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HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH
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Wartime Road Problems

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No. 3

DESIGN OF CONCRETE PAVEMENTS REQUIRING A MINIMUM OF STEEL

HIGHWAY RESEARCH BOARD
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HIGHWAY RESEARCH BOARD

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Special Committee on Design of Concrete Pavements Requiring a Minimum of Critical Materials

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Wartime Road Problems

There are two major wartime road responsibilities; to keep the traffic essential to the war effort moving, and to bring the existing roads through the war period in as good condition as possible. Discharge of these responsibilities entails consideration of many new factors in view of the limitations on time, money, labor, equipment and use of critical materials imposed by the exigencies of the national situation. Obviously changing emphasis from devising better and more economical methods to a program within the wartime limitations of moving the wartime traffic and conserving the existing roads confronts highway engineers with many new problems and new aspects of old problems.

The Highway Research Board believes that it can be helpful by aiding in disseminating in usable form the best available information on those phases of highway technology in which common practice has not become established or in which practice must be modified during the war. To this end a series of bulletins on WARTIME ROAD PROBLEMS will be prepared by qualified committees and published by the Highway Research Board. Recommendations in these bulletins are based upon wartime restrictions and needs and are only intended for use as guides during the periods in which these conditions prevail.

This program has been endorsed by the Executive Committee of the American Association of State Highway Officials.

Suggestions for suitable subjects will be welcomed.

DESIGN OF CONCRETE PAVEMENTS REQUIRING A MINIMUM OF STEEL

Of the several materials used in the construction of concrete pavements, steel is the principal material now classed as critical, which affects pavement design. Certain joint fillers, seals and curing materials are not available or must be used sparingly, but these materials do not affect design and satisfactory substitutes are available.

The need for conserving steel for war uses is universally recognized. Engineers are in agreement that during the emergency its use in construction should be limited to the minimum compatible with sound engineering procedure. For the duration, this policy should be followed even though it may result in more expensive construction than would normally be used.

In order to determine where and in what quantities steel may be eliminated, it is necessary to analyze the function of steel in concrete pavement. Only when that is understood, can the reduction or elimination of steel be accomplished on an engineering basis. Also, consideration should be given to the service records of concrete pavements built with little or no steel. There is considerable experience supporting the recommendations which follow.

Steel is used in concrete pavement in the following forms:

1. Distributed steel in the form of bar mats or wire mesh.
2. Tie-bars across hinged longitudinal joints, including chairs or pins for their support.
3. Deformed metal dividing plate to form a type of longitudinal hinged joint.
4. Dowel bars or other load transfer devices across transverse expansion or contraction joints, including other steel used in connection with their installation.

This report discusses the functions of each of these uses of steel and the modifications in design and construction which will effect a reduction or elimination of steel.

DISTRIBUTED STEEL

Function

It is acknowledged among engineers that the primary function of distributed steel is to hold in close juxtaposition the faces of slabs when intermediate cracks occur between joints, thus avoiding free corners or edges. Distributed steel in quantities commonly used does not increase the load carrying capacity of uncracked slabs nor does it obviate cracking although it does tend to reduce cracking to some extent, but after cracks form it holds them tightly closed so that the interlock of the irregular faces of the fracture will provide for load transference.

This is of significance in thickened-edge-thin-center slabs if the intermediate cracks, which may develop, open wide enough to destroy the interlock of the faces of the fracture and result in the formation of free corners or edges having inadequate strength in comparison with other portions of the slab. In uniform thickness slabs of adequate design, the free edges formed by open transverse cracks do not introduce an element of structural weakness.

A secondary function of distributed steel is that, by holding cracks tightly closed, it minimizes the infiltration of dirt, sand and other materials. This progressive infiltration of foreign material has been commonly credited as being a factor in the development of high compressive stresses and ultimate "blow-ups" in pavements.

Methods of Reducing or Eliminating Distributed Steel

Having concluded that the primary function of distributed steel is to insure close contact of slab faces at cracks which may occur between joints, it seems logical that the first step to effect a reduction or elimination of distributed steel is to joint the pavement so that no intermediate cracks will develop.

It may not be possible to eliminate every crack, but there is ample evidence from experience that a suitable jointing arrangement will reduce intermediate cracking to a negligible amount. The spacing of joints to form slab lengths which will do this depends upon several factors, such as tensile strength of the concrete, type of aggregate, frictional resistance between pavement and subgrade, temperature and moisture conditions, subgrade conditions, and conditions of loading. It is impracticable to consider in this discussion the influence of all of these factors under all conditions and it appears that experience furnishes the best basis for a general determination of the spacing of joints to control cracking.

Surveys and experience over a period of years in many States widely distributed throughout the country have established the conclusion that satisfactory control of transverse cracking can be achieved through the use of joints spaced at about 15 to 20 ft.

The type of coarse aggregate as it influences the characteristics of the concrete and subgrade conditions have a major influence and the spacing on a specific project should be based on local experience with the aggregate proposed for use. Under most favorable conditions and when local experience has demonstrated that it is safe, the spacing may be increased to the maximum interval supported by such local experience. Generally the optimum conditions will not justify a maximum interval greater than 25 ft.

These slab lengths can be formed best and most economically with a combination of expansion joints and dummy contraction joints. Spacing of expansion joints compatible with the proposed spacing of contraction joints and provisions for load transference at both expansion and contraction joints are discussed in subsequent paragraphs.

The foregoing jointing arrangement introduces a considerable number of contraction joints. The dummy groove which is the common method of forming contraction joints provides an excellent anchorage for the bitumen or other joint sealing material, thereby offering much better protection against infiltration of foreign materials than a similar seal on the pavement surface at an ordinary crack.

Summary

Thus it is possible to eliminate distributed steel by:

1. Using a joint spacing to form slab lengths that will reduce intermediate cracking to a negligible amount.
2. Constructing and maintaining joints so as to minimize infiltration of foreign material.

TIE-BARS

Function

Tie-bars are used across longitudinal center joints in thickened edge slabs to hold the slab faces in close contact, thus preventing the formation of free edges in the interior portion of the slab, and to maintain equality of strength between the interior of the slab and the thickened edge portion. They hold the edges of the two halves of the pavement firmly in contact so that load transference is provided, either by a tongue and groove or by the aggregate interlock below the groove in the dummy groove type of longitudinal center joint. This function is not required in slabs of uniform thickness since the edges adjacent to the longitudinal center joint are equal in strength to the exterior edges and require no load transfer to maintain a structural balance. Tie-bars may be needed in uniform thickness slabs at some locations to prevent excessive separation and in this way also help to prevent vertical displacement.

Methods of Reducing or Eliminating Tie-Bars

In slabs of uniform thickness tie-bars are not required for structural reasons. Such slabs may be constructed either lane-at-a-time with a tongue and groove joint between lanes or two-lanes-at-a-time with a surface dummy groove joint or a non-metallic deformed center strip between lanes.

If thickened edge slabs are constructed with the edges along the center joint thickened as along the outer edges, there is no longer need for tie-bars to prevent the formation of inadequate thin edges at that point. Therefore, tie-bars may be omitted in thickened edge slabs so constructed, unless required to prevent separation as heretofore discussed for uniform thickness slabs.

The design with both edges of each lane thickened may be constructed either lane-at-a-time or two-lanes-at-a-time. In many areas lane-at-a-time is the preferred construction procedure. It is suggested that these longitudinal construction joints be keyed by means of tongue and groove. Keying is not needed for load transference to maintain a structural balance but is effective in keeping the edges of adjacent slabs at the same elevation. In two-lane-at-a-time construction the longitudinal center joint will be at a point of maximum thickness of the slab. If a dummy groove type center joint is used the groove must be cut deep enough to insure fracture below the groove rather than in the thin portion of either lane near the point where the center thickening begins. It is suggested that the groove be cut to such depth that the thickness of concrete remaining below the groove is at least 1 in. less than the thickness of the slab in the interior thin portion of each lane.

Another method of forming a longitudinal center joint in the thickened center of two-lane-at-a-time construction is to stake to the subgrade, on the line of the joint, a thin strip of wood or other suitable non-metallic material. This strip has a height equal to the difference between the edge and center thicknesses of the slab and is supplemented by a surface dummy groove of depth one-fourth the thickness of the thin portion of the slab. Unless the parting strip on the subgrade is exactly in line with the surface dummy groove this type of jointing is likely to be unsatisfactory.

There are now available non-metallic materials, shaped in the same form as the conventional deformed metal center strip. This non-metallic deformed center strip may be used to effect a keyed joint along the center line of thickened-edge-thickened-center two-lane-at-a-time construction. If this material is compressible it cannot be depended upon for load transference.

Summary

Thus it is possible except as noted in the next paragraph to eliminate the need for tie-bar steel by:

1. Using uniform thickness slabs.

   If constructed lane-at-a-time the longitudinal joint between lanes can be a butt joint, but a tongue and groove joint is desirable.

   If constructed two-lanes-at-a-time the longitudinal center joint may be constructed with a dummy groove joint, or with a non-metallic deformed plate to produce a keyed joint.

2. Using thickened-edge slabs with the edges along all longitudinal joints also thickened.

   If constructed lane-at-a-time the longitudinal joint between lanes can be a butt joint, but a tongue and groove joint is desirable.

   If constructed two-lane-at-a-time the longitudinal joint may be formed by:

   (a) A deep longitudinal top dummy groove.

   (b) A top dummy groove of normal depth combined with a plane of weakness created by staking to the subgrade a wooden board or plate of other rigid non-metallic material.

   (c) A non-metallic deformed plate to produce a keyed longitudinal joint.

Under some unfavorable conditions it may be necessary or advisable to install tie-bars across longitudinal joints to prevent separation of slabs where such separation might be expected if they are omitted, such as on side-hill locations, heavy fills and sharp curves. It is common practice to allow higher working stresses (approaching the yield point) for tie-bars used only to prevent slab separation.

DEFORMED METAL DIVIDING PLATE

Function

This plate, commonly called "deformed metal center joint" is used to form a hinged type tongue and groove joint which, together with tie-bars, will insure load transfer across the longitudinal center joint. Its function is the same as that of the dummy groove type of longitudinal center joint.

Methods of Eliminating Metal Dividing Plates

At tied and keyed longitudinal center joints in thin-center-thickened-edge slabs built two-lanes-at-a-time the dummy groove type can be used instead of the deformed metal plate. In many areas the dummy groove is the preferred type at the present time and has a satisfactory service record. In lane-at-a-time construction the tongue and groove can be formed at the center construction joint by use of wood or metal strips set against the side forms and later removed and reused. Tie-bars, if needed, are bent at an angle of 90 deg. with one leg lying along the form and later bent out into proper position before building the second lane.

In thickened edge designs the deformed metal plate as well as tie-bars can be eliminated by thickening the edges along longitudinal center joints by the several methods described under "TIE-BARS."

In uniform thickness slabs tied and keyed longitudinal joints are not required structurally and deformed metal plates can be eliminated and longitudinal joints formed by:

1. A construction joint in lane-at-a-time construction. A keyed joint is desirable to prevent faulting.
2. The use of a dummy groove type joint.
3. The use of a non-metallic deformed strip.

STEEL DOWELS

Function

Where the word dowels is used in this discussion, it is meant to include slip dowel bars and other metal devices which may be installed in concrete pavement to provide for the transfer of loads across transverse joints, for free longitudinal movement of the slab ends at the joints and to prevent vertical faulting.

Dowels are provided at joints where needed to avoid excessive stresses. Their primary function is to transfer part of the wheel loads across joints so that adjacent slabs will assist in carrying them and thereby reduce the stresses in slab ends and corners. If edge stress reduction is not necessary dowels may be used to prevent faulting.

In the usual thickened edge designs, dowels maintain a structural balance at transverse expansion joints by obviating excessive stresses from wheel loads in both the corners and the thin interior section of the slab. They have the same purpose when used at transverse contraction joints where no dependence is placed on aggregate interlock.

The primary function of dowels at joints in uniform thickness slabs of adequate design is to prevent faulting.

Methods of Reducing or Eliminating Dowels at Expansion Joints

Dowels are required for load transference at transverse expansion joints unless the slab ends are strong enough to support the loads without assistance from the adjacent slab or unless some other means are provided to strengthen or support the slab ends. The total quantity of dowels can be reduced by placing expansion joints at long intervals. Available laboratory and field data lead to the conclusion that in some cases much less expansion space than is now commonly provided will protect concrete from excessive stresses. If dummy groove contraction joints are spaced to prevent cracking and are properly maintained to prevent infiltration of inert material, as discussed under "Distributed Steel," and if the concrete and included aggregates have normal expansive characteristics, very little expansion space need be provided.

It is not necessary to provide expansion space to effect complete relief from compressive stress. On the contrary, there are distinct advantages in providing only enough space to keep compressive stresses within safe limits. If only a limited amount of expansion space is provided, the slab will be under compression at temperatures above that at which the pavement was laid. At lowered temperatures the openings at contraction joints will be kept at a minimum, which is important in providing for load transference at contraction joints, as will be discussed later. Thickness requirements for pavements are governed by the allowable flexural stresses in the concrete, hence a certain amount of axial compressive stress is beneficial since it reduces tensile stresses arising from flexure due to warping or superimposed loads.

The expansion space depends upon consideration of temperature at which the concrete is placed, subsequent expected temperatures, moisture content, thermal coefficient of the concrete and possibility of infiltration of foreign material into cracks and joints. Joints $\frac{3}{4}$ in. wide, 120 ft. apart have been extensively used. However, experience indicates that under favorable conditions of materials, climate and construction provision of $\frac{3}{4}$ in. expansion space per 400 to 600 ft. has proved satisfactory. The use of such spacings will reduce the amount of steel required for dowels by 70 to 80 per cent of that required for the 120 ft. spacing. Design of spacing in a given case should be guided by the basic factors heretofore mentioned and by previous experience in the locality.

A method which will eliminate dowels at expansion joints involves modifications in design which make the slab ends structurally adequate without load transference. This may be accomplished by thickening the slab ends so that they need no support from abutting slabs or by using a uniform thickness design that is structurally adequate at the end of the slabs. The thickened slab end type of construction has been used in several States over a period of years with results which are satisfactory. A study of past practices, service performance and practical considerations indicates that the slab end should be thickened gradually from the normal cross-section at a point not less than 5 ft. back from the joint to the thickness required at the joint.

Under some unfavorable subgrade conditions and when the pavement is subjected to heavy traffic, it may be desirable to use some dowels for the purpose of preventing vertical faulting of the slab ends at expansion joints.

Another method which may make it possible to eliminate dowels is to support the slab ends at expansion joints by auxiliary support. There is a limited amount of experience with concrete slabs which are cast at the proper locations in advance of paving indicating that this procedure may result in satisfactory performance. These supporting sub-slabs have been built 6 in. thick and support the slab ends for a distance of $1\frac{1}{2}$ to $2\frac{1}{2}$ ft. on each side of the joint. The character of subgrade support is an important factor in such design.

Designs which eliminate the need for dowels at expansion joints may be justified during the war emergency even though the cost is greater than a design employing the use of dowels.

Methods of Reducing or Eliminating Dowels at Contraction Joints

With joints at spacings which will substantially obviate intermediate cracking, the amount of contraction of each short slab is small. Surveys of hundreds of miles of pavements in a number of States, with widely varying subgrades, climates and traffic, show that, under these conditions, the pavements without dowels at dummy groove contraction joints have performed satisfactorily.

Although this evidence, except as it relates to uniform section slabs, is not conclusive to all, the Committee is of the opinion that saving steel by omission of dowels at dummy groove contraction joints is a legitimate method for use during the emergency.

On the basis of these considerations and experience, dowels may be omitted from dummy groove contraction joints under the following conditions:

1. The depth of the groove in the pavement surface should preferably be $\frac{1}{4}$ the thickness and must not exceed $\frac{1}{3}$ the thickness of the thinnest portion of the slab.
2. The groove should be kept sealed with a suitable bituminous or other plastic material.

3. The spacing of the dummy groove contraction joints should be such as will reduce intermediate cracking to a negligible amount.
4. Expansion joints used in conjunction with them should be spaced at reasonably long intervals.

Summary

Steel required for dowels in transverse joints may be conserved or eliminated as follows:

1. When dowels are required at expansion joints the quantity of steel required for them may be substantially reduced by increasing the joint spacing, thereby decreasing their number.
2. Slab ends at expansion joints may be made structurally adequate without dowels by the use of:
   (a) Thickened slab ends.
   (b) Uniform thickness slabs of adequate strength at the expansion joints.
   (c) Auxiliary slab-end supports.
3. Dowels may be omitted at dummy groove contraction joints having a properly sealed surface groove $\frac{1}{4}$ to $\frac{1}{3}$ the thickness of the slab when used at a spacing which will eliminate intermediate cracking and with expansion joints spaced at reasonably long intervals.

SUGGESTED WAR EMERGENCY DESIGNS

The accompanying figures illustrate the application to pavement design of the principles and practices which have been presented in the foregoing discussion.

Figure 1 illustrates three alternate typical thickened edge designs.

In Alternate A:

(a) No distributed steel is used, contraction joints being spaced to control cracking.

(b) Tie-bars are omitted, the edges being thickened at the longitudinal center joint.

(c) The deformed metal center strip has been eliminated either by use of lane-at-a-time construction, or in two-lane-at-a-time construction by use of a deep surface dummy groove.

(d) Dowels have been omitted at expansion joints and the slab ends thickened.

(e) Dowels have been omitted at contraction joints.

Alternate B is similar to Alternate A except that dowels are used at transverse expansion joints instead of thickened slab ends.

Alternate C is similar to Alternate A except that dowels are used in place of thickened slab ends at expansion joints and tie-bars are used across the longitudinal center joint instead of thickening the slab edges at that point.

Three alternate typical uniform thickness cross-section designs are illustrated in Figure 2. Alternate I involves all of the principles outlined for Alternate A of Figure 1, except that it is not thickened along the longitudinal center joint.

Alternate II (Fig. 2) is similar to Alternate I except that the uniform thickness is such that it is structurally adequate at transverse expansion joints without thickened slab ends or dowels.

Alternate III (Fig. 2) is similar in all respects to Alternate I except that dowels are used across transverse expansion joints instead of thickened slab ends.

Figure 3 shows typical transverse joint details and Figure 4 shows typical longitudinal joint details applicable to the designs in Figures 1 and 2.

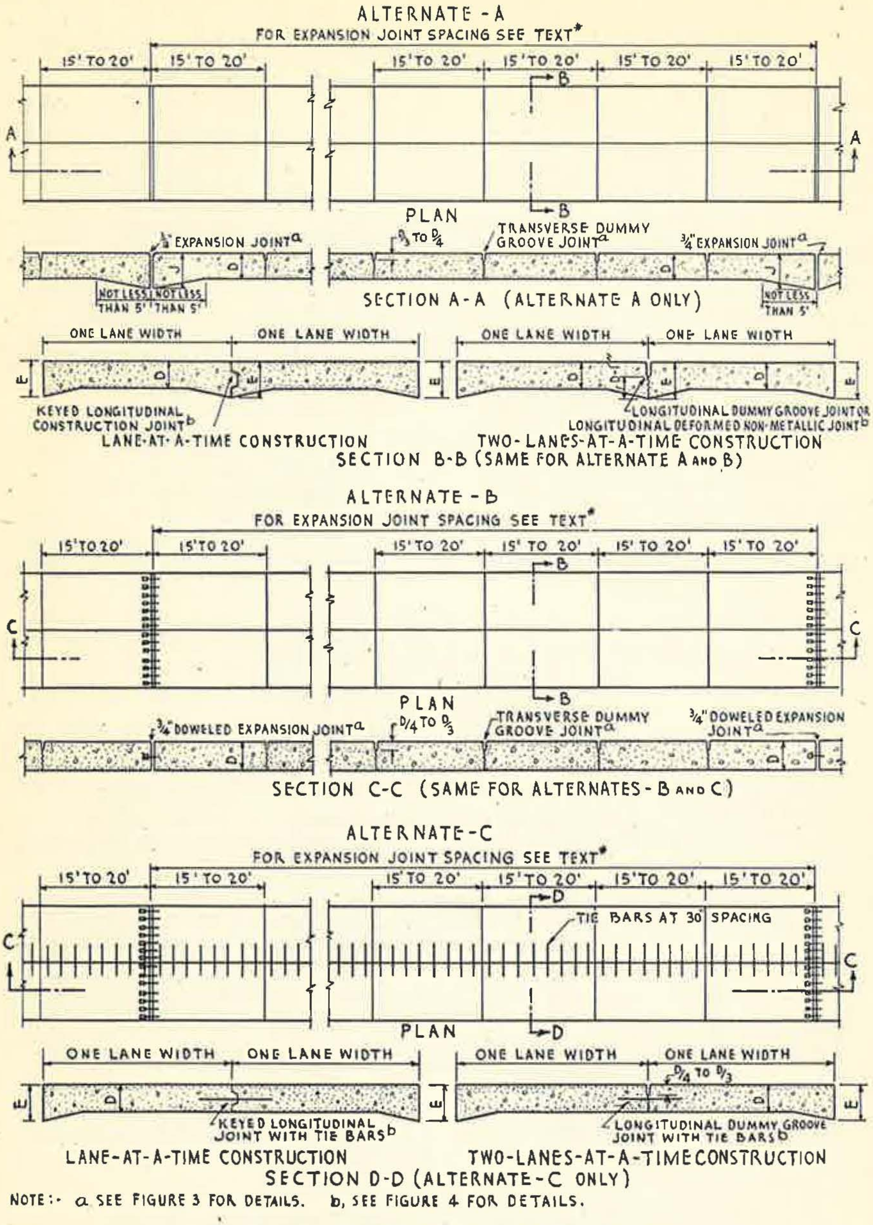

FIGURE 1.—Typical Thickened Edge Designs

Alternate—A, requires no steel, all longitudinal edges being thickened and slab ends being thickened at transverse expansion joints.

Alternate—B requires steel only for dowels at transverse expansion joints, all longitudinal edges being thickened.

Alternate—C requires steel for tie bar across longitudinal center joint and for dowels at transverse expansion joints.

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* For expansion joint spacing see text page 9.

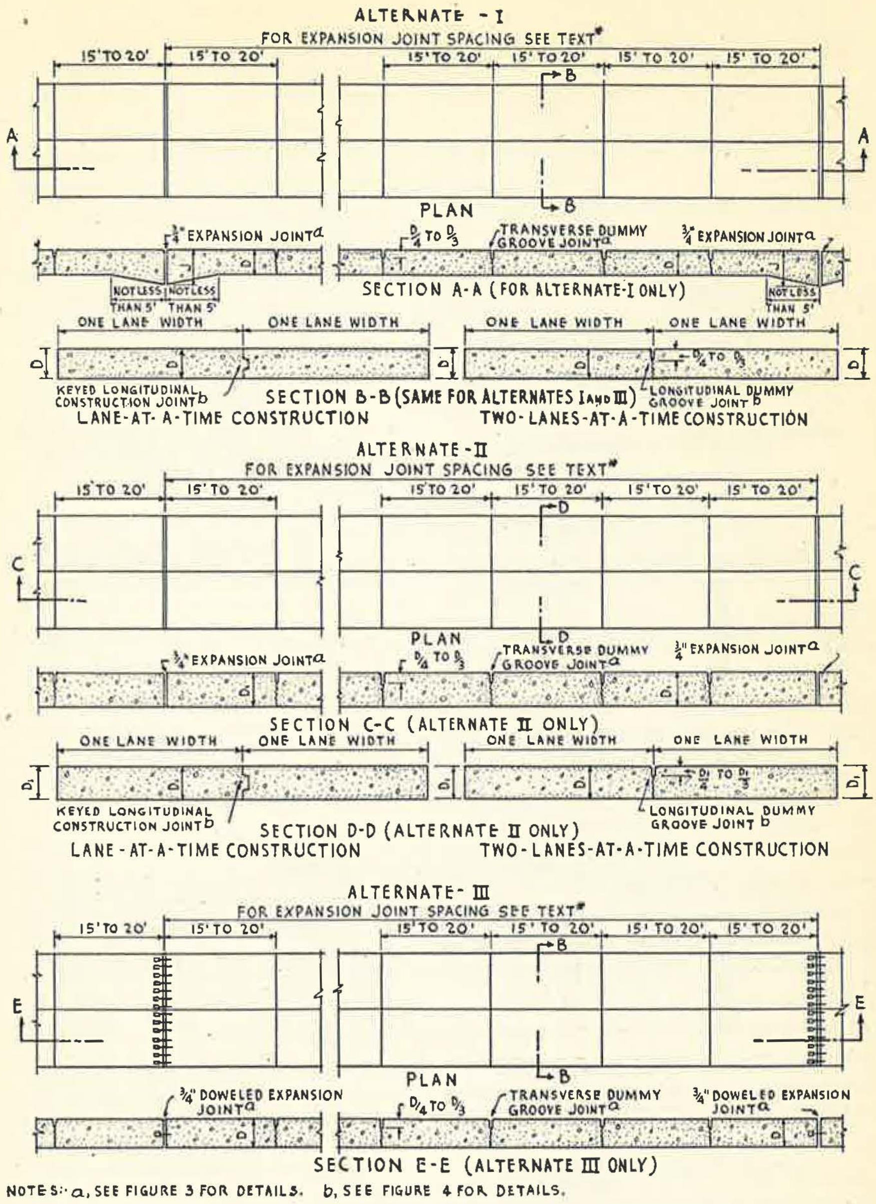

FIGURE 2.—Typical Uniform Thickness Cross Section Designs

Alternates I and II require no steel. In Alternate- I slab ends are thickened at transverse expansion joints.

In Alternate II, the thickness, D, of the entire slab is made equal to that needed at the most critical point.

Alternate III requires steel only for dowels at transverse expansion joints.

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* For expansion joint spacing see text page 9.

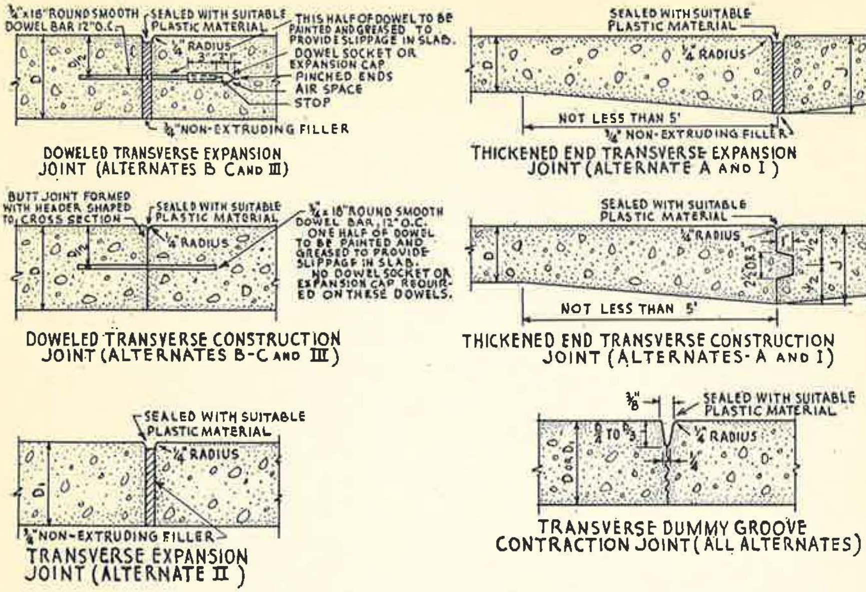

FIGURE 3.—Typical transverse joint details

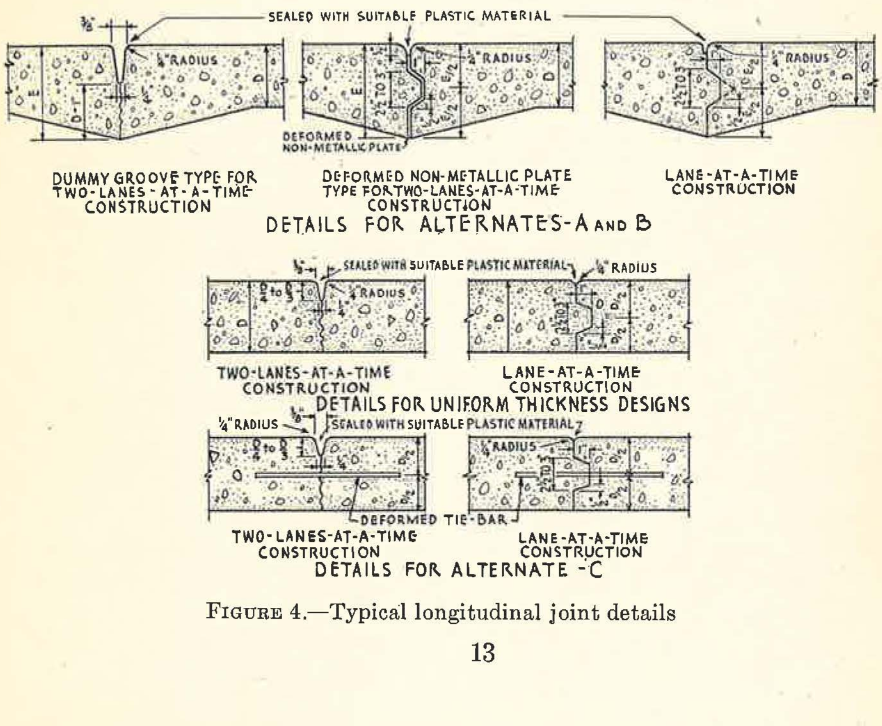

FIGURE 4.—Typical longitudinal joint details

WARTIME ROAD PROBLEMS

No. 1. Curing Concrete Pavements Under Wartime Restrictions on Critical Materials.

No. 2. Design of Highway Guards.

No. 3. Design of Concrete Pavements Requiring a Minimum of Steel.

No. 4. Maintenance Methods for Preventing and Correcting the Pumping Action of Concrete Pavement Slabs.

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