

42 *PURDUE ENGINEERING EXTENSION DEPARTMENT*

mail route over this highway will be discontinued unless this road is completed before a certain time. These are some of the things that will probably cause you to miss the ball game; yet they are problems that must be satisfactorily solved, and are a part of the responsibilities of the county surveyor in the building of county roads.

**THE RESPONSIBILITIES OF THE COUNTY SURVEYOR  
IN THE BUILDING OF COUNTY ROADS**

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By Dave Harker,  
Clinton County Surveyor.

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The county surveyor's responsibilities in the building of county roads are many, but they can all be summed up in two principal responsibilities.

First of all, the surveyor must see that the road is correctly specified. The other two viewers for the road have more to do and say concerning the probable utility and benefits of the road. The surveyor is the engineering brains in the design of the road, and as such has many responsibilities in the correct design. It is not within this topic to discuss what are the proper methods as to size and shape of side ditches, types of culverts and their location, gradation of gravel or the depth and width of gravel. Whatever may be the beliefs of the surveyor, he should specify the road correctly as far as clearness and his views of engineering design are concerned.

When the road is ready for actual construction, the second of the surveyor's principal responsibilities is at hand, that is, he must see that the road is built to specifications. The superintendent of construction is appointed by the board of commissioners to superintend construction, but too often the man appointed knows little about how a road should be built. The surveyor should always take the final responsibility for the building of the road. The position of the superintendent of construction should be approximately that of an assistant to the surveyor. The surveyor is wise who assumes the responsibility in the beginning and has direction of the work, rather than to allow the superintendent of construction to run the job, and then hear the public say, "It was the surveyor's fault." No matter how hard the surveyor may try to shift the responsibility for the failure of a job to other shoulders, the public will place the credit where it rightfully belongs—upon the county surveyor.

We built three miles of gravel road last summer under rather rigid specifications calling for gravel which would test not more than forty per cent through the quarter inch screen. The first five carloads which came in tested sixty per cent through the quarter inch screen and we rejected them. The gravel company's representative—a man from Missouri—had to be shown, so we tested it for him and he admitted that the gravel was finer than that specified. "But," he said, "you can use it anyway, for no county surveyor adheres that closely to specifications." That is a serious charge. Every county surveyor should adhere closely to specifications. If you believe that a greater per cent of fine material is desirable in your gravel, then specify it that way, but once you have specified the gradation of the gravel, adhere to specifications.

In conclusion, let me sum up what I have said in these phrases: First, say what you mean, and, second, mean what you say!

## THE ECONOMICAL DESIGN OF ROADWAY STRUCTURES

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By W. J. Titus,  
Chief Engineer, Indiana State Highway Commission.

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One of the important things which a concrete pavement slab has to do is to support heavy vehicular loads. The function of the pavement slab, as of any other structure, is to transmit these loads to the subsoil, distributing them so that they will not cause too great a load on any area of the soil. Exactly as in any other structure, these loads must be transmitted to the subsoil without any damage to the pavement slab. To design a simple beam supported on piers or abutments at each end is not a difficult matter, but at the present time, it is quite a different matter to rationally design a pavement slab resting on a continuous support throughout its length, which support is yielding to a degree which we cannot determine—in fact to innumerable different degrees within comparatively short distances.

The task seems next to impossible, but much experimental and research work is being done, by the U. S. Bureau of Public Roads and by highway departments and universities, including our own Purdue University, so that I believe in a few years, we will be able to approach a pavement design task with something of the same assurance with which we now start on the

design of a bridge. The situation in pavement design now is probably not less advanced than was the matter of bridge design less than a century ago. There are still many evidences of this right here in Indiana. In most old timber bridges built before the Civil War, the size of all timbers in the upper and lower chords was kept the same for the entire length of the bridge, but we now know very well that in both chords, the stresses are very much greater at the middle of the span. Likewise, in these old timber bridges, the diagonal truss members were usually of the same size in every panel, but we know that the stresses are very much greater and the diagonal members should be much larger near the ends of the spans.

We have been prone to assume that the corners of a pavement slab next to a transverse expansion joint are weaker than any other part of the pavement, but experiments made by the U. S. Bureau of Public Roads within the last year indicate that this may not be true for 90° corners and that the points showing the greatest tensile (and consequently most dangerous) stresses are found on the under side of the slab directly beneath the wheel load when that load is very close to the edge of the slab. This seems scarcely reasonable, but is apparently in accordance with both theoretical and experimental research. Recent experiments also indicate that the same wheel loads, when as much as 21" from the edge of the slab, under the subsoil conditions which existed where the slab was tested, caused tensile stresses somewhat less than one-half those caused when the load was but 9" from the edge of the slab. On the face of it, this indicates that the edges of the pavement should be thicker than other portions or that heavy loads should be kept near the middle of the slab. The latter is of course impossible.

This result was also indicated by the now well known Pittsburg, Cal., and Bates, Ill., experimental roads, which were built at great cost and tested to destruction under careful engineering control. From the data secured in these and other investigations, there have been developed the following formulas for determining the thickness of a concrete pavement slab:

$$(1) \quad t_1 = (3P/f)^{1/2}$$

$$(2) \quad t_2 = 0.7t_1$$

Where  $t_1$  = the edge thickness of the pavement slab in inches;  
 $P$  = the maximum wheel load in pounds;  
 $f$  = the allowable tensile stress in concrete in lbs. per square inch;  
 $t_2$  = the thickness of the slab near the middle of the roadway.

In Indiana, the maximum legal wheel load is 11,200 pounds. If the maximum allowable value of  $f$  be assumed at 350 lbs. per square inch, then

$$t_1 = (3 \times 11,200 / 350)^{1/2}$$

$$= 9.8''$$

and  $t_2 = 6.8''$

There are, however, a good many other factors which must be considered. It is necessary to make transverse joints at certain intervals, at least at the end of each day's run. On each side of these joints will also be unsupported edges, just as truly as along the sides of the pavement slab. In some respects, the conditions will be more severe along the edges at these transverse joints, because all heavy traffic will have to cross such joints—not merely run parallel to them—and the crossing will cause the setting up of impact if there is any variation in the elevation of the surface of the pavement across the joint. So it seems certain that the edges along such transverse joints should also be thickened or otherwise strengthened—that the necessity for such strengthening may be even greater than along the sides of the slab. At the annual convention of the Mississippi Valley Association of State Highway Departments in Chicago last week, a representative of one State said they had, in their concrete pavements, for at least one season, so thickened the edges next all transverse joints, but that within a few months in nearly every case a transverse crack appeared along the line where the thickened section was reduced to normal thickness!

This indicates that there were some forces at work on these slabs which were not considered in the design. I suspect that in this case, the force was that of contraction, due largely to changes in temperature or moisture content. Without the thickened edge next the transverse joint, the slab might slide on the subsoil when contraction takes place—and in fact would do so unless the friction on the base were greater than the ultimate strength of the concrete cross-section of the slab. But the thickened edges next the transverse joints served precisely as an anchor for the end of the slab, so that it could not slide on the subgrade and could not be expected to do other than crack away from the anchored end of the slab. From this it seems that the situation will be made worse by the thickened edge next the transverse joints, unless the thickened portion be extended for a long distance in each direction from the joints so as not to serve as an anchorage to the subgrade.

To complicate the situation still more, there is the certainty that transverse and diagonal cracks will form in the slab at intervals—we do not know just what intervals. As

soon as these cracks have opened a very small amount, so that there is no dovetailing of the broken pieces of concrete, the necessity for thickened or strengthened slab sections adjacent to the cracks will be as great as at transverse construction joints. Because these cracks are liable to occur at any point in the pavement, it seems to follow logically that all portions of the pavement slab should be thickened! This would mean of course a slab of uniform thickness and I am not so sure that this is not the most rational design which can be devised, though large numbers of states and other municipalities have recently adopted and are now using designs with thickened or strengthened edges along the sides of the pavement. But I am not ready to say that this pavement slab should have a 9.8" uniform thickness, in view of our very satisfactory experience with a 7" uniform thickness. All of these ideas are quite confusing, but I believe that if we do not get discouraged, avoid upholstered furniture and keep plenty of sharpened pencils conveniently close, we will, some of these days, know about what is a proper pavement design.

### Longitudinal Joints

There is one design feature about which most state highway officials are now agreed—the keyed longitudinal center joint in pavements of about 18 feet in width, which is being required in Indiana's 1926 pavements. When a pavement slab is subjected to varying temperature and moisture content conditions, these changes occur much faster in the upper surface of the slab. With a dry and perhaps cool condition on the upper surface, as often occurs during a summer night, there will be extreme contraction stresses in the fibres next the upper surface, while the lower surface next the subsoil may be moist and warm, which will cause expansive forces and the slab will warp concave upwards. This warping is often sufficient to lift the edges of the slab clear of the subsoil, so as to create a heavy bending moment near the middle of the slab, due to the weight of the slab itself and of wheel loads on the edges. To use the parlance of the railroad maintenance man, the slab is "center-bound," exactly as railroad ties often are center-bound, causing the breaking of many ties when a train passes over such a stretch of track.

Exactly the opposite condition will of course exist, when the lower surface of the slab is cool and dry and the upper surface is hot and perhaps moist, causing the slab to warp convex upward and even raising the middle of the slab entirely from the subgrade. It is next to impossible to make our slabs of sufficient thickness to reinforce them against the

heavy stresses created under some of these conditions, so there was hit-upon the expedient of making a hinged joint down the middle of the pavement, so that the two halves of the slab can rotate about this joint. The same warping condition will of course still exist for the half-widths of the slab, but the amount of warping will be very much less and the bending moments from wheel loads will probably be less than one-fourth as great. There are several types of these center joints, but there is not much choice between them from a structural standpoint, so long as the two halves of the pavement are efficiently keyed together and so held with dowel bars, that loads supported on one side of the joint will also be very considerably supported by the slab on the other side of the joint.

### Contraction Joints

The feature of pavement design about which perhaps there is now most discussion is the matter of reinforcing the slab against temperature stresses and those stresses due to wheel loads and to changes in moisture content. The use of such reinforcing is with the expectation of predetermining the locations of all cracks or joints and making adequate provision for a slab of uniform strength throughout, including the edges of such pre-formed joints. It is a comparatively simple matter to develop an equation from which the spacing of such transverse contraction joints can be determined, for certain assumed conditions equating the total resistance to sliding on the subgrade for half the distance between contraction joints to the safe working tensile strength of the steel and concrete in a transverse section of the slab. This can be worked out on either one of two assumptions: (1) that the stresses in the concrete of the section shall not be severe enough to cause even half cracks, or (2) that the steel be stressed up to a safe working value, in which case there are sure to be many fine hair cracks in the concrete. There should presumably be no objection to these fine cracks, since they will be keyed together by the rough surfaces of the cracks and will be held tightly together by the reinforcing bars, so that they cannot open wider—in effect a hinged joint exactly like a keyed center joint.

Without any reinforcing bars at all, these pre-determined contraction joints should, under the first of the above assumptions, be about 29 feet apart, under certain further assumptions as to thickness of slab, width of pavement, weight of concrete and the coefficient of friction of the concrete slab on the subgrade. Under these same conditions, this spacing

between transverse contraction joints can theoretically be increased as much as 100 feet or more, by the addition of definite amounts of longitudinal reinforcing steel. There is, however, at the beginning of this computation, an assumption which may not be in accordance with the facts, which is that the steel bars will be able to absorb all the tensile stresses in the section most highly stressed. As a matter of fact these stresses will sometimes be a maximum near the top surface and sometimes near the bottom surface, so that with reasonable amounts of steel, there will, I fear, be many cracks between contraction joints under most any conditions we can secure. The situation can, however, obviously be helped by reducing the coefficient of friction between the slab and the subgrade, so that the slab can more easily slide on the soil. In a number of instances, this has been attempted by the use of building paper spread over all the subgrade and I believe this is said to help the situation somewhat.

From the foregoing, it would seem that the use of transverse expansion or contraction joints is indicated, with some suitable plastic material in these joints to allow for expansion and contraction. A number of state highway departments, including, I think, Wisconsin, Michigan and Pennsylvania, which latter state laid more pavement last year than any state ever before laid in one year, have definitely adopted standards which require such contraction joints at regular or specified intervals. In the Indiana department, we believe that the use of these joints is indicated as an early development in concrete pavement slab design, in an attempt to prevent the unsightly cracks and the "blow-ups" which so often occur under certain weather conditions, usually perhaps at the summits of grades or near horizontal curves, but we are not convinced that the desirability of using such contraction joints has yet resolved itself into what may be termed a definite conclusion. In all arts which are in a formative stage, certain ideas may be only indications, while others may be definitely classified as conclusions—in fact many indications later resolve themselves into conclusions.

Our objections to the transverse contraction joints are chiefly from the human impossibility of making with their use as smooth a pavement as when they are omitted. It seems reasonable, too, to assume that the pavement over these joints will get rougher from year to year, due to the warping or curling action from temperature and moisture content changes, because the slab is, as nearly as I know, as sure to warp parallel to the center line of the road as transversely to it. Each time the slab next a joint is curled upward, it fails to return quite to its original position, so that it seems the joints should con-

tinue to get higher. Perhaps this same action explains why badly cracked pavements are usually rougher than those with few cracks and why they continue to get rougher.

All of this is I think more confusing than any other type of structural design, but by just such rambling discussions as this can we look over a portion of the field and draw at least a few conclusions to guide us through a part or all of another construction season. Before closing I want to give a little time to the design of pavement concrete itself, from an economic as well as a structural standpoint. Concrete must be made of cement, water, sand and gravel or crushed stone or crushed slag. Fortunately Indiana's natural resources are such that we have within our borders satisfactory and convenient supplies of all these ingredients. If we are to do our duty in spending the public funds, these ingredients must be used in such a condition that they will give satisfactory service in a slab or other roadway structure and, subject to that provision, those materials must be used which can be most economically secured. Of these materials, the two which in Indiana are strictly competitive are washed and screened gravel and crushed, screened and perhaps washed stone.

The stone of course occurs in solid ledges and must be crushed before it can be used in concrete. To crush this stone requires power and costs money, so it is evident that, if it is to be used most economically, it must be used in as large particles as can satisfactorily be incorporated in the concrete in order to save the expense of crushing the stone any finer than necessary. On the other hand, the Indiana gravel deposits contain much fine material compared to the amount of larger pebbles. It is quite evident, therefore, that if gravel is to be used as economically as possible, there must be used as large a proportion of the smaller particles as can satisfactorily be incorporated in the concrete. It is my belief that just these assumptions were made when the Highway Commission's specifications for grading of gravel and crushed stone were prepared a number of years ago. There was the further attempt to so design the grading in both cases that the resulting concretes would be of as nearly equal strength as possible. That this result has been fairly accomplished is evidenced by the results of compressive tests made of 2427 cores of concrete taken from our pavement slabs up to June, 1925. Of these 1797 were from projects in which gravel was used and 630 were from projects in which crushed stone was used. The average strength of the former was 4650 pounds per square inch, and of the latter 4520 pounds per square inch.

Because this is the first opportunity I have had to talk to all of you county surveyors and engineers, or in fact to any



of you, in regard to our policy in approving plans and specifications sent to us for review, I could not refrain from outlining to you the reasons for the position we have taken in regard to specifications for these and other materials, which we believe is on the basis of equal opportunity to producers of each material, depending only on the economy with which they are able to produce and transport their material to the point of ultimate use and not at all upon any artificial differentiations between the two materials, none of which we believe to exist, so far as use in cement concrete are concerned. We hope that you will appreciate that we are not attempting to dictate to you as county officials any of the policies of your offices except as we are required by statute to set certain standards, to which requirement and standards we believe you can have no objection. We will always be glad to see you when you are in Indianapolis or near any of our district offices and to discuss with you, as I have today, any of our mutual problems.

### **ECONOMICAL DESIGN OF CONCRETE AND OTHER HARD SURFACE PAVEMENTS**

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By Frank T. Sheets,  
Chief Engineer, Illinois Division of Highways.

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(Note: Mr. Sheets did not present a paper. The following notes cover briefly the main points of his talk.)

Mr. Sheets emphasized that economy of design could be obtained only when pavements having a thickness adequate to carry maximum legal loads were built. He pointed to the folly of jeopardizing high class paving surfaces by inadequate foundations.

Mr. Sheets also pointed to the necessity of determining definitely by laws properly enforced the loads which may be expected upon highways or streets. He further explained the principles of design developed by the Bates Experimental road built and tested by the Illinois Highway Department, and pointed out how these principles, if properly applied, would produce pavements capable of carrying definitely determined maximum loads at minimum cost.

The great importance of building safety into highways was also discussed by Mr. Sheets. He emphasized the necessity of using curves of long radius and with proper super-elevation to obtain proper economy of operation and use. An-