Crack Formation in Continuously-Reinforced Pavements

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The mechanics of crack formation in continuously reinforced pavement slabs, as understood from the literature on several field test pavements, are summarized.

Results of a series of laboratory experiments on simulated continuously reinforced concrete slabs are given, with those results pertaining to the formation of cracks being emphasized. The findings of these laboratory experiments are correlated with the field observations reported in the literature and one criterion for the design of continuously reinforced pavements is suggested.

Some of the more important conclusions reached as a result of this research, subject to the limitations imposed by the range of variables studied, are as follows:

1. The effects of concrete shrinkage, temperature changes, and wheel loads on crack formation in continuously reinforced pavements can be adequately simulated in the laboratory without producing actual temperature changes in an infinitely long pavement slab.
2. The formation of a complete crack pattern in a continuously reinforced pavement is the result of a superposition of the effects of concrete shrinkage, temperature changes, and live (wheel) loads.. Perhaps the importance of live loads has been somewhat underestimated in past discussions of this problem.
3. Crack spacing in a continuously reinforced pavement with some age and use varies inversely with the percentage of longitudinal steel reinforcement, if the steel is placed at mid-depth, with a minimum average crack spacing of about 2 ft in a slab having 0.768 percent longitudinal steel.
4. It is generally agreed that a continuously reinforced pavement slab must be reinforced with longitudinal steel in sufficient amount to maintain all transverse cracks in a tightly closed condition. For mid-depth reinforcement this condition is met when increasing longitudinal forces caused by temperature drops, in combination with live loads, tend to cause additional cracks rather than to open existing cracks forever wider. This standard is suggested as one criterion (among others) for the design of continuously reinforced pavements.
5. The suggested design criterion is satisfied for an 8-in. pavement resting on a subgrade having a modulus of 160 pci, by 0.45 percent longitudinal reinforcement either in the form of deformed bars or welded wire fabric reinforcement placed at mid-depth in the slab.

● THE MECHANICS of crack formation in continuously reinforced pavements is qualitatively understood as a result of long-term observation of the several test strips of such pavements now in existance (1, 2, 3, 4, 6). The formation of the cracks has, in fact, received more attention that any other phase of the experiments — correctly so, since the spacing and configuration of the cracks in continuously reinforced pavements form the common denominator of the other important design parameters such as crack widths, pavement deflections, and steel stresses. Cracks are generally considered to have been formed in these pavements by the combination of concrete shrinkage during curing and climatological temperature changes during and after the curing period.

Longitudinal reinforcement steel in a concrete slab offers restraint against shrinkage of the concrete. The tendency of concrete to shrink builds up longitudinal tension in the concrete and compression in the steel. If the tensile stress reaches the magnitude of the tensile strength of the concrete a crack forms, thus relieving the longitudinal stresses at and near the crack. This action presupposes the presence of adequate steel to resist the compressive force induced in the steel by the shrinking concrete. An infinitely long, adequately reinforced slab will crack at fairly regular intervals due to such concrete shrinkage.

Climatological temperature changes tend to cause similar volume changes of concrete and steel; that is, the coefficient of linear thermal expansion of the two materials is on the same order of magnitude, and an increase in temperature above casting temperature tends to make both materials expand about the same. However, a long continuously reinforced concrete slab is, in all regions at some distance from the slab ends, effectively restrained against longitudinal expansion, and the tendency of the materials to expand tends to close any transverse cracks and to build up longitudinal compressive stresses in the two materials. Since both materials are quite strong in compression, no damage normally comes from such expansion. On the other hand, a decrease in temperature tends to cause both materials to shorten. The effective restraint against this contraction tends to widen any existing transverse cracks, to build up tensile forces in the steel at cracks, to induce tensile forces in the concrete and steel between cracks, and to develop bond stresses between the steel and concrete near the cracks. The tensile stress in the concrete between cracks may reach the magnitude of the tensile strength of the concrete and thus form additional cracks.

The formation of additional cracks by temperature decrease completely relieves the concrete of tensile stress only at the cracks. The flexural action between cracks in slab segments caused by vertical loads (wheel loads) on the pavement superimposes longitudinal compressive and tensile stresses on the upper and lower portions of the slab, respectively, directly under the load and vice versa, but of lesser magnitude, some distance away from the load. The superposition of these flexural stresses upon the temperature and shrinkage stresses may cause the tensile strength of the concrete to be surpassed and may thus form additional cracks.

The formation of the complete crack pattern in a given continuously reinforced pavement slab results from the superposition of concrete shrinkage, temperature changes, and wheel loadings. The first cracks develop as a result of shrinkage alone, more cracks are formed by the combination of shrinkage and temperature change, and the crack pattern finally becomes complete as the result of the combination of all three causes over a long period of time. In the literature, much emphasis has been given to the first two of these three primary causes of slab cracking, shrinkage and temperature changes.

PURPOSE AND SCOPE

The objectives of this paper are:

1. To report the results of a series of laboratory experiments on simulated contінously reinforced concrete slabs, with emphasis on those results pertaining to the formation of cracks in the slabs.
2. To correlate the results of these laboratory experiments with reported field data on the cracking of continuously reinforced pavements.
3. To arrive at tentative criteria for the design of continuously reinforced pavements as suggested by this study of crack pattern formation.

In using the information included in this report, the limitations delineated by the range of the variables introduced in the laboratory experiments should be kept in mind. This range of variables, which is outlined in the following section, is being expanded

TABLE 1

DESCRIPTION OF SLAB SPECIMENS

Slab No.	Reinforcement[2]	Percent Reinforcement	Position of Reinforcement below top	Reinforcement[3] Yield Point Stress, psi	Reinforcement Ultimate Strength, psi	Concrete Compressive Strength, psi
1	D.B. #4 at 9" O.C.	0.278	4 inches	57,300	94,600	4800
2	D.B. #5 at 9" O.C.	0.430	4 inches	56,300	97,500	5200
3	D.B. #5 at 7" O.C.	0.533	4 inches	56,300	97,500	4270
4	D.B. #6 at 7" O.C.	0.768	4 inches	55,800	97,600	4730
5	D.B. #5 at 7" O.C.	0.533	6 inches	69,500	104,400	5690
6	D.B. #5 at 7" O.C.	0.533	5 inches	69,500	104,400	3500
7	WWF 6 x 12 0/3	0.154	4 inches	—	93,400	5360
8	WWF 6 x 12 00000/0	0.303	4 inches	—	80,400	4720
9	WWF 4 x 12 00000/0	0.450	4 inches	—	80,400	4620
10	WWF 4 x 12 00000/0	0.450	5-1/2 inches	—	80,400	4230
11	WWF 4 x 12 00000/0	0.450	2-1/2 inches	—	80,400	4450

[2] D.B. is abbreviation for deformed bars; WWF stands for welded wire fabric.

[3] Section f(a) of ASTM Specification A82-34 for Cold Drawn Steel Wire for Concrete Reinforcement specifies yield stress to be 0.8 ultimate tensile strength. Section 4(d) states that "the yield point shall be determined by the drop of the beam or halt in the gage of the testing machine. In case no definite drop of the beam or halt in the gage is observed until final rupture occurs, the test shall be construed as meeting the requirement for yield point in Paragraph (a)." Thus, while the wire reinforcement had no definite yield point, it satisfied the specification. Specification A82-34 has been in effect during the entire time of this project.

through the continuation of this research program; future results may substantially add to or otherwise alter the findings reported here.

Important criteria for the design of continuously reinforced concrete pavements will result from the studies of stresses in the reinforcement and the deflections of the slabs. Results of such studies are reported elsewhere for laboratory experimental slabs continuously reinforced with deformed bars (7) and welded wire fabirc (8).

LABORATORY EXPERIMENTS AND RESULTS

The specimens for these experiments were reinforced concrete slabs 8 in. thick, 3 ft wide, and 28 ft long (9, 10). The controlled variables included in the experiments were type of reinforcement, percentage of longitudinal reinforcement, position of reinforcement, range of simulated temperature drop after casting of the concrete, and magnitude and position of simulated wheel loading. The partially controlled variables included primarily the strength and stiffness of the concrete. The slabs tested and the magnitude assigned to each variable for the various slabs are summarized in Table 1. The subgrade modulus was maintained constant at 160 pci through the use of a rubber subgrade.

After each slab was cured, it was lowered onto the rubber subgrade and cracked through at each of the three weakened planes by slight non-uniform lifting of the slab. Thus, the central test region of each slab had preformed cracks at 5-ft intervals. This was done to be certain that cracks would occur at the location of SR-4 strain gages on the reinforcement steel, although it was anticipated from the results of reported field tests that additional cracks would develop during the laboratory experiments.

Vertical loads were applied to each slab successively at eight load points on slabs 1 through 6 and 9 through 11 and at seven load points on slabs 7 and 8. The locations of these vertical load points are shown in Figures 1 through 11. The vertical loads were applied in magnitudes of 5,000, 10,000 and 15,000 lb through bearing plates and rubber pads 12, 18, and 18 in. in diameter, respectively.

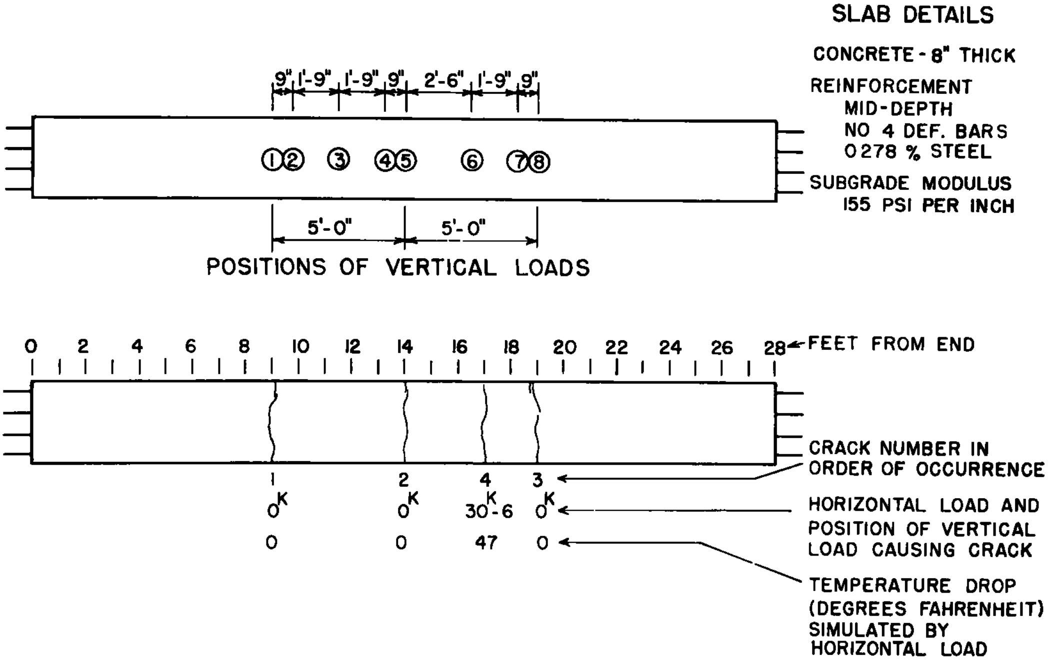

Figure 1. Crack formation — Slab 1.

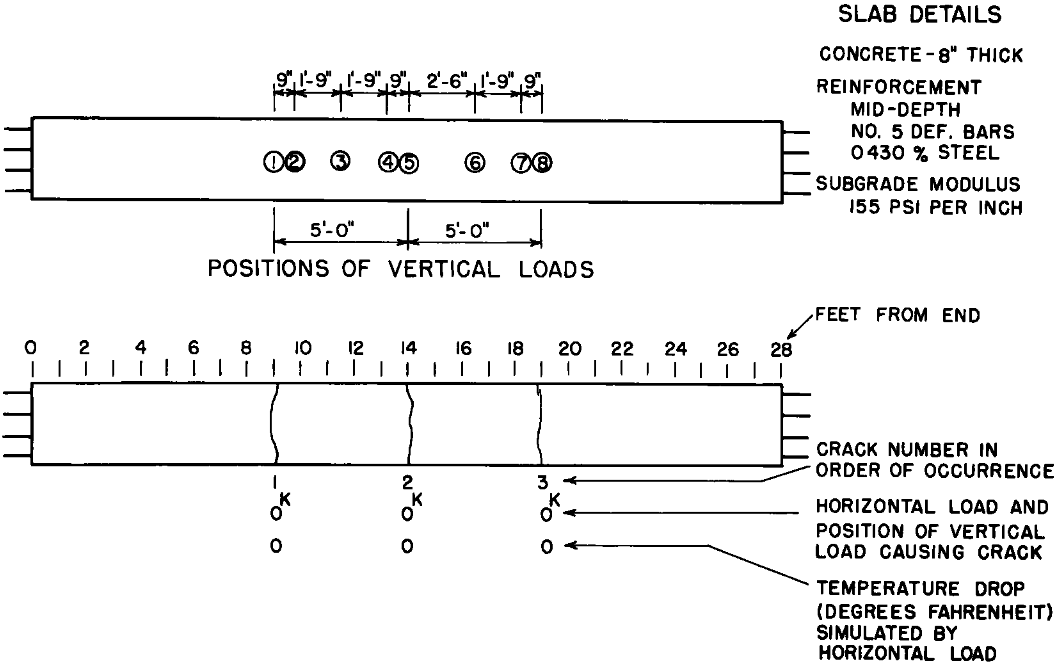

Figure 2. Crack formation — Slab 1.

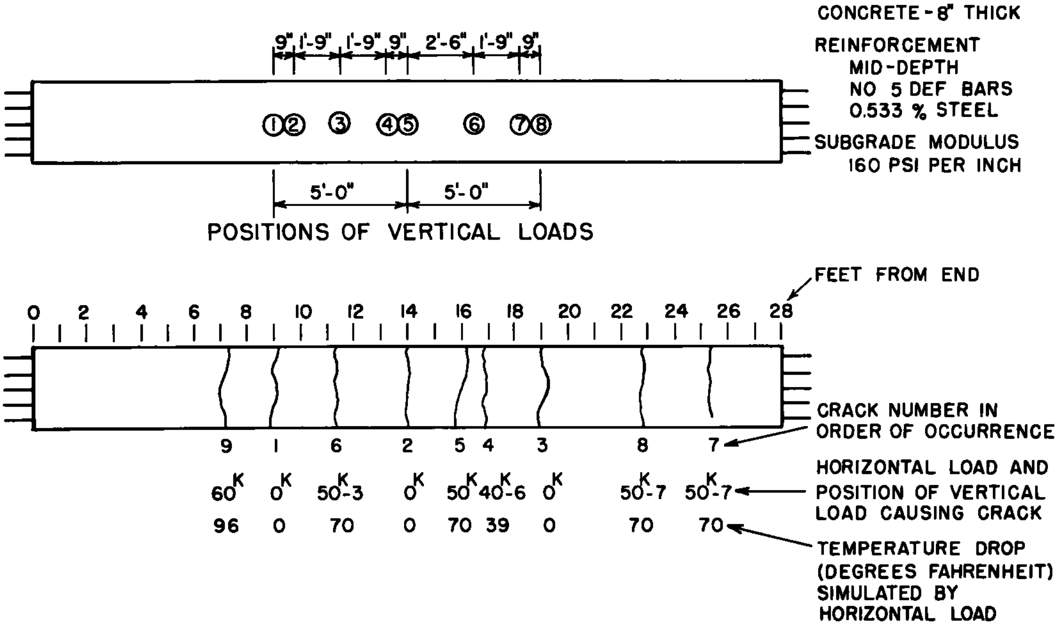

Figure 3. Crack formation — Slab 3.

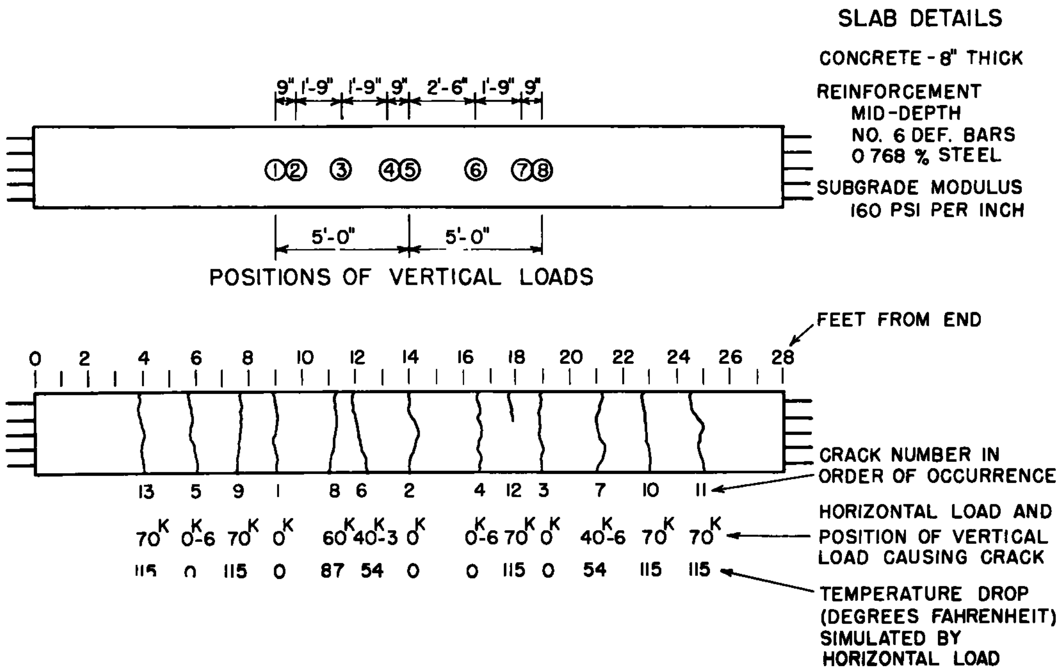

Figure 4. Crack formation — Slab 4.

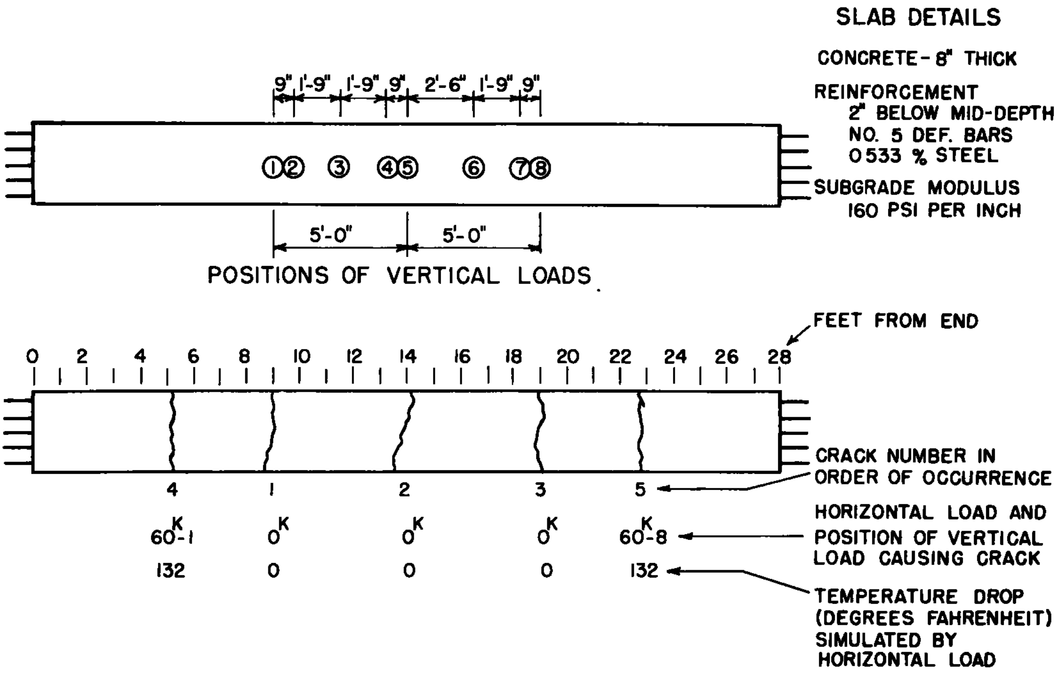

Figure 5. Crack formation — Slab 5.

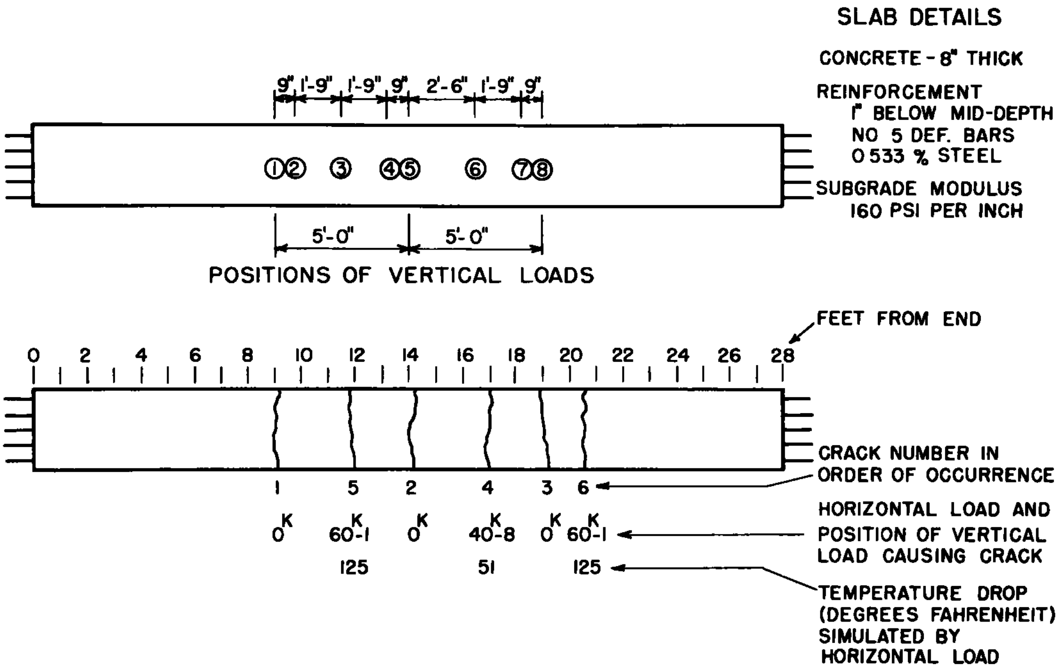

Figure 6. Crack formation — Slab 6.

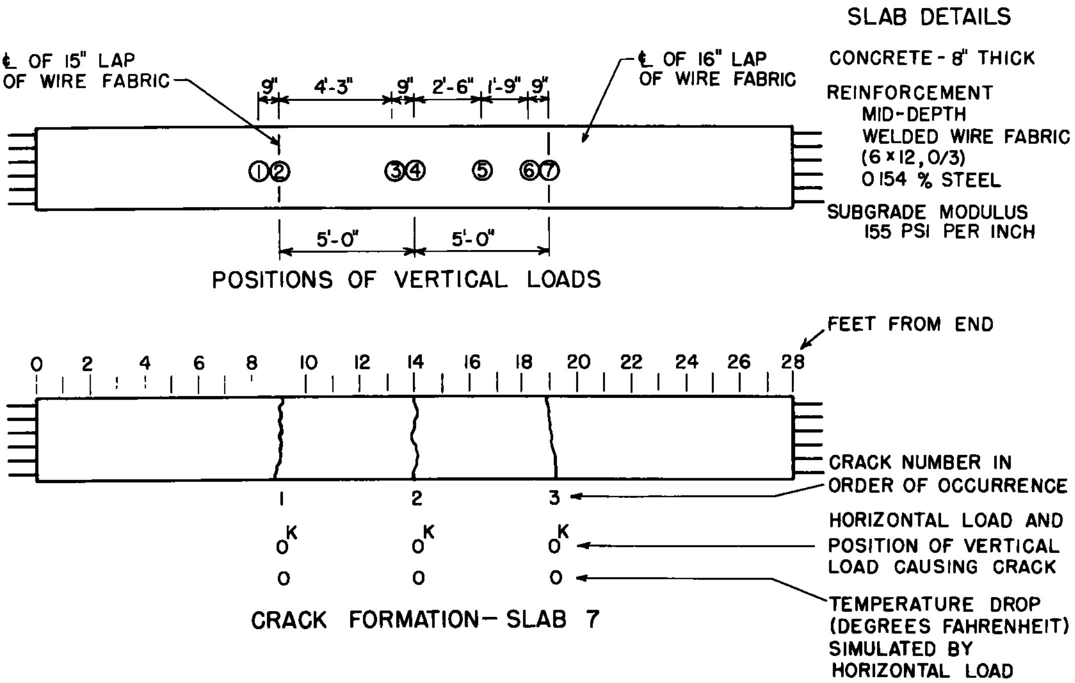

Figure 7. Crack formation — Slab 7.

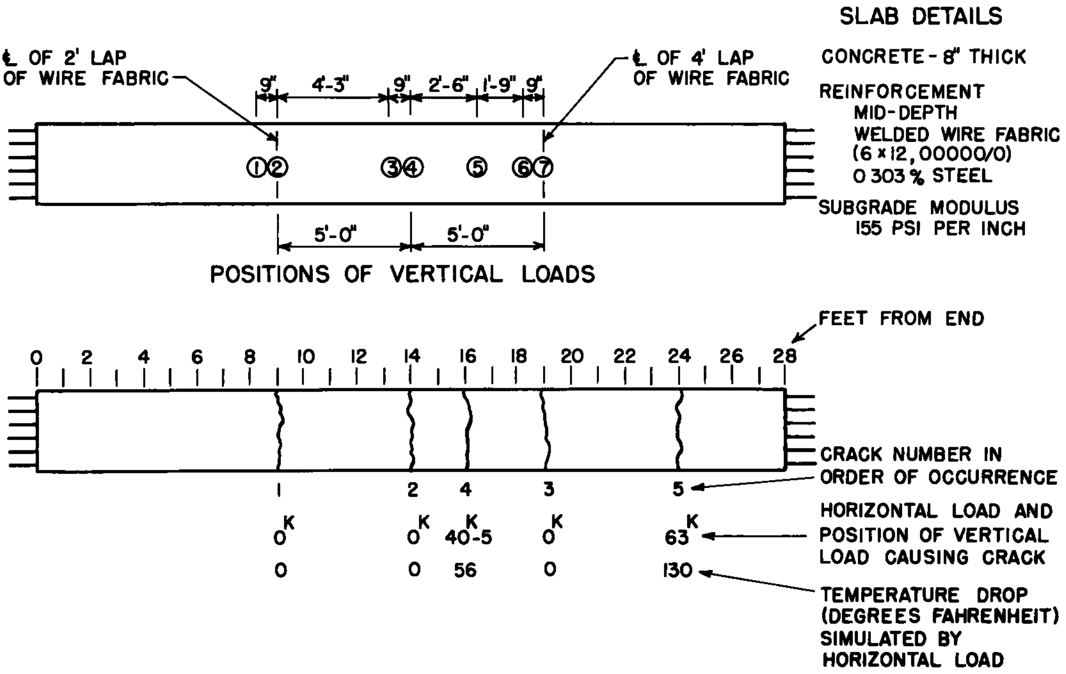

Figure 8. Crack formation — Slab 8.

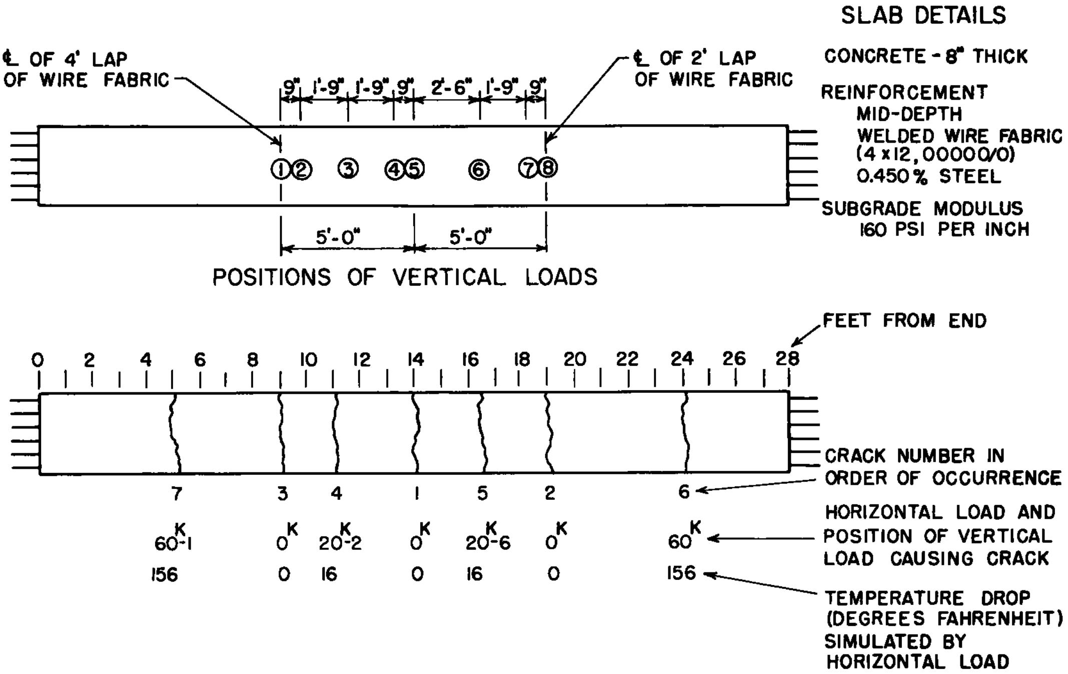

Figure 9. Crack formation — Slab 9.

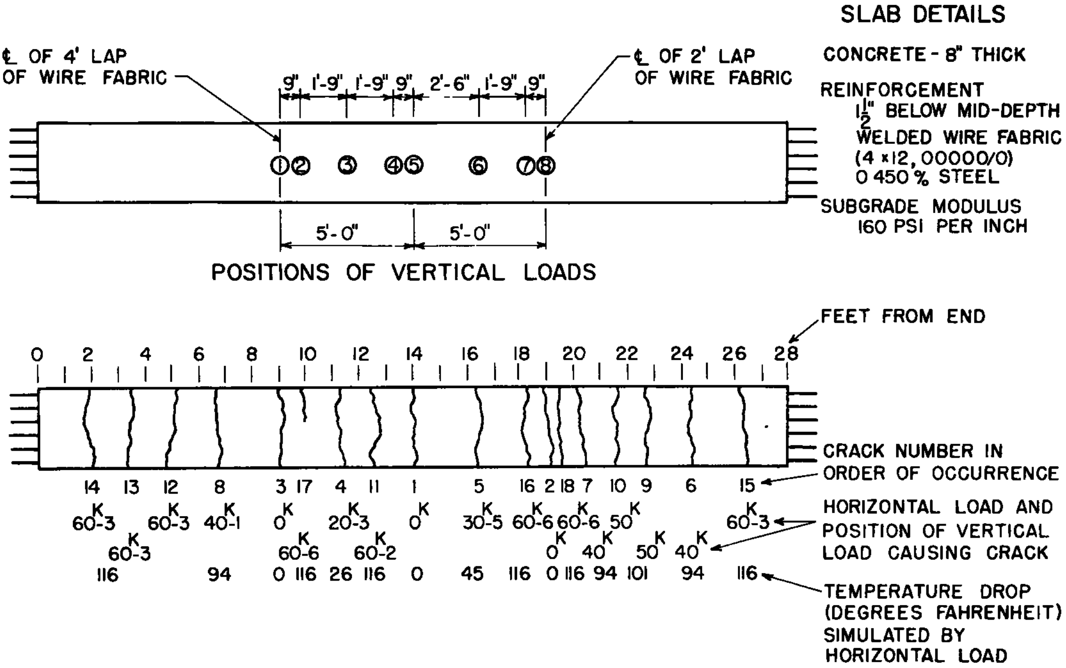

Figure 10. Crack formation — Slab 10.

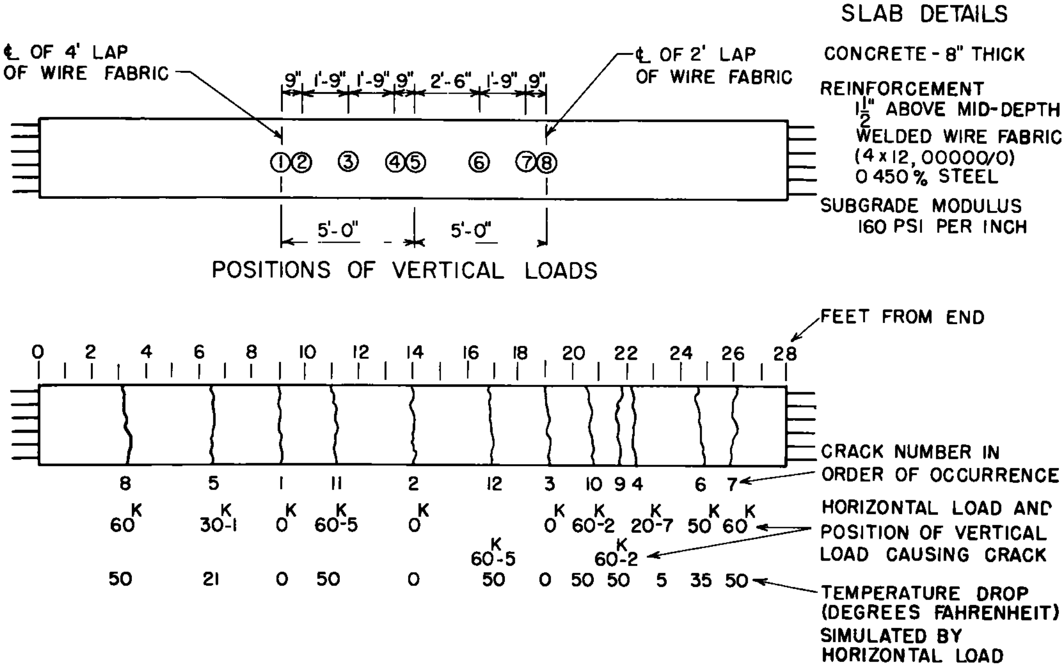

Figure 11. Crack formation — Slab 11.

In general, horizontal (longitudinal) loads were applied to each slab in increasing 10,000-lb increments, although 5,000-lb increments were used for slab 7 which had only 0.154 percent reinforcement. Horizontal loads were increased in each case until it became apparent that the longitudinal reinforcement steel had been stressed beyond its yield strength.

The usual sequence of applying combined vertical and longitudinal loads was as follows:

1. No longitudinal load — vertical loads (5, 10, and 15 kips) at load points 1 through 8 successively.
2. 10,000-lb longitudinal load — vertical load sequence repeated.
3. 20,000-lb longitudinal load — vertical load sequence repeated.
4. And so forth — to yielding of reinforcement.

During the entire loading sequence, measurements of concrete strain and crack widths were made at the upper surface of each slab. Steel plugs had been embedded in the surface of each slab in the test area at 10-in. intervals, longitudinally. Gage holes were drilled in these plugs and a 10-in. Whittemore strain gage was used to make surface strain and crack width measurements. For an uncracked gage length the average unit strain was taken as the change in the gage length divided by ten. When a transverse crack occurred between two plugs, it was assumed that the total change in that gage length was due to a change in the crack width. This continuous set of gage lengths thus made it possible to determine the over-all change in length of the 130-in. test region due to the various combinations of horizontal and vertical loads. Throughout the testing of each slab specimen, the formation of new cracks (in addition to the preformed cracks) was observed and recorded.

The longitudinal tensile loads simulated the effects of temperature drops. Correlation of the magnitude of longitudinal load to temperature drop was made by calculations. The over-all increase in length of the central test region of a slab due to longitudinal load was equated to the decrease in length of the same span of reinforced concrete due to a temperature drop, Δt. Thus, the condition of effective full restrain against longitudinal movement in a continuously reinforced slab away from the end regions was assumed.

$$e = \alpha L \Delta t$$

or

$$\Delta t = \frac{e}{\alpha L}$$

where

e = elongation (inches) of central test region
L = length (inches) of central test region
α = coefficient of linear contraction — assumed to be 0.000006 in./in./deg F for both steel and concrete
Δt = temperature drop (deg F)

Concrete curing shrinkage does not affect appreciably the foregoing computation. Shrinkage of the concrete in a continuously reinforced pavement slab tends to cause the length of concrete between adjacent cracks to shorten and the cracks to widen. In the measurement of the over-all length of a central region of slab the shortening of concrete and the widening of cracks compensate for each other. Shrinkage is accompanied by stress changes in the concrete and steel; however, these stress changes are nonuniform throughout the length, with tendencies toward tensile stresses in the steel at cracks, compressive stresses in the steel between cracks, tensile stresses in the concrete between cracks, and compatible bond stresses between the concrete and the steel. These alternating type stresses have no appreciable influence on the over-all change in length of a central test region and thus can be neglected in the temperature correlation calculations.

During the experiments, as the loading sequence was followed, each slab specimen was scrutinized carefully for the development of new cracks. New cracks would usually begin in the vicinity of the vertical load position and advance under increasing loads from the bottom to the top of the slab. The progress of crack formation was observed and marked with chalk on the side of the slab. Figures 1 through 11 summarize the cracking history of slabs 1 through 11, respectively. In each of these figures, the upper plan view shows the vertical (wheel) loading positions; the lower plan view shows the number of the cracks in the order of their occurrence, the horizontal load and the position of the vertical load causing each crack, and the temperature drop (deg F) simulated by the horizontal load.

Figures 1 through 4 show the effect of percentage of deformed bar reinforcement (placed at mid-depth) on the crack pattern. In the lightly reinforced slab (0.278 percent steel), one additional crack formed — at a 47-deg temperature drop with the vertical load at load point 6. Simulated temperature drops of 86 deg combined with vertical loads caused no more cracking. No cracks in addition to the three preformed ones formed in slab 2 which had 0.430 percent steel. Longitudinal loads simulating a 103-deg temperature drop, along with the vertical loads, only altered the widths of the preformed cracks in this slab. Slab 3 with 0.533 percent steel showed additional cracks at 39-deg drop and vertical load at point 6, 70-deg drop and no vertical load, 70-deg drop and vertical load at point 3, 70-deg drop and vertical load at point 7 (2 cracks), and 96-deg drop and no vertical load. Thus, slab 3 showed a total of nine cracks in a length of about 21 ft (average crack spacing 2.3 ft) after a simulated temperature drop of about 100 deg. In slab 4, which had 0.768 percent steel at mid-depth, two additional cracks developed during loading of point 6 with no simulated temperature drop, one developed at 54-deg drop with vertical load at point 3, one at 54-deg drop with vertical load at point 6, one at 87-deg drop without vertical load and five at 115-deg drop with no vertical load. Slab 4 contained a total of 13 cracks in a length of about 24 ft (average crack spacing about 2 ft) after a simulated temperature drop of 115 deg.

Thus, it is seen that within the range of variables studied, an increase in percentage of deformed bar steel reinforcement at mid-depth tends to result in a more closely spaced crack pattern in the slab, with individual crack widths of less magnitude. The two slabs having the lower percentages of steel (0.278 and 0.430) remained essentially with the preformed crack pattern. This indicates that one could expect crack spacings on the order of magnitude of 5 ft or more in slabs having these amounts of reinforcement if the experiments were conducted without preforming cracks in the slabs. The slabs with the higher percentages of steel showed a definite decrease in crack spacing (to about 2 to 2 ½ ft) with very little difference between the slab reinforced with 0.533 percent steel and that having 0.768 percent steel. It is doubtful that the crack spacing would average significantly less than 2 ft for any practicable amount of reinforcement.

The nature of the formation of individual cracks in the slabs reinforced at mid-depth is of interest. When one of the more significant horizontal loads (temperature drops) was applied to either slab 3 or 4, a crack would usually begin at the bottom of the slab under a 5,000-lb vertical load and would break completely through under the 10,000- or 15,000-lb vertical load. During the late stages of testing each of these slabs, several cracks appeared to be caused directly by the large horizontal loads being applied. The influence of vertical loads can be seen, however, since most of the cracks formed in the region of influence of vertical loads until the simulated temperature drop was extremely large.

Comparison of the cracking of slabs 3, 5, and 6 having 0.533 percent deformed bar reinforcement at mid-depth, 2 in. below mid-depth, and 1 in below mid-depth, respectively, shows the influence of position of steel on the crack pattern. Slab 5 differed markedly from slab 3 in that the simulated temperature drops and the vertical loads both caused many cracks to start in the lower portion of slab 5, but caused only few to break completely through. In fact, up to 132-deg equivalent temperature drop, no complete cracks in addition to the three preformed cracks at 5-ft spacing had formed. At 132-deg equivalent temperature drop, one complete crack developed at each end of the slab, each at 4 ft from the nearest preformed crack. These cracks each formed completely as a result of the negative bending moment produced during the application of vertical load at the adjacent preformed crack, superimposed upon the simulated temperature change. Slab 6 with its 0.533 percent reinforcement at 1 in. below mid-depth contained six complete cracks after a temperature drop of 125 deg. These six cracks were spaced nearly uniformly at 2 ½ ft. This slab also contained some of the partial cracks that characterized slab 5, but not as many as appeared in slab 5.

The eccentricity of the longitudinal forces which simulated the temperature drops in slabs 5 and 6 produced positive bending moments in slab segments between complete cracks which tended to cause compression in the top surface of the slab and tension in the bottom surface. This effect, when superimposed upon the influence of the direct tensile force of temperature drop and the effects of vertical loading, accounts for the partial cracks produced by the eccentrically placed steel reinforcement. The partial cracking was most pronounced in slab 5 which had its steel placed with greatest eccentricity.

The influence of percentage of welded wire fabric reinforcement placed at mid-depth is shown in Figures 7, 8, and 9 for slabs designated by the same numbers. In studying these figures, one must keep in mind that the reinforcement in each 28-ft specimen consisted of three separate lengths of fabric, lap spliced as shown in each figure. Slab 7 with 0.154 percent longitudinal steel in its fabric reinforcement developed no cracks in addition to the three preformed cracks, even though it was subjected to horizontal (longitudinal) tensile forces equivalent to temperature drops greater than any practical value. Slab 8 which had 0.300 percent longitudinal steel sustained one additional crack at a temperature drop of about 60 deg, approximately under a vertical load at position 5. No other cracks developed until the slab was in a condition of general yielding to longitudinal tension force. Slab 9 with 0.450 percent longitudinal steel in its welded wire fabric received an additional crack under a vertical load at point 2 accompanying a temperature drop of 16 deg and another at the same temperature drop under a vertical load at point 6. In addition, this slab cracked 5 ft from one of the outermost preformed cracks and 4 ft from the preformed crack nearest the other end. These two cracks occurred, however, at a horizontal load equivalent to more than 150-deg temperature drop — beyond any practical range of temperature change. Cracks would probably have occurred somewhere in the same vicinity at less temperature drop if the slab had been subjected to vertical loads throughout its length. Thus, slab 9 indicated that a crack spacing of about 2 ½ ft could be expected in a slab 8 in. thick, reinforced at mid-depth with fabric providing 0.45 percent longitudinal steel, and resting on a fairly flexible subgrade (k = 160 pci).

Slab 10 was also reinforced with 4 x 12 00000/0 fabric but had its reinforcement placed 1 ½ in. below mid-depth. The crack pattern which developed in this slab did not differ greatly from the pattern of slab 9; however, slightly greater temperature drops were required, in combination with the vertical loads, to cause the first cracks to appear. Crack 7 appeared at the end of the 2 ft lap over preformed crack 2 during a horizontal force of 40 kips which was equivalent to a temperature drop of 94 deg. Stress concentration in the concrete caused by the lap ending was probably the cause of this crack at only 1 ft away from the preformed crack.

Slab 11 with its 0.450 percent reinforcement placed 1 ½ in. above mid-depth developed a crack pattern having little significant difference from that of slab 10 in the central test portion; however, it showed more top surface cracks near its ends at practical temperature drops than did slab 10. The greater number of top surface cracks was obviously due to the eccentricity of the reinforcement. It could not be ascertained if these cracks extended clear through to the bottom of the slab.

CORRELATION OF LABORATORY RESULTS WITH FIELD TESTS

The crack patterns developed in the seven laboratory slabs with the reinforcement at mid-depth agree in general with the patterns reported for the field experiments in Indiana, Illinois, New Jersey, California, and Texas which contained somewhat comparable reinforcement (11). The minimum crack spacing reported for each of those field test pavements was in the same order of magnitude as the crack spacing finally obtained in these laboratory experiments; that is, 2 to 2.5 ft for slabs having 0.45 percent or more longitudinal reinforcement and up to 5 ft or more for less reinforcement. Although these laboratory experiments did not include the effects of the great numbers of repeated loads obtained in the field tests, the maximum combined effects of shrinkage, maximum wheel loads, and equivalent temperature drops were obtained in a relatively short time in the laboratory with slabs resting on a relatively flexible subgrade.

The laboratory slabs in which the reinforcement was placed below mid-depth have no counterparts among the continuously reinforced test pavements in existence. It is anticipated that the results reported here for these eccentrically reinforced test specimens will be comparatively verified in the laboratory where additional slabs having eccentric reinforcement are to be tested on a stiffer subgrade. Results of these laboratory experiments may suggest the need for additional field tests.

It is to be noted that the data presented show, in general, the effects of equivalent temperature drops as great as 100 deg with some crack formation described for temperature drops of 125 deg. The horizontal forces applied to the slabs in the laboratory were in most cases carried to magnitudes corresponding to considerably greater temperature drops. Those data which extended far beyond limits of practicality have been omitted in this presentation.

Depending upon the construction locale and the temperature at the time of pouring the concrete, data presented for temperature drops greater than 90 to 100 deg may be unreliable in predicting the behavior of continuously reinforced pavement. A temperature decrease to below freezing would freeze and stiffen the concrete and would thus temporarily provide a greater subgrade modulus.

DESIGN CRITERION

It is the common theme of all engineers involved with design or research on continuously reinforced pavements that the slab must be reinforced with continuous longitudinal steel in sufficient amount to maintain all transverse cracks in a tightly closed condition without adverse effect on the concrete. The laboratory experimental results obtained for slabs having reinforcement at mid-depth indicate that this condition is met when increasing longitudinal forces (temperature decrease), in combination with live (wheel) loads tend to cause additional cracks to form rather than to cause excessive opening of existing cracks. If this criterion were to be applied to choose slabs adequately reinforced at mid-depth from among those tested in the laboratory, 0.430 percent deformed bar reinforcement would be inadequate while 0.533 percent deformed bar reinforcement would be judged adequate. Likewise, 0.30 percent welded wire fabric longitudinal reinforcement would be inadequate while 0.45 percent welded wire longitudinal reinforcement would be judged adequate. Within the limitations of the properties of the materials used in these experiments one could conclude from the research data that 0.450 percent longitudinal reinforcement, either in the form of deformed bars or welded wire fabric, would satisfy this one criterion for an 8-in. continuously reinforced concrete pavement slab resting on a subgrade having a modulus of 160 pci.

While the design criterion discussed above appears to be fundamental, one should expect that other criteria will come out of the study of stresses and deflections in continuously reinforced concrete pavements. Such other criteria may be more severe than this one, thus making this one automatically satisfied. Too little data now exist to determine what alterations to this design criterion should be made in order to judge the adequacy of eccentrically placed reinforcement. This question will receive attention in the laboratory experiments which are continuing.

CONCLUSIONS

As a result of this study of the formation of cracks in continuously reinforced pavements, and within the limitations imposed by the range of variables studied, the following conclusions are draw:

1. The effects of concrete shrinkage, temperature changes, and wheel loads on the crack formation in continuously reinforced pavements can be adequately simulated in the laboratory without producing actual temperature changes in an infinitely long pavement slab.
2. The formation of a complete crack pattern in a continuously reinforced pavement is the result of a superposition of the effects of concrete shrinkage, temperature changes and live (wheel) loads. Perhaps the importance of live loads has been somewhat underestimated in past discussions of this problem.
3. Crack spacing in a continuously reinforced pavement with some age and use varies inversely with the percentage of longitudinal steel reinforcement if the steel is placed at mid-depth. A minimum average crack spacing of about 2 ft may be expected in a slab having 0.768 percent longitudinal steel in the form of deformed bars.
4. The position of 0.533 percent deformed bar reinforcement in an 8-in. slab has a marked difference on the crack pattern. With the steel 2 in. below mid-depth, temperature decreases and vertical loads cause many cracks to start in the lower part of the slab but only a few to break completely through. Five feet seems to be about the minimum spacing between complete cracks in a slab thus reinforced. With the same amount of steel 1 in. below mid-depth, the spacing of complete cracks decreases to about 2½ to 3 ft, and less partial cracks appear.
5. Welded wire fabric reinforcement of 0.450 percent longitudinal steel placed 1½ in. below mid-depth in the slab produces a crack pattern only slightly different from that produced by the same steel placed at mid-depth. However, slightly greater temperature drops are required to cause the first cracks to appear at the surface of the slab having the lowered reinforcement.
6. It is generally agreed that a continuously reinforced pavement slab must be reinforced with longitudinal steel in sufficient amount to maintain all transverse cracks in a tightly closed condition without adverse effect on the concrete. For mid-depth reinforcement this condition is met when increasing longitudinal forces caused by temperature drops, in combination with live loads, tend to cause additional cracks to form rather than to cause excessive opening of existing cracks. This standard is suggested as one criterion (among others) for the design of continuously reinforced pavements.
7. The single design criterion stated in conclusion number 6 is satisfied in these laboratory tests for an 8-in. pavement slab resting on a subgrade having a modulus of

160 pci, by 0.45 percent longitudinal reinforcement either in the form of deformed bars or welded wire fabric reinforcement placed at mid-depth in the slab.

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