MAINTENANCE METHODS FOR PREVENTING AND CORRECTING THE PUMPING ACTION OF CONCRETE PAVEMENT SLABS

Rex M. Whitton, Engineer of Maintenance,
Missouri State Highway Department

SYNOPSIS

This paper describes experience in Missouri with the correction of pumping at joints in concrete pavements by the use of a semi-fluid soil-cement mixture forced under the slab with a mudjack. The slurry used consisted of four sacks of cement per cubic yard of topsoil and 50 to 55 per cent of water. The spacing of the holes for elimination of pumping and correction of faulting is discussed. The equipment and personnel required is given in detail. On an average section of pavement, it was found that 354 holes per mile and 35.45 cubic yards of slurry were required per mile of road. The average cost of the work was \$24.78 for drilling 1½-inch holes and \$256.66 per mile for the material and pumping operation.

In a study of the deflections of the pavement under moving loads, it was noted that deflections increased immediately after filling the voids under the pavement with the soil-cement slurry and then decreased after a period of time had elapsed. For a 12,000-pound rear axle load, the deflections were reduced as much as 0.007 in. and for a 16,000-pound wheel load as much as .011-in. between measurements made 9 days and 153 days after mudjacking.

It was found that a few of the mudjacked slabs resumed pumping and that the work had to be supplemented with joint and crack water-proofing to keep surface water from reaching the subgrade. On pavements that were cracked extensively, the best method of waterproofing joints was by the use of a substantial bituminous surface or upper deck not less than 1-in. in thickness.

After a study of design features from the viewpoint of a maintenance engineer, the author concludes that expansion or contraction joints should not be used in concrete pavements except at highway intersections, bridge ends or other locations where the pavement abutts a fixed object. The relation of the type of aggregate to the crack interval in concrete pavements in which no joints were placed is discussed.

The type of concrete pavement failure that is causing the most concern today in Missouri is the result of "slab pumping" or the deflection of the pavement under a moving load. "Slab pumping" is the ejection of water thru the joints and cracks in concrete pavements carrying soil particles from the subgrade. Continued "slab pumping" results in voids under the concrete pavement and finally the breakdown of the pavement itself. "Slab pumping" is indeed a malignant disease of concrete pavement.

It has been proven through both research and observation that four factors must be present to create a "pumping slab". They are: (1) heavy axle loads; (2) joints or cracks in the pavement; (3) unsuitable subgrade soil; (4) "free" water under the slab.

The elimination of any one or more of these factors extends the life of the concrete pavement for many years.

Since the legal limit for axle loads in Missouri has been increased during the present war from 16,000 lb. to 18,000 lb., and since it seems to be generally accepted that an 18,000 lb. axle limitation should be adopted as standard in all the States, this axle load factor cannot be readily changed.

Joints and cracks which have been delibberately placed, or cracks which have occurred from natural causes, in the concrete pavement cannot be eliminated; but their effectiveness as a means by which free water gets under the pavement can be reduced very materially in most instances by keeping the joints and/or cracks properly filled and by placing a bituminous upper deck over the entire area of the affected pavement.

It is not feasible to remove and replace the undesirable subgrade soil now in place under the concrete pavements constructed in the days when little or no thought was given to obtaining the most satisfactory type of supporting soil. It is, however, possible to stabilize the undesirable subgrade soil to such an extent that it is more effective in sustaining the load.

The range of soil types on which pumping has occurred is quite extensive. Any soil that can be puddled into a suspension in water will react to the rocking action at pavement joints and cracks and in the presence of water will develop pumping. There are some soil types developed in areas of low relief possessing a distinct clay-pan, such as the Putnam Silt or Lebanon Silt, which are relatively more susceptible to pumping than the more drainable types such as the Knox Silt or the Marshall Silt. However, any clay or silt type soil in the proper environment will develop pumping.

It is also possible to overcome the "free" water under the pavement and extend the life of much concrete pavement until a post war reconstruction program permits the older pavements to be replaced or adapted to the needs of today and tomorrow. By pumping a slurry mixture of soil, cement, and water through the pavement, the void is filled and the reservoir for the accumulation of "free" water is thereby eliminated. The history of the development and methods adopted in Missouri will be discussed briefly for performing this operation.

As early as 1935, attention was directed to "slab pumping" on the most heavily traveled routes in Missouri, which forced the free water thru the cracks in the pavements, causing erosion and displacement of the subgrade and the resulting voids under the pavement. In 1937, one division of the State Highway Department used a mudjack to pump a semi-stiff mixture of soil and cement under the badly damaged pavement to fill these voids, force out the free water, stabilize the subgrade, and reduce the "slab pumping". The soil-cement mix was injected through a hole drilled at the intersection of each transverse crack with the longitudinal centerline. In 1938 the method was extended over other sections, but the original single hole at each crack was supplemented by two other holes; one being drilled in the transverse crack at the middle point of each lane of traffic. The results obtained by the use of the three holes were more satisfactory than by the one hole method of 1937. During the next two years, the sections pumped by both methods did not progress in failure as rapidly as the sections not treated.

In 1941, when the pumping action was noted on other heavily traveled routes where the condition had heretofore been present but less intense, a special study was made of the problem. After obtaining the experience of other States, a decision was made to use a slurry mix of loam top soil and portland cement instead of the semi-stiff mix. A more fluid mix was necessary to give a greater spread of the mixture under the pavement and to fill more of the small voids and channels.

This slurry mix was obtained by mixing the soil and cement, the proportions being four sacks of portland cement per cubic yard of top soil with 50 to 55 per cent water; in the pugmill of the mudjack.

Observations in the field indicated that, by the use of this slurry mix, the soil-cement would be pushed or pumped through to the top of the pavement at cracks 20 and 25 ft. from the point of injection. Also by using this mix the pavement was not set up on stools as was the probable condition in previous years when the stiff mix was employed for raising settlements.

Experiments have been instigated and are still being carried on to determine admixtures for the present soil-cement slurry mix to improve its quality. A mix is sought that will set up rapidly, will have strength without too much rigidity, and will have a minimum shrinkage.

The holes for corrective and preventive mudjack work are now placed 10 in. to 12 in. from the centerline and 10 in. to 12 in. beyond the transverse crack or joint in the direction of traffic. Since the use of air in conjunction with the pressure supplied by the mudjack has not been utilized due to lack of equipment, we have come to the conclusion that one hole should be drilled in diagonal corners at the location mentioned above so that the greatest amount of slurry can be pumped under the pavement. Experimental sections were set up using both the one hole method and the two hole method and it was found that 0.09 cubic yards more slurry was pumped per crack where two holes were used instead of one. When it is necessary to use a hole on the outside of the pavement for filling or for raising purposes, it should be placed 30 in. in from the edge of the pavement and 30 in. beyond the crack in the direction of traffic. By using this spacing, the inside and outside hole will not be in the same line; which, if it were the case, would establish a plane of weakness and could cause a break if the treated joint should resume pumping in future years.

The holes are drilled with a pneumatic jack hammer using 18 in. drill steel and a $1\frac{1}{2}$ in. removable bit. Where the selected soil desired is not available, it is more desirable to use a 1-3/4 in. or 2 in. hole so that a larger nozzle opening can be used and thus avoid delays from the rocks and roots in the mixture. However, the $1\frac{1}{2}$ in. hole is used in all cases where desirable soil can be obtained for the work. Usually a single man not only drills the holes, but moves the equipment ahead as his work progresses, takes care of the compressor, and shifts the barricade which protects him from traffic. He may drill as many as 325 holes $1\frac{1}{2}$ in. in diameter per ten hour day, but the total varies with the condition of the pavement to be treated and the number of moves required per mile, as well as with the kind of coarse aggregate that has been used in the concrete.

The $1\frac{1}{2}$ in. holes cost an average of $0.07 per hole, and in some sections of the State, 402 holes are required per mile to treat every joint and crack.

The mudjack is mounted on a four wheel pneumatic tired trailer equipped with a four cylinder gasoline motor that supplies the power to operate a pugmill and the two pistons delivering the slurry through a 2 in. diameter, 5-ply rubber hose to a tapered steel nozzle. The nozzle is equipped with a 2 in. quick opening gate valve and is tapered from $1\frac{1}{4}$-in. to $2\frac{1}{2}$-in. outside dimensions.

The mudjack trailer unit is towed by a truck carrying a 500 gallon water tank and a small gas driven centrifugal water pump. The water tank is connected to the water pump of the mudjack by a 1-in. hose, which can be readily disconnected when it is necessary to refill the water tank.

The mudjacking work is performed by an eight-man crew, consisting of a foreman, mudjack operator, nozzle operator, a laborer adding soil and cement to the pugmill, a truck driver operating both trucks between the mudjack and the dirt pit, a laborer who plugs the holes and cleans the surface of the pavement after jacking, a laborer at the soil pit, and a flagman. Such a crew has pumped as much as 28 cubic yards of slurry per ten hour day and averaged 18 cubic yards per day over the 1943 season.

One division so far this season has treated every joint and crack on 31.7 miles of U.S. Route 40, drilling 11,212 holes and pumping 1,125 cubic yards of soil-cement slurry under the pavement. This is an average of 354 holes per mile and 35.45 cubic yards of slurry per mile. This work is costing on the basis of $24.78 per mile for drilling the $1\frac{1}{2}$-in. holes and $256.66 per mile for the material and pumping operation, or a total cost of $281.44 per mile.

Usually no attempt is made to raise the pavement from its warped position, unless a local condition is encountered where the pavement surface still has good riding quality on either side of the settlement. It is now our policy in Missouri to merely fill the voids under the pavement, thereby materially reducing the deflection of the slab; and then restore the riding surface and relieve the impact by resurfacing the concrete pavement with a bituminous upper deck, which will also aid in water-proofing the surface of the old pavement.

Deflection tests have been made in the field to ascertain the deflections of the concrete pavement under a moving load and some of the results obtained are tabulated in Table 1.

Deflections were measured before and after mudjacking or filling the voids with a soil-cement slurry. It was noted that the deflections increased nine days after mudjacking. This was caused from the quantity of water necessary to prepare the slurry mixture which saturates the subgrade, but 153 days after mudjacking, when additional tests were made, the deflections had reduced materially. This condition does not always exist, depending on how badly the pavement is cracked before mudjacking. In the case of the 12,000 lb. rear axle load the deflections were reduced as much as .007 in. whereas in the case of the 16,000 lb. rear axle load the deflections were reduced as much as .011-in. between the tests run 9 days after mudjacking and 153 days after mudjacking.

TABLE 1

Deflection Tests - Route 40 - Cooper County

Test Slab No. 1					Test Slab No. 1A				
Run No.	Velocity M.P.H.	Axle Loads Rear	Axle Loads Front	Deflec. Inches	Run No.	Velocity M.P.H.	Axle Loads Rear	Axle Loads Front	Deflec. Inches
	(Before Mudjacking)								
1	9.9	12000	3100	.018		No measurements made before mudjacking			
2	18.8	12000	3100	.014					
3	28.4	12000	3100	.013					
4	38.3	12000	3100	.009					
	(Same Day - After Mudjacking)								
9	9.4	12000	3100	.016		No measurements made on same day after mudjacking.			
10	19.4	12000	3100	.013					
11	28.6	12000	3100	.010					
12	38.7	12000	3100	.009					
	(9 Days After Mudjacking)					(9 Days After Mudjacking)			
21	10.2	12000	3200	.020	1	10.4	16000	3000	.011
22	18.8	12000	3200	.015	2	18.6	16000	3000	.008
23	29.2	12000	3200	.018	3	28.2	16000	3000	.011
24	38.0	12000	3200	.016	4	38.0	16000	3000	.014
	(153 Days After Mudjacking)					(153 Days After Mudjacking)			
29	8.3	12000	2900	.012	7	13.6	16000	3000	.000
30	9.9	12000	2900	.012	8	19.6	16000	3000	.000
31	19.8	12000	2900	.007	9	29.0	16000	3000	.003
32	29.0	12000	2900	.006	10	39.5	16000	3000	.003
33	40.6	12000	2900	.006					

Not only do we receive a benefit from the decrease in deflections of the pavement by filling the voids beneath the pavement in the subgrade; but, if the pavement can be made to stay in contact with the subgrade, the weight of the pavement will keep the subgrade in compression, and will thereby reduce the quantity of water which can be absorbed by the soil, since soil under pressure will not absorb water nearly as readily as soil that is not under pressure.

The slurry mixture is pumped under the pavement until all of the free water under the pavement is forced out of the voids and is drained off through the cracks and holes dug at the edge of the pavement at the transverse crack for that purpose, and the slab begins to rise. This drainage hole, which is made with a spud bar or a pick, is extended about 2-in. below the bottom of the pavement. As soon as the water has been forced out and the slurry mixture appears at the shoulder, the hole is closed and tamped with earth.

When the nozzle operator has added sufficient slurry at the hole, he inserts a tapered wooden peg to retain all of the mix under the pavement until the cleanup man can plug the hole with a mix of soil and cement. This workman, after the soil and cement plug is added, passes his shoe over the hole and so obtains a slick finish that will not be destroyed by traffic. Enough moisture seeps through from below to provide the necessary dampness to make this plug set.

After the first pumping, the slab is usually disturbed by traffic before the mixture has taken its initial set, so that the voids remaining are not completely filled. Also the shrinkage of the slurry mix due to the high water content leaves some small voids. Thus, it is usually necessary to repump all sections where pavement failure has progressed to any great extent.

Results obtained by mudjacking, during the past ten years, indicate that voids underneath the slab where "free" water might collect can be eliminated. However, due to the impact from heavy axle loads and the depth of the muck in the subgrade (caused by both "free" water and capillary action), the layer of soil and cement injected under the slab by mudjacking is not a cure-all and generally lacks sufficient thickness to withstand heavy loads for long periods. A percentage of joints and cracks stabilized by mudjacking will in time resume pumping.

In view of the fact that a few of the "mudjacked" slabs will resume "pumping", it is our theory that mudjack work must be supplemented with some type of joint and crack waterproofing to keep the surface water from the subgrade and so obtain the best results in the maintenance of "slab pumping" pavements.

Keeping the joints and cracks in concrete pavement properly filled and waterproofed is a maintenance problem that has not been satisfactorily solved as yet, even though it has been a subject for research and field investigation for many years. However, with the advent of heavy axle loads and "pumping slabs", it seems imperative that every effort should be made to keep the joints and cracks filled and as waterproofed as possible in an attempt to prevent surface water from reaching the subgrade.

Depending on the degree of failure in the concrete pavement from "slab pumping", another method of waterproofing the joints and cracks is used. This is the placing of a bituminous surface or upper-deck on the pavement.

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. With this condition of pavement prevalent, the best maintenance procedure is to follow the mudjack work with a bituminous deck of a thickness of 1-in. upward depending on the condition of the concrete pavement. It is desirable to prevent the cracks in the concrete pavement from continuing upward thru the bituminous surfacing. The thickness of the bituminous upper-deck will affect the number of cracks being reflected thru it from the base. Experiments are now being carried on to determine more accurately the effect of thickness of the bituminous surfacing on the number of cracks reflected thru it from the base. It is, however, easier to keep the cracks in bituminous surface sealed than those in concrete pavement.

It has, also, been noted that if the concrete pavement failure from "slab pumping" has progressed to such a point that the pavement has broken either at the corners or into narrow half-lane blocks, it is difficult to stabilize such areas by the use of the mudjack; and so the only solution in those cases is to replace the badly broken areas with concrete patches. The pavement surrounding a concrete replacement area is "mudjacked" so as to insure the minimum deflection of the old pavement in the vicinity of the new patch. This will prolong the life of the pavement surrounding the patch, as well as the patch itself. This mudjacking procedure is performed ahead of the concrete replacement work.

Thus it can be concluded that the proper maintenance methods for preventing and correcting the pumping action of concrete pavement slabs involves the first two and sometimes more of the following activities: (1) mudjacking, (2) joint and crack sealing, (3) patching full depth with concrete, (4) upper-decking with bituminous mats.

It is well to keep in mind in this work that the common goal in all highway maintenance is a smooth riding surface.

Up to this point attention has been devoted entirely to maintenance; but now, with the experience that has been obtained, it seems imperative that thought be given to the design and construction of concrete pavement to the end that "slab pumping" may be prevented.

It is generally accepted that "free" water under concrete pavement is one of the causes "slab pumping". The only way that "free" water can enter the subgrade from the surface is through the expansion and contraction joints, through natural contraction cracks, and along the edge of the concrete pavement. Therefore, the more joints and cracks present in the pavement surface, the more water will be found between the bottom of the pavement and the subgrade.

It is the opinion of our Bureau of Maintenance Engineers that the use of joints and/or contraction cracks should be omitted except at such locations where it is required to maintain adequate expansion at bridge ends, at the intersections of two concrete surfaced highways, and at other locations where the pavement is abutting any fixed object.

The theory for the use of expansion joints and contraction cracks may be well founded, in that they are designed to allow for pavement expansion and to control transverse cracks in the concrete pavement; but actually to our knowledge a joint has not been designed that is 100 per cent efficient. A joint to be 100 per cent efficient must transfer the load from one slab to the other with no deflection and be absolutely waterproof throughout its life in the pavement. To date these two features have not been attained in Missouri.

The maintenance of occasional concrete pavement "blow-ups" due to expansion, is certainly more economical and desirable than the maintenance of joints constructed at 20 to 50 ft. intervals. It has been the experience in this State that concrete pavements constructed with expansion joints are shorter lived, rougher riding, and more expensive to maintain than those constructed without joints. As a result, a Maintenance Engineer fails to see the justification of expansion joints, since the pavements with joints are also more expensive to construct.

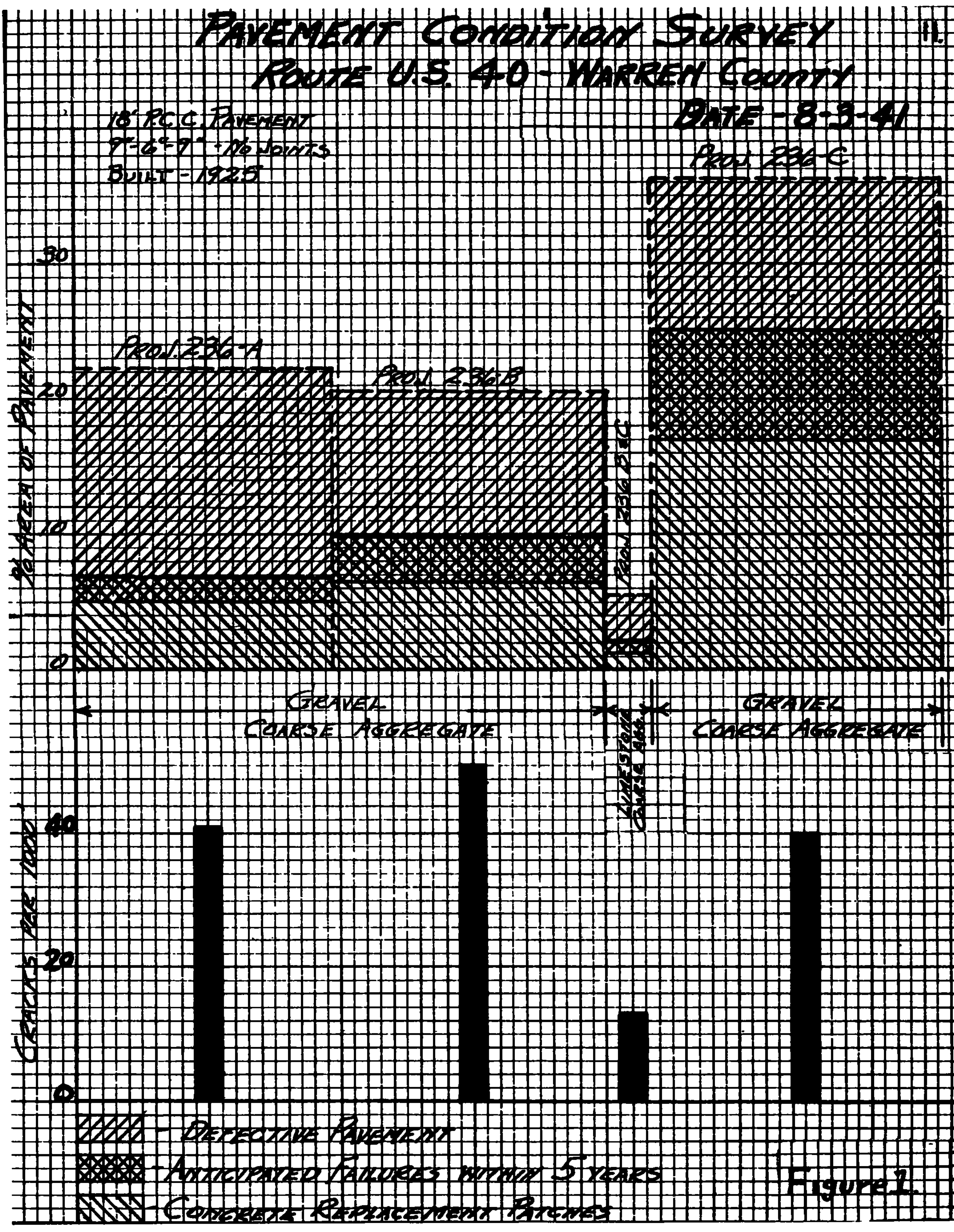
The crack interval in concrete pavement has a very definite relation to slab pumping. The shorter the interval the more apt the pavement is to pump. Due to this fact, it is, therefore, advisable from the viewpoint of present slab pumping to have as great a distance as possible between cracks. This greatest distance possible can best be accomplished by not putting in contraction cracks. If contraction cracks are placed, it is necessary to predetermine the crack interval of a certain aggregate, and it almost invariably happens that additional contraction cracks occur between the installed contraction cracks. This results in a short crack interval that is so conducive to slab pumping. If the pavement is constructed without contraction cracks, the cracks will then form naturally at the greatest interval for the aggregate; which is the desired condition.

It so happens that we have two excellent examples in Missouri that very definitely show the effect of crack interval on pavement life. On Route 40 in Warren County there is a 17 mi. section of pavement, that was constructed in 1925 and 1926, using high expansive type coarse aggregate that causes a short interval - 22.9 ft. - between contraction cracks. It also happens that there is a half-mile section of pavement in this longer section constructed at the same time and under the same conditions, but using a low expansive type coarse aggregate which results in a longer crack interval - 76.8 ft. (See Figure 1). The difference in maintenance cost and pavement life has been very material. The pavement with the shorter crack interval has been patched with concrete, mudjacked and upper-decked, while only minor surface maintenance work has been done on the short section with the longer crack interval. A similar example can be found on Route 66 in Webster County. The crack interval in 1939 ranged from 21.6 ft. for the high expansive type coarse aggregate to 92.8 ft. for the low expansive type coarse aggregate. (See Figure 2.)

In view of the fact that a short crack interval encourages "slab pumping", it seems logical that considerable thought should be given to the aggregate used in the construction of concrete pavement.

Another of the generally accepted causes of "slab pumping" is unsuitable subgrade soil. This condition can be and is being corrected in many instances by the use of suitable subgrade soil or the proper stabilization of the subgrade prior to the construction of the concrete pavement.

It has been stated previously, but it can bear repeating, that the common goal of all highway maintenance activity is a smooth riding surface. This statement can be enlarged to read that the common goal of all highway design, construction, and maintenance activity is a smooth riding surface and maximum life. The elimination of expansion joints and contraction cracks, selection of proper aggregate, and the proper stabilization of the subgrade in the construction of concrete pavement will constitute a step in the direction of the goal of a long life and a smooth riding surface.


PAVEMENT CONDITION SURVEY
ROUTE U.S. 40 - WARREN COUNTY
DATE - 8-3-41
18' P.C.C. PAVEMENT
9"-6"-9" - NO JOINTS
BUILT - 1925
PROJ. 236-A
PROJ. 236-B
PROJ. 236 D & C
PROJ. 236-C
% AREA OF PAVEMENT
0
10
20
30
GRAVEL
COARSE AGGREGATE
LIMESTONE
COARSE AGG.
GRAVEL
COARSE AGGREGATE
CRACKS PER 1000'
0
20
40
- DEFECTIVE PAVEMENT
ANTICIPATED FAILURES WITHIN 5 YEARS
- CONCRETE REPLACEMENT PATCHES
Figure 1.

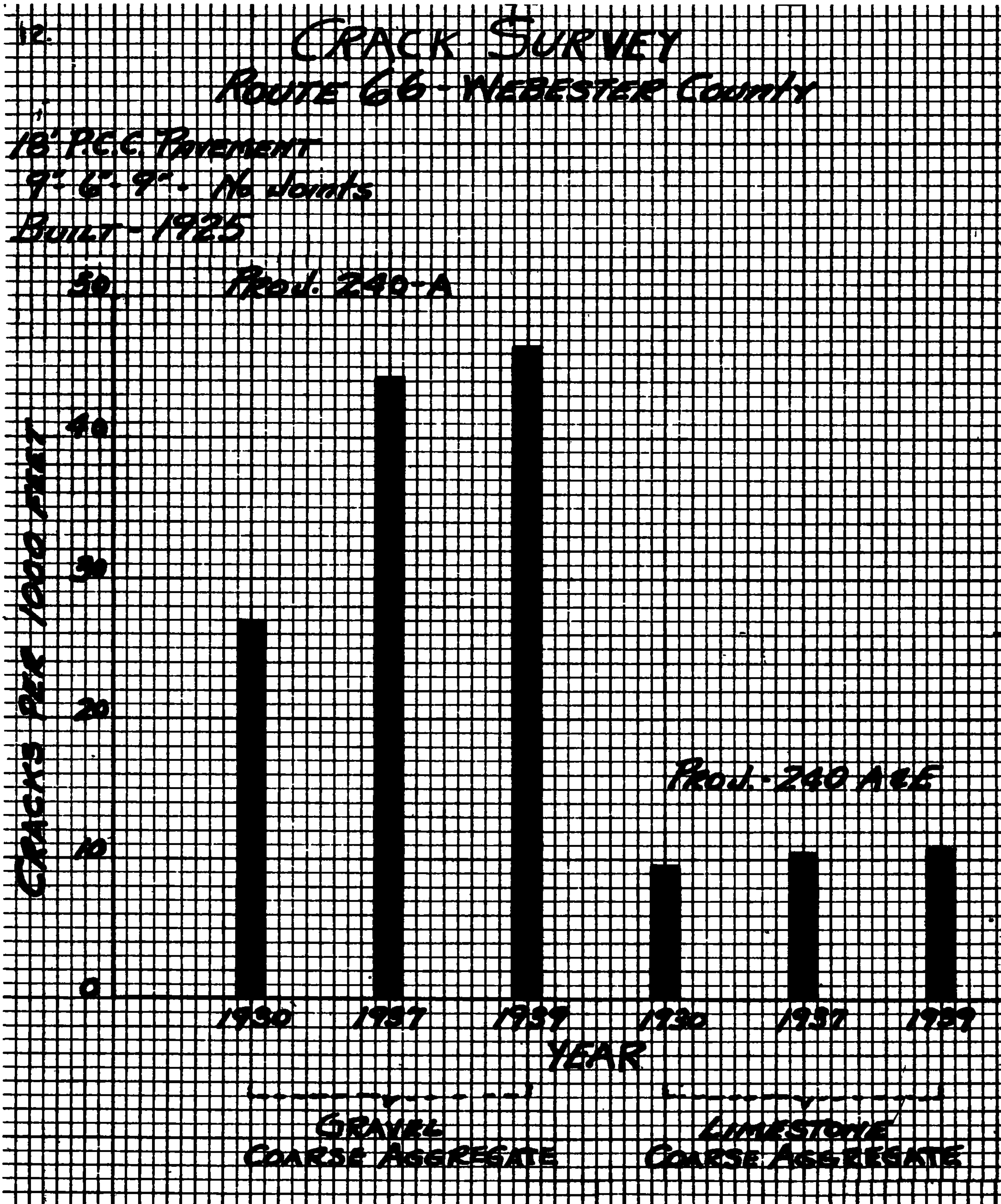

CRACK SURVEY
ROUTE 66 - WEBESTER COUNTY
18' P.C.C. PAVEMENT
9"-6"-9" - No Joints
BUILT - 1925
PROJ. 240-A
PROJ. 240 A&E
CRACKS PER 1000 FEET
0
10
20
30
40
50
1930
1937
1939
1930
1937
1939
YEAR
GRAVEL
COARSE AGGREGATE
LIMESTONE
COARSE AGGREGATE

Figure 2