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DEPARTMENT OF DESIGN

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CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS WITHOUT JOINTS

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SYNOPSIS

Over a period of years many weaknesses have become apparent in the design of concrete pavements. Such things as pumping, high joints, faulted joints, faulty load transfer devices, corner breaks, and blowups are known to almost everyone interested in pavement design. Entirely satisfactory solutions for many of these difficulties have not been found. If a concrete pavement could be designed which would eliminate these weaknesses, it would constitute a major step forward.

A careful study suggests the possibility that a continuously reinforced concrete pavement having heavier than normal reinforcement and no joints would be subject to very few, if any, of the weaknesses now inherent in concrete pavement. The available information indicates that longitudinal steel in the amount of 0.5 percent of the cross-sectional area of the pavement may be sufficient to prevent open transverse cracks. Transverse steel, perhaps slightly heavier than normal, extending across two lanes of pavement should allow the elimination of the longitudinal joint and prevent objectionable longitudinal cracking. Thus, by means of steel reinforcement, it may be feasible to eliminate all joints and open cracks and the elimination of these, it is believed, would avoid most of the difficulties previously mentioned. The cost of such pavement would probably be comparable with the present designs for heavy duty roads. The exact amount of steel required to prevent open cracks, the thickness of the concrete, and the service behavior cannot be stated definitely until experimental pavements have been constructed and observed.

About 25 years ago the construction of concrete pavement on an extensive scale was begun. During the ensuing period engineers have designed and redesigned pavement without obtaining their objective, a perfect pavement design. Expansion and contraction joints were introduced to prevent blowups and to control cracking. The introduction of transverse joints introduced new problems. Because no water-tight joint has been developed, high joints and pumping have been accentuated. The lack of an adequate load transfer device has resulted in faulting of the joints causing large impact forces, broken slabs and a rough riding pavement.

The longitudinal joint was introduced to eliminate longitudinal cracking, which it generally does, but it also created a pavement weakness which results in interior corner breaks and sometimes spalling and disintegration due to moisture getting in and saturating the concrete at that point. In fact, all joints and open cracks tend to promote pavement breakage due to inadequate load transfer, and pavement disintegration due to saturation of the concrete in the vicinity of the joint or crack and the fact that concrete in the vicinity of joints is frequently less durable than in other parts of the pavement.

Primarily to control pumping, granular bases have been used in recent years. So far as we know at this time the introduction of the granular sub-base has not created new design problems, but engineers have not yet agreed on the proper design of this sub-base. Such sub-bases have eliminated pumping but high joints and faulting have not always been avoided.

It is perhaps safe to say that no one has yet proposed a pavement design that is entirely satisfactory. If a pavement could be designed without any joints and in which no open cracks would form, in which blowups would be unlikely, and in which granular material is not necessary to prevent pumping—if such a pavement could be built at a reasonable cost—certainly it would be a wonderful thing. A careful study indicates that a continuously reinforced pavement having heavier than normal reinforcement may fulfill these requirements.

Prior to 1947 such a pavement had never been built although the possible advantages of this type of construction had been suggested as early as 1936 by Mr. E. M. T. Ryder, then Way Engineer of the Third Avenue Railroad, New York City. In 1945 the writer became impressed with the possibilities of continuously reinforced concrete pavements and in 1947 the Illinois Division of Highways, with the cooperation of the Public Roads Administration, undertook the construction of a pavement of this type to test some of the theories advanced in this paper. During the same year the State Highway Department of New Jersey constructed a similar experimental pavement.

WHAT WE NOW KNOW ABOUT CONTINUOUSLY REINFORCED PAVEMENT

In 1921 the Columbia Pike experimental pavement (*1*)[1] was constructed near Washington, D. C. It contained a series of reinforced slabs 200 ft. long and one reinforced slab 350 ft. long. In 1925 Public Roads Administration built several experimental slabs 2 ft. wide and 200 ft. long containing varying amounts of steel (*2*). A study of the data from these two projects indicates that longitudinal steel in the amount of 0.5 percent of the cross-sectional area of the pavement slab is approximately the correct amount of steel required to cause closely spaced, tightly closed transverse cracks to form in long slabs. In the 18 years during which the Columbia Pike was in use and under observation, in the sections containing this amount of longitudinal steel, the closely spaced cracks were held tightly together and did not ravel (*3*). As the longest slab was only 350 ft., however, this experiment does not necessarily show what would happen in reinforced slabs of greater lengths.

In 1938 another attempt was made to see what would happen in larger sections of pavement continuously reinforced. In this year the State Highway Commission of Indiana and the Public Roads Administration cooperated in the construction of an experimental pavement west of Indianapolis on U. S. 40 in which slabs up to a maximum length of 1320 ft. were included. The latest published report of this experiment may be found in the *Proceedings* of the Highway Research Board Vol. 23 (1943). Here again it was found that approximately 0.5 percent of longitudinal steel (½-in. round bars at 6-in. spacing in concrete 7 in. thick) caused frequent, tightly closed, cracks in slabs having a maximum length of 330 ft. Unfortunately the design of all sections was so conservative that no open cracks occurred in any section and no minimum requirements for amount of reinforcement could be determined. The 1320-ft. section has longitudinal reinforcement consisting of 1-in. round bars spaced at 6 in. and has very tightly closed cracks in the center portion spaced about 3 ft. apart. The pavement is laid on a silty clay subgrade subject to pumping and rather serious pumping has developed at a number of the joints, but no pumping has developed at any place other than at the joints.

The 1320-ft. section is of sufficient length that approximately the center 500 ft. shows no daily longitudinal movement. It appears that the action in this central 500 ft. is similar to that which might be expected in a continu-

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[1] Italicized figures in parentheses refer to list of references at the end of the paper.

ous pavement of very great length. It is believed this experiment provides a definite indication that a continuously reinforced slab of any length is possible and practical. As no open cracks have formed in any section, however, we have no very good indication as to the minimum amount of steel required to prevent open cracks in slabs—say a mile or more long. As previously mentioned, 0.5 percent steel does appear to cause frequent tightly closed cracks in slabs of moderate length.

Perhaps the nearest approach to an answer to this problem is in the performance of drainage structures built under the direction of the Bureau of Reclamation. Information received from this Bureau states that a considerable group of structures containing continuous longitudinal reinforcement was built several years ago. These structures consisted of:

Concrete canal linings, 3 to 4 in. thick containing from 0.31 to 0.42 percent longitudinal steel,
Bench flumes containing 0.50 percent steel,
Monolithic pipelines (buried) containing 0.25 percent steel.

With these amounts of reinforcement, concrete lining quite generally cracked at intervals of 4 to 6 ft. Bench flumes cracked at similar or smaller intervals, the cracks generally being so fine as not to permit passage of water and often not detectable except by close examination. Cracking in monolithic pipelines was more erratic, but usually was widely spaced and of appreciable opening. Thus for drainage structures of this type, continuous reinforcement in the amount of 0.25 percent was inadequate and 0.50 percent seemed to be sufficient. However, the stresses in such structures are not identical to those in pavements. Stresses in concrete pavement would probably be greater because of the traffic loads.

THE ACTION OF STEEL IN LONG SLABS

The maximum temperature drop in pavement from summer to winter is often considered to be about 100 F. If we assume a steel bar which has its ends rigidly fixed, and lower its temperature 100 deg., the stress introduced is only about 18,000 lb. per sq. in. If, however, the steel is embedded in a concrete pavement the action is not so simple. It is generally assumed that the steel takes a low stress until the concrete breaks and that then all of the stress at that point is taken by the steel. In turn, the stress in the steel is gradually transferred back to the concrete by the bond between the concrete and steel. Of course, the fact that a crack in the concrete opens means that the steel has stretched somewhat in the immediate vicinity of the crack and probably that the bond is broken for a short distance on each side of the crack. This slight opening of the crack relieves the tension. As the temperature continues falling more tension is introduced. If the steel in a continuously reinforced pavement is inadequate in area it will stretch enough to allow an open crack to form and will eventually break. If the tensile strength of the steel exceeds that of the concrete, however, the steel will cause another crack and the stress in the steel will again be relieved by the slight opening of another crack in the concrete. This action will be continued until the entire pavement, except that near the ends, contains frequent narrow cracks.

In the Indiana project the center portion of the 1320-ft. slab contains cracks about every three feet. Measurement of these cracks with a special measuring microscope indicated a width of 0.002 or 0.003 in. No ravelling has occurred at these cracks and it appears that they are practically water tight.

From the standpoint of stresses introduced by temperature changes, the essential principle of the design of a continuously reinforced pavement appears to be that the steel be stronger in tension than the concrete. Then the steel will always cause another crack in the concrete before the steel itself is overstressed. If we assume a yield point of 50,000 lb. per sq. in. for steel and a tensile strength of 350 lb. per sq. in. for concrete, then the minimum area of the steel must be 0.7 percent of that of the concrete. By making allowance for a stress in the steel itself of 18,000 lb. per sq. in. due to a possible lowering of temperature of 100 deg., the effective strength of the steel is reduced from 50,000 to 32,000 lb. per sq. in. and the theoretical percent of steel becomes about 1 percent. Then a cross-sectional area of one sq. ft. of concrete would be equal in tensile strength to 0.01 sq. ft. of steel.

This principle of design is the same as that used in the design of structures to prevent the formation of open cracks due to shrinkage and temperature. Hool and Johnson's "Concrete Engineers' Handbook" has this to say of reinforcing steel for structures:

> "To prevent plainly noticeable cracks due to shrinkage and lowering of the temperature, all exposed surfaces should be reinforced with about 0.3 percent steel based on the cross-section of the concrete. This is less than the amount required theoretically, but experience shows this amount to give very satisfactory results where foundations are stable."

Other authorities recommend steel to resist the effects of temperature and shrinkage in structures in amounts ranging from 0.2 to 0.5 percent. This is in spite of the fact that about 1 percent is apparently required by theory. The writer believes that continuous reinforcement in pavements should be in the neighborhood of 0.5 percent if tensile stresses only are considered. It may be that the effect of other stresses such as shear will make more than 0.5 percent necessary. The determination of the correct percentage must be deferred until the results of experimental pavements are available.

Why less temperature steel may be required than indicated to be necessary theoretically presents an interesting problem. There may be a perfectly valid reason however. When fresh concrete sets, the action is accompanied by shrinkage of the concrete. Hatt and Mills in Purdue University Bulletin No. 34, published in 1928, shows that in 40-in. beams the plain concrete beams shrunk during setting about 2½ times as much as reinforced concrete beams. For years it has been accepted that steel controls shrinkage of concrete, but the mechanics of what happen are often overlooked. During its early life the concrete shrinks and steel does not. The steel therefore, causes many small cracks in the concrete at the time the shrinkage occurs. In other words, the steel does not keep the concrete from shrinking, but distributes the shrinkage into numerous small cracks instead of the wide open cracks that occur in plain concrete.

For the moment, in order to eliminate temperature stresses, let us consider a sample of reinforced concrete which is maintained at a constant temperature while shrinkage is occurring. This shrinkage causes a compressive stress in the steel and a tensile stress in the concrete. The magnitude of the stresses developed and the frequency of cracks in the concrete depend on several factors of which an important one is the tensile strength of the concrete at the time shrinkage occurs. This is materially affected by the efficiency of curing. The more curing is delayed and the lower the efficiency of curing, the sooner shrinkage will occur. The absence of curing promotes early shrinkage, and early shrinkage, occurring while the tensile strength of the concrete is low, causes closely spaced, tightly closed, cracks in reinforced concrete with a minimum of steel. Later on, when a material drop in the temperature occurs, shrinkage cracks already formed become miniature contraction joints.

These small cracks are visible only in cool weather and when the pavement is drying after a rain. The author has not been able to find this type of cracking in unreinforced pavement. It may be that these very small cracks, formed when the concrete shrinks, explain why less than the theoretical amount of temperature steel is required. Actually the steel does not have to be strong enough to pull the entire pavement apart because the latter has already been partially cracked at the time shrinkage due to drying occurred.

THE PROBABILITY OF BLOWUPS

The cause of blowups is not entirely certain. The compressive stress introduced by raising the temperature 100 deg. in concrete having fixed ends does not exceed 2500 lb. per sq. in., which is hardly enough to cause blowups in standard pavement concrete. Mr. Griffin of New Jersey (*4*) has given an explanation that undoubtedly applies in at least some cases. Dirt getting into a crack at the top and perhaps also at the bottom, causes the concrete to spall when the temperature rises and the crack tends to close. After a while, as a result of spalling, the compression across the crack must be carried by a much smaller section of concrete than the original full depth. Blowups then occur due to the entire compressive force being concentrated on an area considerably less than the full cross-section of the pavement.

It is recognized that dirt getting into cracks fills up space that would otherwise be available to relieve compressive forces. In a properly designed continuously reinforced pavement the cracks are held so tight that dirt does not get into them and spalling does not occur. Very likely these features will prevent many blowups that would otherwise occur. Whether or not blowups will be entirely prevented can only be proved by building such pavements and watching developments.

PAVEMENT THICKNESS

Two of the major items of design that control the required thickness of pavements are free edges and warping stresses. The designs in question, if satisfactory, would have no transverse cracks or joints other than the tightly closed cracks, across which effective load transfer would be maintained. The transverse cracks spaced at 3- or 4-ft. intervals may be expected to reduce warping stresses in a longitudinal direction to a negligible amount. The author does not know how to solve the problem mathematically, but there is a possibility that less thickness will be required than is being generally used.

SUBGRADE TREATMENT TO PREVENT PUMPING

As is implied by the word "pumping" the action that takes place involves the vertical movement of one slab end with respect to the adjacent end. Water accumulated in the void under the crack or joint is agitated until a slurry of mud and water is formed and forced out from under the pavement. It is not believed this would happen in a continuously reinforced slab because:

1. There can be no appreciable vertical movement of one slab with respect to the adjacent slab.

2. The absence of open cracks or joints will prevent most surface water from reaching the subgrade.

3. So far as the author is aware, pumping is always associated with cracks and joints. Pumping has not developed in the long reinforced slabs in Indiana except at the joints. Therefore, it is believed subgrade treatment will not be required in order to prevent pumping.

AMOUNT OF STEEL REQUIRED

It has been suggested that the amount of steel required to accomplish the purpose may be about 0.5 percent of the cross-sectional area of the pavement. In a 7-in. pavement this would require an amount equivalent to a ½-in. round bar spaced at 5½ in. This amount of longitudinal steel is about 145 lb. per hundred sq. ft. The amount of transverse steel required will depend on the details of the design of the reinforcement and also on whether or not one desires to eliminate the center longitudinal joint and provide enough transverse steel to hold the longitudinal cracks very tightly closed. If one allows 25 lb. per 100 sq. ft. for transverse steel where the center joint is retained and 36 lb. if the center joint is eliminated, a total weight of steel of either 170 lb. or 181 lb. per 100 sq. ft. is obtained. For 8-in. pavement, these weights become 191 and 202 lb. per 100 sq. ft.

SUMMARY OF POSSIBLE ADVANTAGES

The elimination of joints will avoid the bump, bump, bump, of the uniformly spaced transverse joint. The surface will provide a waterproof cover over the subgrade. It is believed that the elimination of joints plus a water-tight surface will eliminate pumping. The occurrence of corner breaks would seem unlikely. There should be no cracks open wide enough to need sealing so that in addition to a reduced maintenance cost, there will be no black lines across the pavement. It would be expected that the pavement will remain permanently about as smooth as when constructed. The elimination of joints and open cracks would prevent the saturation of the concrete adjacent to these openings and probably would result in the concrete being less susceptible to damage from freezing and thawing.

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PRELIMINARY REPORT ON CURRENT EXPERIMENT WITH CONTINUOUS REINFORCEMENT IN NEW JERSEY

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SYNOPSIS

In the fall of 1947 two sections of continuously-reinforced concrete pavement were constructed on New Jersey Route 25 between Hightstown and Cranbury. This section of highway carries a considerable volume of heavy truck traffic. The northerly section is 5430 ft. long, of 8-in. uniform thickness, and contains 0.90 percent of longitudinal reinforcing steel. The southerly section is 5130 ft. long, of 10-in. uniform thickness, and contains 0.72 percent of longitudinal reinforcing steel. The project also included the construction of a series of experimental slabs 187 ft. in length having an additional amount of longitudinal reinforcing steel within their central portions.

Reference lines were established to determine the magnitude of subsequent longitudinal movements of the ends and interior portions of the continuously-reinforced sections. Numerous gauge points were installed to subsequently determine: (1) the widths of cracks; (2) changes in the lengths of various parts of the sections; (3) changes in the widths of all transverse joints, and (4) the amount of opening of the longitudinal joints. Series of gauge points were installed in the 187-ft. slabs to determine the changes in length of various parts of the slabs during expansion and contraction. Levels were taken in several locations to determine the amount of subsequent changes in pavement elevation.

This paper pertains primarily to the details of the design, materials employed, construction procedures, and incidental research. Data pertaining to behavior during construction and early life are included.

It appears needless to elaborate on the fact that the joints in the conventional design of concrete pavement constructed in the past have been a major contributing cause of various kinds of serious difficulties. Although very definite improvements in the design of joints and other incidental pavement features appear to have been made in recent years, the joints nevertheless remain as points of weakness. This situation has provoked thought as to whether, by means of installing a sufficient quantity of longitudinal reinforcing steel, a successful concrete pavement could be constructed that, in effect, would be continuous throughout. The design of pavement that has evolved from this line of thinking is commonly called "continuously-reinforced". The outstanding features of this design are:

1. The installation of a substantially greater amount of longitudinal reinforcing steel than is installed in pavements of conventional design.