The Johns Hopkins University*

A method is demonstrated of using urban origin and destination survey material for information concerning the power of buildings of various types to attract traffic and create parking demand. Fifteen buildings such as department stores, schools, theatres, factories, hospitals, etc. and one shopping community are analyzed as generators in such a way as to bring out the purposes of trips made to them, the mode of travel used, the time-of-day distribution of the travel, and where the trips originated. In two cases information about the sex and color of those making trips is also provided. These data are then translated in terms of vehicular attraction of the several generators.

A second method is presented which uses origin and destination data to secure mass information about the parking demands created by various generators. By segregating the trips of those who drove passenger cars and by assuming that each such trip represented a potential parker, the total daily parking demand of each generator is established. The purposes of the trips and the hour they were made are then taken into account and turnover factors developed for each trip purpose for each generator. These turnover factors are used to establish parking space requirements. These, in turn, are related to physical properties of the generators to produce such basic units as the number of square feet of department store selling space per parking space required, the number of theater seats per parking space required, etc.