DESIGN MANUAL
FOR
CONTINUOUSLY REINFORCED CONCRETE PAVEMENT

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Pittsburgh, Pennsylvania

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INTRODUCTION

Continuously reinforced concrete pavement (CRCP) may be defined as a concrete pavement in which the longitudinal reinforcing steel is continuous for its length and no transverse joints other than construction joints are installed. In actual practice, the continuity is interrupted by expansion joints at structures. Except for these, there is technically no limit as to the length of CRCP.

CRCP is considered a relatively new pavement type by many engineers, although it has been in use since 1938. State highway departments for Indiana, Illinois, Texas, California, Mississippi, New Jersey, Michigan, Maryland, and Pennsylvania have pavements of this type that have provided good service for a number of years. The older of these pavements range in age from 17 to 30 years. Seventeen other state highway departments and the Chicago Airport Authorities have also used CRCP(1). As of January 1, 1969, approximately 5700 miles of two-lane-equivalent CRCP had been constructed or let to contract in the United States(1).

Concrete pavement is used on highways because of its structural strength, durability, adaptability to exacting construction control, low maintenance, and high visibility. The highway user wants and expects good riding quality and a minimum of delay due to maintenance. By applying the design principles of this manual, the designer will retain all the benefits of concrete pavement and also give more satisfaction to the highway user through the following added features of CRCP:

1. a smoother ride by elimination of joint thumping,
2. reduced maintenance cost and traffic delay,
3. longer pavement life, and
4. lower annual cost of operation.

Transverse contraction joints were long considered essential to preventing pavement damage from volume-change stresses. CRCP takes care of these stresses in another way: it allows the pavement to develop a filagree of very fine cracks, seemingly uncontrolled and random, mostly transverse. The principle of design for this pavement type is to provide sufficient reinforcement to keep the cracks tightly closed and to provide adequate pavement thickness for the wheel loads.

Two basic types of pavement designs are covered in this manual: design for new pavement and design for concrete overlays of existing concrete pavements. The manual is divided into six sections. Section 1 provides guidance as to the specifications and test procedures for the materials used in continuous pavement. Sections 2 and 3 provide nomographs and charts for designing the various component parts of new pavements and overlay pavements, respectively. Section 4 covers pertinent items and potential problem areas that must be carefully monitored during construction. Sections 5 and 6 are example problems covering the step-by-step procedure used in a typical design analysis for a new CRCP and a CRCP overlay, respectively. Although the manual is intended to be as complete as possible, some reference to other manuals and specifications is relied on. The following three sources may be especially useful in supplementing the information herein, as indicated:

1. "Study of Continuously Reinforced Concrete Pavements" by J. E. Funnell and D. K. Curtice. for background information, engineering data, design details, and suggested specifications (Ref. 37).
2. "Design of Subbases for Concrete Pavement" by B. F. McCullough and W. R. Hudson, for more specific information on design of subbases. *
3. "Use of Linear Elastic Layered Analysis for the Design of Concrete Pavements. Concrete Overlays and Subbases" by B. F. McCullough and K. J. Boedecker, Jr., for technical development of the design curves. **
FIGURE 1.1—Pictorial Description of Pavement Structure Terms

- Shoulder Base
- Shoulder Surface
- Finished Grade
- Subbase Grade
- Subgrade, Treatment
- CRCP
- Natural Ground or Embankment (Roadbed Soil)
The engineer is encouraged to design each pavement for the soil conditions, traffic, materials, etc., present at the site and to be wary of stereotyped minimums and practices. In this age of rapid equipment and material development, the engineer must be progressive and use experience as a guideline for the future. Such an approach will insure the highway user the most economical product for his investment.

Figure 1-1 is a pictorial definition of the pavement structure terms used in this manual.

*To be published by U. S. Steel Corporation—Spring 1970.
SECTION 1

MATERIALS

§ 1.0—General

The two basic materials in CRCP are concrete and reinforcing steel. Subbase and joint sealing materials are also required. For quality control of the materials on the job, either the AASHO or the ASTM standard specifications may be used by the engineer to specify the materials to be used in constructing a planned and designed project (2, 3).

§ 1.1—Concrete

Usually, the agency planning a pavement has some experience on which design is based and on which rational modifications of the AASHO and ASTM designations may be introduced. An example might be a more detailed specification on the aggregate gradation than specified by either AASHO or ASTM. Figure 1.1-1 is an index of some of the more important tests and specifications for concrete and component materials.

In designing the thickness of the continuously reinforced concrete pavement, the following concrete properties are of prime importance: flexural strength, modulus of elasticity, and Poisson’s ratio.

Flexural strength of concrete is determined from a simple beam test with third-point or center-point loading as indicated in Figure 1.1-1. The charts in this manual are based on third-point loading. If center-point loading is used, the flexural strength should be reduced to 90 percent of that indicated by third-point loading or as indicated in Reference 4.

<table>
<thead>
<tr>
<th>Specification For</th>
<th>Agency</th>
<th>Designation</th>
<th>Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Portland Cement</td>
<td>ASTM</td>
<td>C 150</td>
<td>Covers five types of cement</td>
</tr>
<tr>
<td></td>
<td>AASHO</td>
<td>M 85</td>
<td></td>
</tr>
<tr>
<td>Air Entrained Portland Cement</td>
<td>ASTM</td>
<td>C 175</td>
<td>Covers factory air entrained cement</td>
</tr>
<tr>
<td>Normal Weight</td>
<td>AASHO</td>
<td>M 134</td>
<td>Covers fine and coarse aggregates</td>
</tr>
<tr>
<td>Aggregates</td>
<td>ASTM</td>
<td>C 33</td>
<td>Covers light weight aggregates for structures</td>
</tr>
<tr>
<td>Lightweight Aggregates</td>
<td>AASHO</td>
<td>No Spec</td>
<td>Covers materials to be added in the field</td>
</tr>
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<td>Air Entraining Admixture</td>
<td>ASTM</td>
<td>C 260</td>
<td>Procedure for testing cylinders</td>
</tr>
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<td>Compressive Strength</td>
<td>ASTM</td>
<td>C 39</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AASHO</td>
<td>T 22</td>
<td></td>
</tr>
<tr>
<td>Flexural Strength</td>
<td>ASTM</td>
<td>C 78</td>
<td>Procedure for simple beam for (\frac{1}{4}) point loading</td>
</tr>
<tr>
<td></td>
<td>AASHO</td>
<td>T 97</td>
<td>Procedure for simple beam for center point loading</td>
</tr>
<tr>
<td>Flexural Strength</td>
<td>ASTM</td>
<td>C 293</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AASHO</td>
<td>T 177</td>
<td></td>
</tr>
<tr>
<td>Volume Change of Concrete</td>
<td>ASTM</td>
<td>C 342</td>
<td>Procedure for determining concrete volume change properties</td>
</tr>
<tr>
<td>Concrete Freeze-Thaw Resistance</td>
<td>AASHO</td>
<td>No Test</td>
<td>Resistance to repeated cycles of freeze-thaw</td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>ASTM</td>
<td>C 469</td>
<td>Modulus of elasticity and Poisson’s ratio in compression</td>
</tr>
<tr>
<td></td>
<td>AASHO</td>
<td>No Test</td>
<td></td>
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**FIGURE 1.1-1—Index of Standard Specifications and Tests for Concrete**
The concrete modulus of elasticity and Poisson's ratio are determined from compression tests on cylindrical concrete specimens as set forth in ASTM Designation C 469.

Other concrete properties important in pavement design are the tensile strength and the volume change characteristics. These two properties are not considered in selecting the pavement thickness, but are important from the standpoint of performance or crack-pattern development. A concrete attaining a high tensile strength at an early age can cause excessively long crack spacings and high steel stresses. To prevent these, the use of Type III or IIIA Cement should be avoided, since these types develop high tensile strengths during the first few days of crack pattern development. The concrete volume-change properties—shrinkage and coefficient of thermal expansion—are important from the standpoint of pavement growth at ends or bridge abutments. Excessive movement of the pavement at the terminals can cause failures in the bridge structure if proper design is not utilized.

Where practical, small trial batches of concrete should be mixed using the aggregates and cement anticipated on the project. Proportions for the concrete and selection of the materials should be based on the most economical use of available materials which will produce a concrete of required workability, placeability, durability, and strength.

Good design requires modification of the usual coarse-aggregate specifications. The maximum size of the coarse aggregate should be less than 1/2 of the longitudinal wire or bar spacing indicated in §§ 2.2.4—Design Charts. This modification will reduce the honeycombing problem described in § 4.4—Vibration and § 4.5—Placement. Figure 1.1-1 indicates that lightweight coarse aggregates are a permissible alternate for conventional aggregates. With concrete pavements, however, the unit weight requirements may be modified or eliminated since the lightweight qualities in themselves are immaterial.

The use of air-entrained concrete is strongly recommended to improve durability and resistance to the disruptive action of freezing and thawing. In addition to increasing concrete workability, air entrainment reduces the possibility of bleeding and segregation. Generally an air entrainment of 3.0 - 7.0 percent will be satisfactory.

§ 1.2—Reinforcing Steel

The second and very purposeful basic material in CRCP is the reinforcing steel. The reinforcing steel, regardless of the type used, should have deformations or deformation properties adequate to insure that crack widths can be controlled at the steel stress design levels. This is an essential criterion of design, and it should not be compromised for any reason. There are two steel types available at the present time that satisfy this criteria: deformed wire and deformed bars.

As a guide for the designer, Figure 1.2-1 presents general information pertaining to specifications, size, and length of reinforcing types. The following table lists the yield-point strengths of most of the grades currently used in CRCP:
<table>
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<tr>
<th>Steel Grade</th>
<th>Yield Point Strength, psi</th>
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<tr>
<td>A 496 (in fabric)</td>
<td>70,000</td>
</tr>
<tr>
<td>A 615, Gr. 40</td>
<td>40,000</td>
</tr>
<tr>
<td>Gr. 60</td>
<td>60,000</td>
</tr>
<tr>
<td>A 15 or M—31 St.</td>
<td>33,000</td>
</tr>
<tr>
<td>Int.</td>
<td>40,000</td>
</tr>
<tr>
<td>Hard</td>
<td>50,000</td>
</tr>
<tr>
<td>*A 431 or M—184</td>
<td>75,000</td>
</tr>
<tr>
<td>**A 432 or M—185</td>
<td>60,000</td>
</tr>
</tbody>
</table>

(A new ASTM Spec.—A 615—now replaces A 15, A 431, A 432, A 305 and A 408.)

*For No. 11, 14, and 18 bars, A 615 Grade 75 has replaced A 431. Bars of smaller diameter are now generally *not* available with 75,000 psi yield strength.

**A 615 Grade 60 has replaced A 432 for all sizes of deformed reinforcing bars. There may, however, be an occasional specification reference to A-432 steel, which has a slightly different definition for determination of experimental stresses.

<table>
<thead>
<tr>
<th>Item</th>
<th>Reinforcement</th>
<th>Deformed Wire</th>
<th>Deformed Bars</th>
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<tr>
<td>ASTM Specs.</td>
<td></td>
<td></td>
<td>A-615**</td>
</tr>
<tr>
<td>Longitudinal Transverse</td>
<td>A - 496 *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tie Bars</td>
<td></td>
<td>A - 496 *</td>
<td></td>
</tr>
<tr>
<td>AASHO Specs.</td>
<td></td>
<td></td>
<td>M-31, M-185, M-184, M-137</td>
</tr>
<tr>
<td>Longitudinal Transverse</td>
<td>—</td>
<td></td>
<td>Above</td>
</tr>
<tr>
<td>Tie Bars</td>
<td>—</td>
<td></td>
<td>M-31 (Str. or Int. Grade)</td>
</tr>
<tr>
<td>Size</td>
<td></td>
<td></td>
<td>#3, #4, #5, or #6</td>
</tr>
<tr>
<td>Longitudinal Transverse</td>
<td>D 11 to D 31</td>
<td></td>
<td>#3, #4, or #5</td>
</tr>
<tr>
<td>Length</td>
<td></td>
<td>Min.16', Max.50'</td>
<td>Min.16', Mar.60'</td>
</tr>
<tr>
<td>Longitudinal</td>
<td>D 4 to D 11</td>
<td></td>
<td>Min.11'-9&quot;, Max.50'</td>
</tr>
<tr>
<td>Transverse</td>
<td>Min.68&quot;, Max.156&quot;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 1.2-1—General Information for Reinforcing Steel**

*Fabricated in accordance with A-497.

**A 615 has replaced the specifications for A 15, A 431 and A 432, although occasional specification reference may be made to these specifications.
Deformed steel wire conforming to ASTM A-496 may be fabricated into mats in accordance with ASTM A-497. These mats insure the correct spacing of the wires. If properly designed in a systems framework, considering plan requirements, transportation equipment, and project handling equipment, deformed wire fabric mats provide an economical product. Deformed wire has the capability of being bent and straightened without fracture or loss of strength.

Several different sizes and grades of deformed bars are satisfactory for use in CRCP. The type selected is dependent on availability and construction procedures. Generally, deformed billet steel bars with 60,000 psi minimum yield strength conforming to ASTM Designation: A-432, or A-615, grade 60, are used for longitudinal reinforcing bars. If bending of the transverse steel or tie bars is anticipated, structural or intermediate grade bars conforming to ASTM Designation: A-615, grade 40 should be used to avoid fracture. If coupled tie bars are permitted, stronger steels may be utilized, provided the couple develops the full potential of the bar.

§ 1.3—Subbase Materials

The subbase may consist of one or more layers of properly compacted granular or stabilized materials between the subgrade and the CRCP. Granular materials — both dense graded and open graded—are by far the most commonly used to accomplish these purposes. In many cases, granular materials are available of such quality that the only requirements are gradation uniformity and good compaction. Marginal materials may be improved by use of stabilizing agents to meet specific requirements. Highway department's and/or airport authorities' standard specifications are recommended for local requirements as to composition, plasticity index, and compaction(6, 7, 8, 9). The subbase material must provide for protection against frost action (applicable to northern part of the USA), for pumping of fines to the surface, and for a support strength adequate to reduce subgrade stresses to an acceptable level.

If frost heave is a problem, then very fine sand, silts, and clays should be avoided or used only in small quantities. References 10, 11, 12, 13, and 14 may be consulted for information on design for frost heave. To reduce pumping of non-treated granular materials to a minimum, it is recommended that the material passing the No. 200 sieve be limited to 10 percent or less.

When available granular materials for subbases do not conform to specification requirements or the support conditions are such as to require additional strength, the materials may be improved by means of stabilization. Acceptable materials for stabilization are portland cement, lime, and bituminous materials. Both lime and portland cement will reduce the plasticity for a great variety of soils and soil-aggregate mixtures. Stabilization is generally covered by highway departments and Federal specifications. References 15, 16, 17, 18, and 19 give guidance for design and construction of stabilized layers.

The subgrade modulus of reaction for use in design may be measured directly on top of the finished subgrade or subbase. The modulus is equal to the load in pounds per square inch divided by the elastic deflection in inches or the total load by the displaced volume in inches. A rigid, 30-inch-diameter plate, loaded in increments, should be used. Generally, the modulus is measured at a pressure of 10 psi. References 20 and 21 or ASTM D-1196 may be referred to for further details for performing the tests.

As an alternate to performing plate load tests which are expensive, plate load tests may be correlated with soil properties. Reference 4 gives such correlations with Unified Soil Classification, AASHO Soil Classification, FAA Soil Classification, R-value, and CBR. Another possible correlation is with elastic properties such as the Resilient Modulus Test(22) or pavement deflection(23, 24).
§ 1.4—Joint-Sealing Materials

Joints are used in CRCP at selected points such as construction joints and expansion joints in the vicinity of structures. Two basic types of sealants are presently acceptable for sealing these joints:

1. Liquid sealants—These include a wide variety of materials of three types: asphalt, hot-poured rubber, and polymers (listed in increasing order of quality). These materials are placed in the joint in a liquid form and allowed to set. When using liquid sealants, care should be taken to provide the proper shape factor for the movement expected\(^{(25)}\).

2. Preformed compression seals — These are extruded neoprene seals which have internal webs that exert an outward force against the joint face keeping the sealant in compression at all times. The size and installation width depend on the amount of movement expected at the joint. These materials, if properly designed, can tolerate considerably more movement than the liquid sealants\(^{(26)}\).

For longitudinal joints, any of the liquid sealants or the preformed compression seals may be used. For transverse expansion joints with expected movements of less than \(\pm \frac{1}{4}\) inch, only the polymer types of the liquid sealants or preformed compression seals should be used. For transverse expansion joints with expected movements greater than \(\pm \frac{1}{4}\) inch, only the preformed compression seals should be used.
SECTION 2
DESIGN OF NEW PAVEMENTS

§ 2.0—General

The principles of design for CRCP are: (1) to provide sufficient steel to insure that the cracks in the concrete are small enough to prevent passage of surface water downward into the underlying material and to provide adequate aggregate interlock for load transfer across the crack and (2) to keep the flexural stresses in the pavement below a predetermined allowable value. Studies of in-service CRCPs by various investigators indicate that when these principles are fulfilled, pavements with long service lives and low maintenance costs are obtained.

In designing a CRCP system, four subsystems must be considered. Each of these four subsystems is considered as an independent procedure, but the four are closely related and, in several cases, the same variables are used for each of the procedures. The four subsystems are: pavement thickness design, reinforcing steel design, subbase design, and terminal treatment design. Each of these is considered in § 2.1 through § 2.4, and the four are combined to form the resulting pavement structure in § 2.5.

The design procedures must take into account stresses developed by both external and internal forces. The external forces (wheel loads) affect pavement thickness and subbase design. The internal forces (developed by concrete shrinkage and temperature change) affect the design of the reinforcing steel and the terminal treatment.

§ 2.1—Pavement Thickness Determination

The concrete pavement thickness may be determined by one of two methods: the fatigue method takes into consideration the repetition of wheel loads, whereas the static wheel load method designs for a limiting wheel load to be placed on the pavement. If satisfactory data is available pertaining to projected traffic, it is recommended that the fatigue method be used. If projected traffic is unavailable or the replication of wheel loads are not considered a factor, then the static wheel load method may be used.

§§ 2.11—Fatigue Method—The fatigue method of design is taken from the “AASHO Interim Guide for the Design of Rigid Pavement Structures” as extended by Hudson and McCullough. The equation and explanation of symbols are given in Figure 2.1-1, which is nomograph for solving the equation. An estimate of the following parameters will be required for using the fatigue method of design:

1. The equivalent 18-kip single-axle loads.
2. The concrete’s modulus of rupture and modulus of elasticity.
3. The supporting capacity of the material the pavement will be placed on.

The traffic projection is the total number of equivalent 18-kip single-axle loads expected to use the pavement during the design life of the pavement. The value for this traffic projection may be obtained from a traffic agency or computed by methods described in References 28 and 30. The design life should be specified by the designer; it is recommended that the pavement be designed for twenty years or more.

The concrete properties required with the fatigue method are the modulus of rupture and the modulus of elasticity at an age of 28 days as described in Section 1.1. For specifications used in construction control, the flexural strength at 7 days or earlier should be used, since large quantities of concrete can be placed in 28 days by present-day construction procedures.
FIGURE 2.1-1—Pavement Thickness Design by Fatigue Method
FIGURE 2.1-2—Pavement Thickness for Static Methods
The actual value of concrete strength is used without a safety factor in the fatigue method of designs because a safety factor for the number of load repetitions is included in the design equation. The modulus of a support reaction should be estimated by procedures described in § 1.3 and § 2.3. This support value should reflect the strength of the subbase as well as the native material.

The above-described parameters may be used with Figure 2.1-1 to determine the required thickness of a continuously reinforced CRCP for a highway (Figure 2.1-1 is not applicable to airports). In using the chart, the projected traffic and the concrete strength are entered on Scales 1 and 2, respectively. These values are then used to project a point on turning line 1. The concrete modulus of elasticity and the modulus of support are entered on Scales 4 and 5, respectively. These two values are used to project a point on turning line 2. The points on turning lines 1 and 2 are then connected, and the intersection of this line with Scale 3 is the required pavement thickness.

§§ 2.12—Static Wheel Load Method—The design charts for the static wheel load can be derived from Westergaard’s interior stress formula as presented in Reference 27 and 31. (Figures 2.1-2 and 2.1-3 are graphical solutions of this formula): Or the stress may be determined from influence charts for interior loading prepared by Gerald Pickett and Gordon Ray (Transactions ASCE Paper No. 2425—Volume 116, 1951, Page 49).

Both of these methods require values for the following parameters: wheel loads, concrete properties, and modulus of subgrade support. The wheel load used for design should be the prevailing maximum wheel load expected during the life expectancy of the facility, with an allowable working stress in the concrete obtained by dividing the 7-day modulus of rupture by the factor of two. This will provide for an unlimited number of stress repetitions of the maximum prevailing wheel load.

The estimated allowable number of stress repetitions for any load in excess of the prevailing wheel load can be determined from fatigue curves(1) by dividing the working stress under that load by the modulus of rupture of the concrete. Where repetitions of loads are not frequent as in airport runways and taxiways, a safety factor of 1.5 to 1.7 is satisfactory.

Figure 2.1-2 may be used with the previously described properties to determine the required pavement thickness. In using the chart, the allowable working stress is entered to the left of the chart and projected across to the appropriate value of the modulus of support. This point is then projected vertically to the intersection of the design wheel load. The value of thickness is then obtained from the right-hand scale by projecting horizontally across. Figure 2.1-2 is for concrete with a modulus of elasticity of 4.0-6.0 x 10^6 psi. If special coarse aggregates or special concrete mix designs are used, so as to produce values that are substantially lower than this, Figure 2.1-3 should be used to determine required thickness.

Figure 2.1-4 may be used for the design of pavements for runways and taxiways at airports. The design chart is used in the same manner as for Figure 2.1-2 described above. The safety factor used for the concrete strength will depend on the traffic expected and the type of facility. Following are the pertinent characteristics as to wheel loads and tire pressures used to develop the design chart:

(1) Concrete pavement design by Phil Fordyce and R. G. Packard—AASHO Committee on Design—39th Annual Meeting at Portland, Oregon. Fig. 8.
FIGURE 2.1-3—Pavement Thickness for Static Methods
<table>
<thead>
<tr>
<th>Airplane</th>
<th>Wheel Load—lbs</th>
<th>Tire Pressure—psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 2707 (1,000,000)</td>
<td>59.375</td>
<td>230</td>
</tr>
<tr>
<td>B 2707 (750,000)</td>
<td>44.530</td>
<td>230</td>
</tr>
<tr>
<td>B 747</td>
<td>42.330</td>
<td>205</td>
</tr>
<tr>
<td>L 1100</td>
<td>49.520</td>
<td>173</td>
</tr>
<tr>
<td>DC-10</td>
<td>49.040</td>
<td>168</td>
</tr>
<tr>
<td>DC-8</td>
<td>38.600</td>
<td>187</td>
</tr>
</tbody>
</table>

The design curves account for combined effect of the entire gear configuration for a given aircraft. Therefore, if the wheel loads or gear configuration vary substantially from the standard aircraft. Figure 2.1-4 may not be applicable. For these cases, the designer should develop appropriate design curves using either the Shell or the Chevenon oil company's layered system computer programs. For background information, refer to the paper entitled "Use of Linear Elastic Layered Analysis for the Design of Concrete Pavements, Concrete Overlays and Subbases," listed in the introduction. Two lines are presented for the B 2707 representing gross weights of 750,000 and 1,000,000 pounds.

§§ 2.13—Thickness Adjustment for Construction Method—For both the static wheel load and the fatigue method, odd fractions of thicknesses will be obtained from the design charts. In some instances, the thickness may be rounded off to the nearest \( \frac{1}{4} \) inch, but most construction practices require that the thickness changes be in 1-inch increments. For the normal case, it is recommended that the thickness greater than \( \frac{1}{4} \) inch be rounded off to the next highest inch. e.g., 8 inches would be used if the chart indicates 7.4 inches. Where paving is to be by slip form, slip form paver, the designer may call for minimum thicknesses to the closest \( \frac{1}{4} \) inch especially on large projects. Since the replacement of side forms on the equipment is a small cost item. e.g., if the chart indicates 7.2 inches, a minimum thickness of 7.25 inches would be used. Some slip form pavers with vertical control off wire guides can accommodate small changes in thickness and effect thickness transitions over short distances. Where use of such equipment is contemplated, consideration may be given to varying the pavement thickness along a project, within reasonable bounds, thus taking advantage of such variations in thickness requirements as a soil profile study and traffic loadings may indicate. The feasibility of this approach and the substantial savings realized were demonstrated on a recent airport project(32). With this design and wire-guide control, thickness transition distance is governed by geometric grade rather than being a matter of construction control. For new pavements, the recommended minimum thickness is 5 inches.

§ 2.2—Reinforcement Design

The design of longitudinal and transverse reinforcing steel for CRCP involves the parameters: (1) steel properties, (2) concrete properties, and (3) pavement width and supporting friction factor.

§§ 2.21—Steel Properties—For this phase of design, the tensile yield-point strength of the reinforcing member is required. The yield-point given in the specifications and listed in § 1.2 for the deformed wire or deformed bars may be used. For design computations, the yield-point tensile strength is divided by a safety factor of 1.33. Experience has indicated this value to be adequate.

§§ 2.22—Concrete Properties—The modulus of elasticity and the tensile strength are required for these computations. The modulus of elasticity may be determined as outlined in § 1.1, and the tensile strength may be determined from direct tensile tests. If equipment is not available for a direct
FIGURE 2.1.4—Pavement Thickness for Airports
concrete tensile test, then a value of 0.4 of the design modulus of rupture used in § 2.1 is acceptable. For these computations, no safety factors are applied; the values are used directly in the computations.

§§ 2.23—Pavement Width and Supporting Friction Factor—The distance between edges or free joints (no tie steel) is the pavement width to be used for designing the transverse steel. For slab width on a divided highway it is suggested that a minimum of 36 feet be used, since this will provide for a safety factor for an additional lane on a 24-foot roadway if future traffic volumes require it. In cases where a small traffic growth is expected during the life of the facility, lesser widths may be used. On freeways where numerous lanes are required, the pavement width used for design will depend on how lanes are tied together across the longitudinal joints (See §§ 2.41). The same applies to wide airport pavements. If a decision is made to eliminate the tie bars at a longitudinal construction joint, this joint becomes a free edge and the design width may be reduced appropriately. In general, this procedure is not recommended, as the design should provide for maximum load transfer between slabs. This is especially important in the design of airport pavements where heavy wheel loads may be moving down the longitudinal joint. As an alternative to tie bows, the edges at longitudinal construction joints may be thickened to increase their structural capacity.

For a friction factor to account for friction between the pavement and the base, subbase, or other supporting materials. Figure 2.2-1 may be used. The subbase type used is entered in the figure and the appropriate friction factor selected.

§§ 2.24—Design Charts—The longitudinal steel is designed by considering the pavement as a continuous restrained member, and the transverse steel is designed by considering that the slab is of limited width and fluctuates in width with volume changes, thereby reducing the stresses. Figure 2.2-2, taken from Reference 28 and modified to include higher-strength steels, is used to determine the percentage of cross-sectional area required for longitudinal steel. The equation and an explanation of the symbols are shown in the figure. The appropriate value of the concrete's tensile strength is entered on Scale 1, and the appropriate working stress for the steel on Scale 2. A point is then projected on turning line 1. The friction factor is entered on Scale 3 and the points on the turning line and Scale 3 are connected. The intersection with Scale 4 is the required percentage of cross sectional area of steel.

The percentage of longitudinal steel should not be less than 0.4 percent for concrete made with conventional coarse aggregates even though Figure 2.2-2 may indicate less. Deflection studies on in-service pavements have shown that the continuity condition across a transverse crack (full load transfer) is lost when the percentage of longitudinal steel decreases below 0.4 percent\(^{33}\). For a high-strength steel, the stresses due to volume change may be considerably less than the yield strength, but in order to develop the strength a large amount of strain is required. This leads to excessive crack widths, with a resulting loss of load transfer. Pavements with less than 0.4 percent have stayed in service for extended periods, but not without problems\(^{34}\). In special cases, where the concrete coarse aggregate has a thermal coefficient of from \(2 \times 10^{-4}\) to \(4 \times 10^{-6}\) in/in/\(^\circ\)F. the minimum allowable longitudinal steel may be reduced to 0.35 percent.
<table>
<thead>
<tr>
<th>Subbase Type</th>
<th>Subbase Coefficient&lt;sup&gt;(1)&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Treatment</td>
<td>2.2</td>
</tr>
<tr>
<td>Lime Stabilization</td>
<td>1.8</td>
</tr>
<tr>
<td>Asphalt Stabilization</td>
<td>1.8</td>
</tr>
<tr>
<td>Cement Stabilization</td>
<td>1.8</td>
</tr>
<tr>
<td>River Gravel</td>
<td>1.5</td>
</tr>
<tr>
<td>Crushed Stone</td>
<td>1.5</td>
</tr>
<tr>
<td>Sandstone</td>
<td>1.2</td>
</tr>
<tr>
<td>Natural Subgrade</td>
<td>0.9</td>
</tr>
</tbody>
</table>

<sup>(1)</sup> These recommendations were derived from a field study reported in Reference 42.

**FIGURE 2.2-1—Subbase Coefficients for Use in Empirical Design Equation**

The subgrade drag theory is used for the design of the transverse steel and tie bars<sup>(55)</sup>. The equation and an explanation of the symbols are shown in Figure 2.2-3, which is a nomograph solution of the equation. The equation is a modification of the general format that was developed by Hudson and McCullough<sup>(29)</sup> to give the solution in terms of percent of cross section area so as to be compatible with solutions for longitudinal steel. The chart is for a concrete weighing 145 lb/cu. ft. If concrete proposed for use differs substantially, the answers from Figure 2.2-3 should be multiplied by a ratio of the unit weight to 145.

The pavement width is entered on Scale 1 and the friction factor on Scale 2. These points are then connected by a straight line to the pivot line. The tensile strength of the steel is entered on Scale 4, and the points on the turning lines are connected. The intersection on Scale 3 gives the required percentage of transverse steel.
NOMOGRAPH

SOLVES: \[ P_s = (1.3 - 0.2F) \times \frac{S_C}{f_s} \times 100 \]

Example Problem:

\[ S_C = 300 \]
\[ f_s = 45000 \]
\[ F = 2.0 \]

Answer: \[ P_s = 0.60 \]

Where:

\[ P_s = \text{Required steel percentage - \%} \]
\[ F = \text{Friction factor of subbase} \]
\[ S_C = \text{Tensile strength of concrete - psi} \]
\[ f_s = \text{Allowable working stress in steel - psi} \]

(0.75 of yield strength recommended, the equivalent of safety factor of 1.33)

---

**FIGURE 2.2-2—Longitudinal Steel for CRCP**
On two- or three-lane highway pavements, a constant transverse steel percentage is used across the width. It may be economically feasible to reduce the steel transversely across the pavement width on multiple lane freeways and on airport pavements. To illustrate the design principles the following sketch shows the influence line for required percent steel in terms of pavement width:

NOMOGRAPH

SOLVES: \( P_s = \frac{LF}{2f_s} \times 100 \)

Example Problem:
- \( L = 36\) ft
- \( F = 1.9 \)
- \( f_s = 52,500\) psi
- Answer: \( P_s = 0.067\% \)

Where:
- \( P_s \) = Required steel percentage - %
- \( L \) = Width of slab - feet
- \( F \) = Friction factor of subbase
- \( f_s \) = Allowable working stress in steel - psi
(0.75 of yield strength recommended, the equivalent of safety factor of 1.33)

Note: Nomograph is based on concrete weighing 145 lb/cu ft For concrete weights differing this value multiply the percentage by a ratio of the uni weight to 145

FIGURE 2.2.3—Distributed Steel Percentage
N = Width of concrete placement module. Generally 24 feet or greater.

l = Distance from a free edge to the most interior point for the area under consideration.

P₁ and L as previously defined.

P = Reduced percentage of transverse steel

By definition the term 1 must satisfy the following: 1 \( \leq \frac{L}{2} \)

Using the influence diagram, the steel percentage required for any area may be computed as follows:

\[ P₁ = 2 \cdot P₁ \cdot \frac{1}{L} \]

For example, the transverse steel for:

1. Modules M₁ and M₅: \( P₁ = 0.4P \)
2. Construction joints C₂ and C₃: \( P₁ = 0.8P \)

Figure 2.2-4 may be used to determine the proper spacing of the reinforcing members. The percentage of steel obtained from Figures 2.2-2 or 2.2-3 is entered on Scale 1. The pavement thickness determined in \( \S \) 2.1 is entered on Scale 2. These points are used to project to a point on the pivot line. The cross-sectional area of the reinforcing members entered on Scale 3, and with the point on the turning line, are used to project a point on Scale 4. This value is the minimum spacing for the reinforcing member. This procedure is applicable to the design of both the longitudinal and the transverse steel.
§§ 2.25—Reinforcement Layout—Figure 2.2-5 is a suggested detail that may be used for deformed wire mats. The detail shows a 4x12-inch grid with the longitudinal wires at 4 inches and the transverse wires at 12-inch center-to-center spacing. The diameter for the wires would be as determined in §§ 2.24. The overhang for the transverse wire is 1 inch from each of the exterior longitudinal wires and the overhang for the longitudinal wires is one-half the spacing of the transverse wires. This particular illustration shows the dimensions to be 30 feet long and 11 feet 10 inches wide. The mats may be made up to 13 feet wide and 50 feet long if such dimensions prove to be economical in the light of available transportation modes and handling equipment. The smaller the mat size, the easier the handling during transportation and placement, but a larger amount of steel is lost in the laps.

In the center of Figure 2.2-5 is a suggested placement plan for the mats. The mats have a 1-inch clearance between the pavement edge and the end of the transverse wire. In the center, a 2-inch clearance is provided between the ends of the transverse wires. Note the laps diagram pattern of the mats. In this particular case, a 4-foot or greater dimension is specified between laps in the adjacent lane (see § 4.2 for a more detailed explanation).

Tie wires (deformed) or tie bars are used to provide a continuity condition between the mats in a transverse direction. If deformed wires are used, they should be placed at the same spacing as the transverse wires in the mats. If deformed bars are used, the size and spacing should be in accordance with that determined in Figures 2.2-3 and 2.2-4. After each transverse construction joint, the first lap should be at a minimum distance of 4 feet from the construction joint.

In the lower part of Figure 2.2-5 is a detail for the lap of the longitudinal steel. In this particular instance, an 18-inch lap is used. It is recommended that the lap distance be at least 32 times the diameter of the longitudinal wire; an allowable curvature for the longitudinal wires is illustrated. In the manufacturing of the prefabricated mats, a slight curvature is obtained in the longitudinal overhang. The retention of some of this curvature after assembly of the mats in the field is acceptable. This particular detail shows the transverse wire being placed on top of the longitudinal wire. As the relative positions of these two wires are immaterial from a design standpoint, positioning should be dictated by convenience in construction operations. As an additional precaution against failure, all splices occurring within 8 feet beyond the header, in the direction of paving, and three feet back of it, could be double that normally specified or the laps may be strengthened by splicing in, symmetrically with each lapped bar or wire. A 6 foot length of deformed bar of the same approximate size as the longitudinal reinforcing member.

The longitudinal steel should be placed at or slightly above the mid-depth of the slab for pavement thicknesses less than 10 inches. although there has been a difference of opinion among engineers about the proper placement height. One study found that longitudinal reinforcement placed 1½ inches above mid-depth must resist stresses due to temperature drops and wheel loads that are considerably greater than those for the same amount of reinforcement placed at mid-depth[85]. The Texas Highway Department, which has placed a substantial mileage of CRCP, places the steel at mid-depth. Cores of transverse cracks, taken by this organization from pavements from 3 to 17 years old, indicate that the crack widths do not significantly vary with depth. Figure 2.2-6 is a photograph of core taken at a transverse crack between longitudinal bars on a 17-year-old Texas project where the steel was placed at mid-depth. Note that the crack cannot be traced without difficulty any lower than ½ inch from the surface. With pavement thicknesses in excess of 10 inches, consideration should be given to raising the longitudinal steel above midpoint, but in no case should less than 2 inches of cover be provided. The final position of the reinforcing steel should be within a tolerance of ±½ inch of the prescribed height.
Example Problem:
\[ \rho_s = 0.5\% \]
\[ D = 6\text{ in.} \]
\[ A_s = 0.16 \text{ in}^2 \]

Answer: \( Y = 4 \text{ in.} \)

Where:
\[ \rho_s = \text{Required steel percentage - \%} \]
\[ D = \text{Thickness of Concrete Pavement - in.} \]
\[ A_s = \text{Cross Sectional Area of steel bar or wire - in}^2 \]
\[ Y = \text{Center to Center Spacing - in.} \]

**FIGURE 2.2.4—Bar Spacing Design**
**Deformed Wire Mat**

**Placement Plan**

30" Tie Wires @ same spacing
or $\frac{1}{4}'' \times 30'' @ 30'' c-c$

**Lap Detail**

**End View of Lap**

FIGURE 2.2-5—Suggested Detail for Prefabricated Deformed Wire Mat
FIGURE 2.2.6—Photograph of a Core from Over a Transverse Crack on a Project Where Steel Placed at Mid-Depth—Approximately 17 Years Old

If two CRCP’s intersect, the longitudinal steel for each of the pavements should be carried through the intersection and the transverse steel should be omitted. A 4-foot inset from the width of the intersection pavement will be required in the first pavement placed to permit the second pavement to be tied in properly in accordance with procedures outlined in § 4.3—Construction Joints.

The principles illustrated for the deformed wire mats are also applicable to deformed bars. The deformed bars may be prefabricated or assembled on the subbase. They may be in lengths of from 16 to 60 feet. Bar sizes used for highways are usually Nos. 3, 4, and 5. No. 6 bars are sometimes used for thick slabs. To assume minimum crack widths, the ratio of the bond area of the longitudinal bars to the concrete volume should not be less than 0.03 in²/in³. The bond-area ratio should be checked by the following formula⁹⁷:

\[ Q = \frac{4P}{D} \]

where

\[ Q = \text{Ratio of bond area to concrete volume in in}²/\text{in}³ \]
\[ P = \text{Steel area ratio, As/AC} \]
\[ D = \text{Diameter of reinforcing bars} \]

For further details as to deformed wire and bar placement, refer to Reference 37.

§ 2.3—Subbase Design

In all cases it is recommended that a granular subbase or a stabilized material be used unless the CRCP slab is subjected to only a few wheel load replications per day. The subbase material serves one or more of the following purposes:

1. To provide uniform support.
2. To increase the supporting power above that provided by the subgrade soil.
3. To minimize or eliminate the detrimental effects of frost action.
4. To prevent edge pumping.
Thickness requirements are determined largely by experience, and for present loads, 4 to 9 inches have proved to be satisfactory. Greater thicknesses, 12 inches or more, may be required on highly active clays, very unstable soils, poorly drained locations, and highly resilient soils. Figure 2.3-1 may be used as a general guide for determining the thicknesses of subbases for highway pavements. To protect against frost heave, it is recommended that the thickness of the selected material be at least one-half the full depth of frost penetration. Detrimental frost action can be reduced in most granular materials if under-drains are installed at proper locations so as to intercept and remove water that would otherwise tend to collect in the subbase layer.

<table>
<thead>
<tr>
<th>Type and Thickness:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Type of Subgrade Soil</strong></td>
<td><strong>Recommended Thickness</strong></td>
</tr>
<tr>
<td>High bearing (Sand and Sandy Loam Soils)</td>
<td>4-6 inches</td>
</tr>
<tr>
<td>Medium bearing (Silt and Silty Clay Soils)</td>
<td>6-9 inches</td>
</tr>
<tr>
<td>Low bearing (Highly active Clay Soils)</td>
<td>8-12 inches</td>
</tr>
<tr>
<td>Strength Requirements:</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Type of Subbase</strong></td>
<td><strong>Recommended Strength</strong></td>
</tr>
<tr>
<td>Cement Treated</td>
<td>400-750 psi compressive*</td>
</tr>
<tr>
<td>Lime Treated</td>
<td>100 psi minimum compressive*</td>
</tr>
<tr>
<td>Bituminous Treated</td>
<td>20 min. Hveem Stabilometer</td>
</tr>
<tr>
<td></td>
<td>500 min. Marshall Stabilometer</td>
</tr>
<tr>
<td></td>
<td>*Strength at an age of 28 days</td>
</tr>
</tbody>
</table>

**FIGURE 2.3-1—Subbase Design Guides**

The control of water accumulation in the subbase is essential if satisfactory performance is to be attained. The use of trench sections for the subbase material should be avoided. Crown width subbases with adequate transverse slope are recommended where economically feasible (see Figure 1-1).

If the roadway is subjected to a large number of heavy vehicles, subbase stabilization may be required to provide protection against pumping and to develop adequate support strength. As an alternative to stabilizing a granular layer, a one-course surface treatment or chip seal may be placed on the granular material to serve as a barrier to prevent pumping of fines. The asphalt content of this layer should be high to insure durability during the life of the facility. Although CRCP is not subjected to pumping at the joints, it may be susceptible to edge pumping if a poor subbase material with excessive fines is used and if heavy traffic and excess water are present. Where water and traffic problems are not severe, excellent performance may be obtained by using an asphalt seal in the joint between a paved shoulder and the edge of the CRCP.

Figure 2.3-2 may be used as a qualitative measure to determine if the subbase material should be treated or not. The nomograph in the figure was developed from a deflection study by the Texas Highway Department on in-service pavements. This figure is applicable only to high-traffic-volume highways. The K value or a relative measure of subgrade support characteristics (good, fair, or poor) is entered on Scale 1. A straight line is used to connect the image point and representative subgrade point. The recommended subbase characteristics are then read on Scale 2. The relative value of subbase characteristics read on the scale will provide deflection and stress charac-
FIGURE 2.3-2—Subbase Design Chart
FIGURE 2.4-1—Examples of Longitudinal and Transverse Joints
teristics to insure long life on a heavy-duty highway. The data on the left side of Scale 2 are for untreated subgrades and these on the right side are for cases where the native material is stabilized. If, for construction experience or other reasons, the subbase is formed of treated native material, the support value after treatment should be accounted for in the design. The stabilized native material should be 5 inches or more in thickness if it is to be considered as a load-carrying component.

§ 2.4—Joints and Terminal Treatment

Although the use of joints in CRCP is limited, joints are used at specific locations. Joints may be longitudinal or transverse joints. Design of transverse joints encompasses the subject of terminal treatment which is covered herein as a separate item. Reference 37, 40, and 41 may be used to obtain details of these various types of joints.

§§ 2.41—Longitudinal Joints—Longitudinal joints for CRCP are either construction joints dictated by construction procedures or warping joints. Warping joints are used to control the location of longitudinal volume-change cracks in order to prevent an irregular crack formation. Although it is not strictly necessary from a design standpoint to include warping joints, their use is recommended from an aesthetic viewpoint since the longitudinal crack is visible to the driver (whereas transverse cracks are not). The longitudinal joints should be located at the edge of traffic lanes to eliminate the possibility of tire pulling from an uneven joint if located in the wheel path. The spacing of the longitudinal joints on highway pavements should not exceed 15 feet. On airport pavements, the appearance of a random longitudinal crack is not as important aesthetically, therefore the spacing may be increased to 25 feet.

The transverse steel through longitudinal construction joints should be equivalent in load carrying capacity to that in the slab. The length of the tie bar should be a minimum of 60 diameters with one-half of the bar length on each side of the joint. If construction procedures require the bending of the tie bars, only deformed wire or deformed bars of ASTM Designation: A-615 grade 40 should be used.

Figure 2.4-1 illustrates two types of longitudinal construction joints: i.e., tongue and groove, and butt. Of the two, the butt joint is recommended since several construction problems are associated with the tongue and groove (see § 4.3). Experience has shown that sufficient mechanical interlock for load transfer between slabs can be developed with butt joints containing an adequate amount of tie bar steel (see §§ 2.25). The tie-bar spacing will generally be less than that of the transverse steel for equal bar sizes, if a lower yield strength steel is used. The final design details should provide for the optional use of multiple-piece tie bars (threads and couples) or two-piece hook bolts since they may be the most economical and practical in some instances. These multiple-piece combinations should be required to develop a failure force of 1.5 times the yield strength of the steel. Precautions should be taken by the designed that the size and spacing of the tie bars be compatible with construction procedures: e.g., large bars may be difficult to straighten, and conversely, if bars are too closely spaced, it may be difficult to arrange them.

Figure 2.4-1 also illustrates a typical warping joint that may be used between lanes on a highway pavement. Care should be taken that the joint is not vertically aligned with a longitudinal bar, thus reducing its load carrying capacity when a crack forms. Warping joints may be formed during concrete placement or cut by a concrete saw at an age of 3-5 days. This decision should be left to the option of the contractor since the type of coarse aggregate used will influence his final decision. The joints should be equal in depth to 1/4 the full thickness of the slab. The joints may be filled with one of the sealants listed in § 1.4.

§§ 2.42—Transverse Joints—Transverse joints are divided into construction joints dictated by con-
struction progress and expansion joints located at fixed objects. The transverse construction joint should be designed to provide slab continuity by permitting continuation of the basic longitudinal steel. The basic steel should be supplemented by enough additional steel to provide adequate resistance to repeated shear and bending stresses caused by traffic loads. As a general guide, a cross-sectional area of 1.0 percent should be provided across the joint. Current practice in some states is to specify an additional 5-foot-long bar between every other longitudinal bar. Figure 2.4-1 illustrates a typical transverse construction joint.

<table>
<thead>
<tr>
<th>Subbase Type(b)</th>
<th>± ½ in.(c)</th>
<th>± ¼ in.(c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Treatment (Chip Seal)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lime Stabilization</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Asphalt Stabilization</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Cement Stabilization</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>River Gravel</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Crushed Stones</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Sandstone</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Natural Soil</td>
<td>3</td>
<td>6</td>
</tr>
</tbody>
</table>

Notes:
(a) These recommendations were derived from a field study in Texas reported in Reference 42.
(b) The material the CRCP is resting directly on should be used in this analysis.
(c) These columns indicate the number of terminal anchor lugs required to restrict the end movement to variation indicated.

**FIGURE 2.4-2—Recommended Number of Anchor Lugs for Subbase Type and Allowable Joint Movement**

Due to the large, seasonal free-end movement of CRCP, which may be as much as 2 inches, special terminal treatment is sometimes required at fixed structures, such as bridges. Either of two systems may be used to cope with these movements. The principle of one is to anchor the end, and the principle of the other is to allow the pavement to fluctuate as a free end. The first method is recommended for end treatment adjacent to major structures. Studies of 186 terminal anchorage units by the Texas Highway Department found that the number of end anchorages depends on the allowable movement, the length of the pavement contributing to end movement, pavement profile, temperature variation, and subbase coefficient of friction\(^{(42)}\). This data was derived over a wide variety of soil conditions and should be applicable to most conditions. Figure 2.4-2 is a table of terminal treatment derived from the Texas study showing the number of end anchorages required for different subbase types to combat a 100°F temperature change. The number of end anchorages may be determined by entering the table with the subbase type and the allowable movement for the expansion joint sealer material proposed for use.

Anchoring lugs, as shown in Figure 2.4-3, are usually 2 feet wide and extend into the subbase and subsoil 3 feet from the pavement bottom and across the full pavement width. In cases where Figure 2.4-2 indicates lugs are not required, the lugs are left off the detail in Figure 2.4-3. For further information as to reinforcing these lugs, References 37, 40, and 42 are recommended. For conventional sealing materials, such as hot-poured rubber, polymers, and asphalt, it is recommended...
Relief Section for CRCP

Terminal Anchorage Treatment

Anchorage Lugs

FIGURE 2.4-3—Examples of Terminal Treatment for CRCP
that the allowable joint movement be ±¼ inch; for neoprene compression sealers it is recommended that the allowable joint movement be ±½ inch.

Pillings may be used in lieu of anchor lugs, but the variation of number with project conditions is an unknown factor. The Texas Highway Department has found it feasible to tie the CRCP directly into a bridge in special cases where continuous slab bridges are used.

The other system of terminal treatment, as indicated in Figure 2.4-3, provides for a series of short, conventionally reinforced slabs with dowelled expansion joints to accommodate the expected movement. The number of expansion joints will depend on the estimated free end movement, the thickness and type of expansion joint filler and the type of seal. If local data is not available, Figure 2.4-4 may be used as a guide for estimating the number of expansion joints needed. The figure is entered with the subbase type, expected yearly temperature range, and the allowable movement for the joint seal type selected (§ 1.4), and an estimate for the number of expansion joints needed is obtained. The pavement slabs should be reinforced in accordance with Figure 2.2-3. The size of the dowells depends on the wheel load expected, and a general formula for diameter of the dowells is ½ inch times the pavement thickness, e.g., an 8-inch pavement would require 1-inch-diameter dowells.

Another example of free-end treatment is the wide flange expansion joint illustrated in Reference 41.

<table>
<thead>
<tr>
<th>Subbase Type(s)</th>
<th>Free End Movement</th>
<th>Number of Expansion Joints for(b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100°F Temp. Var.</td>
<td>100°F Temp. Var. and Allow. x</td>
</tr>
<tr>
<td></td>
<td>130°F Temp. Var.</td>
<td>130°F Temp. Var. and Allow. x</td>
</tr>
<tr>
<td></td>
<td>(inches)</td>
<td>± ¼ in.</td>
</tr>
<tr>
<td></td>
<td>(inches)</td>
<td>± ½ in.</td>
</tr>
<tr>
<td>Surface Treatment</td>
<td>0.4</td>
<td>1</td>
</tr>
<tr>
<td>Lime Stab.</td>
<td>0.7</td>
<td>2</td>
</tr>
<tr>
<td>Asphalt Stab.</td>
<td>0.7</td>
<td>2</td>
</tr>
<tr>
<td>Cement Stab.</td>
<td>0.7</td>
<td>2</td>
</tr>
<tr>
<td>River Gravel</td>
<td>1.0</td>
<td>2</td>
</tr>
<tr>
<td>Crushed Stone</td>
<td>1.0</td>
<td>2</td>
</tr>
<tr>
<td>Sandstone</td>
<td>1.7</td>
<td>4</td>
</tr>
<tr>
<td>Natural Soil</td>
<td>2.6</td>
<td>6</td>
</tr>
</tbody>
</table>

NOTES:
(a) The material the CRCP is resting directly on should be used in this analysis.
(b) These recommendations were derived from a field study reported in Reference 42.

FIGURE 2.4-4—Free End Movement and Number of Expansion Joints for Subbase Type and Allowable Joint Movement

§ 2.5—Pavement Structure Section

The components of the pavement structure (see Figure 1-1) must work together as an integral unit if the structure is to efficiently perform its function of carrying the design traffic. Therefore, the pavement, subbase, subgrade, and shoulder base must be assembled taking into consideration the relative role of each layer with regard to such factors as drainage, probable construction conditions and methods, equipment, maintenance, and available finances. In this section, several examples of typical pavement structure sections for urban and rural roads are discussed. The examples, shown in Figure 2.5-1, are not presented as the final solutions but rather to illustrate prin-
FIGURE 2.5-1—Examples of Typical Sections for Roadways
ciples that should be considered. Reference 37 may be referred to for typical sections used on in-
service projects. The example at the top of Figure 2.5-1 is of an urban roadway and the one at
the bottom is of a rural freeway. The rural pavement structure section illustrates two possible treat-
ments, one (at left) for heavy traffic and poor soil conditions and the other (at right) for lighter de-
sign.

The CRCP in both typical sections of Figure 2.5-1 is of uniform thickness. Pavements with
thicker edges are expensive to construct and should be avoided except where the thickness can be
uniformly increased from the crown line toward the edge. On the other hand, curbs as shown on
the typical urban section may be used without any problem. Curbs should be continuous, without
contraction joints, and should be reinforced with approximately the same longitudinal steel per-
centage as the pavement. They should be monolithically placed either as a part of regular construc-
tion operations or at a later date by using vertical ½-inch deformed tie bars spaced at 30 inches.

Granular subbases, both with and without stabilizing agents, are illustrated in Figure 2.5-1.
For granular materials without stabilizing agents, it is recommended that the subbase layer be car-
rried the full crown width out to the front slope to allow free drainage of surface water that might
enter the layer. This precaution is essential if an underlying impermeable layer is formed by intro-
ducing a stabilizing agent in the native soil, a procedure that may result in a "container" which traps the free moisture in the layer. Where stabilized subbases are used, the layer may be carried
the full crown width, or if economics dictate, it may be carried only 2 feet past the edge of the
CRCP. The edge of any layer represents an interruption in continuity and a stress concentration.
Hence, the designer should avoid placing these edges in a vertical alignment. In urban areas, where
curbs are used, the edge condition is reduced; hence, the extension may be reduced to 6 inches.

The native soil or embankment soils should be treated for a depth of 4 to 6 inches. In some
cases, a stabilizing agent may be used to provide a working platform for construction operations
or increased strength. As a minimum requirement, the soil should be scarified and recompacted as
shown in Figure 2.5-1 to insure uniform support. The following requirements may serve as a gen-
eral guide:

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Percent Compaction</th>
<th>AASHO Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granular</td>
<td>95% min</td>
<td>T-180</td>
</tr>
<tr>
<td>Sand. Silt. and Clayey (PI 10)</td>
<td>95% min</td>
<td>T-99</td>
</tr>
<tr>
<td>Clayey (PI 10)</td>
<td>95% min</td>
<td>T-99</td>
</tr>
</tbody>
</table>

The thickness of the shoulder base in Figure 2.5-1 should be designed by flexible pavement
design methods. The edge of the CRCP represents a grade control for the shoulder base. The load-
carrying capacity of the shoulder can be increased by either increasing the subbase thickness or im-
proving the quality of the shoulder base.
SECTION 3

DESIGN OF OVERLAYS

§ 3.0—General

This section provides guidance for the design of CRCP overlays for existing concrete pavement. The design concepts and charts are essentially the same as for the design of a new concrete pavement as presented in Section 2. The principal difference is in the design charts for pavement thickness.

The first step is to obtain an estimate of the effective load carrying capacity of the existing slab. This involves an evaluation of the condition and the strength of the existing pavement by classifying it into one of the following three categories:

Intact Condition—The pavement retains an excellent profile with very little pavement roughness. The existing slabs do not show excessive load cracking. Transverse cracks are only of a volume-change nature; there are not more than two such cracks per slab, and at least about half the slabs are crack free.

Broken Condition—About half the slabs have multiple cracks, producing about six pieces per slab. These multiple cracks involve both volume-change (transverse) and load-associated cracks (transverse and longitudinal). The cracks may have required maintenance consisting of routing and sealing.

Shattered Condition—Half the slabs have multiple cracks, producing in excess of 10 pieces per slab, or slab segments which may be less than 12 to 15 square feet in area. The maintenance of the cracks has been heavy and possibly some thin asphalt concrete overlays have been placed to maintain the required smoothness. Considerable spalling has been experienced at the cracks.

§ 3.1—Pavement Thickness Determination

The present state-of-the-art for the overlay design requires that the static wheel load method be utilized. For determining the thickness, an estimate of the following factors is required:

1. the design wheel load.
2. classification of the existing condition of the pavement.
3. the flexural strength of the existing pavement and the new concrete.
4. subgrade support conditions.

The design wheel load should be estimated as indicated in §§ 2:12. “Static Wheel Load Method.” A survey of the existing facility would place it in one of the three categories defined above. The flexural strength of the existing pavement may be obtained from beams cut from the pavement. An alternate method is to take cores of the existing pavement and perform a splitting tensile test. The values of splitting tensile strength may be used to estimate the flexural strength by utilizing correlations of the two tests that are available elsewhere\(^{14}\). The flexural strength, determined from the pavement, will take into account the fatiguing effect of previous load applications. A compatible design requires that the concrete for the overlay be equal or greater in strength than the existing slab. For design analysis, the flexural strength of both the existing concrete pavement and the concrete pavement overlay should be divided by a safety factor of two.

The thickness of the existing pavement structure may be obtained from the cores used to obtain the tensile strength. The subgrade support value may be obtained from k-value tests or resilient modulus tests as indicated in Subsection 2.11. Deflection tests are especially applicable to this study\(^{23, 24}\). For this design analysis, the subgrade is categorized as “poor” or “good.” A poor subgrade would be considered as one with a k value or resilient modulus value less than 400 pci or 10,000 psi, respectively. and a good subgrade as anything greater.
Prior to placing the CRCP overlay, it is recommended that the existing concrete pavement be overlaid with a ½- to 3-inch layer of bituminous mix (asphalt or coal tar). The one exception is when the existing pavement is categorized as in intact condition and the joint spacing is 15 feet or less. The bituminous overlay will serve as a stress-relieving layer to insure that the volume-change movements of the original slab will not induce stresses in the new CRCP overlay. Otherwise, additional steel would be required over the joints to insure that the transverse cracks in the CRCP overlay would not open excessively. In some cases, previous maintenance operations may have placed an asphalt concrete overlay over the portland cement concrete pavement. In these cases, this layer will be satisfactory unless additional material is required to restore the grade line.

Three design charts are provided for the overlay thickness design of highways, i.e., Fig. 3.1-1 thru 3.1-3. Selection of the proper one will depend upon the classification of the existing facility and the thickness of the stress-relieving course proposed or existing as an asphalt concrete level-up. Figure 3.1-1 is for the pavement slab in the intact condition, and a stress-relieving layer is not used. Figure 3.1-2 is used where the pavement is classified as intact, and the geometric profile conditions are such that a thin stress-relieving course of ½ - 1 inch may be used. Figure 3.1-3 is used where the existing pavement structure is either (1) intact, but pavement roughness or profile requires 3 inches or more of bituminous material, (2) intact or broken with existing bituminous overlay and no “rocking” slabs are present, or (3) broken. A 3-inch bituminous stress-relieving course is recommended for (3). For slabs classified as shattered, Figure 3.1-3 may be used as a general guide provided 3 inches or more of bituminous material is used. The existing pavement thickness used with these graphs should be the minimum value found. For example, the interior thickness would be used for thickened-edge pavements.

Figure 3.1-4 is used for the design of pavements for airports. The aircraft characteristics used in developing this chart are as described in § 2.12. For cases where the wheel loads and gear configuration vary substantially from the standard, the design chart may not be applicable. For airport pavements it is recommended that a stress relief course be used in all cases on top of the existing pavement since excessive amounts of steel may be required over the joints to prevent the transverse cracks from opening two wide. The design chart is based on a stress relieving layer of 1½ -3 inches thick. The safety factor used with the concrete will depend on the facility type and traffic as described in § 2.12.

To use the charts, the allowable working stress is entered on the vertical scale and projected horizontally across until it intersects the design wheel load. This point is then projected vertically downward to an intersection of the line indicating the subgrade support conditions. This point is then projected horizontally across to the existing pavement slab thickness. This point is then projected vertically upward to obtain the overlay thickness. If slipform paving is to be used, the exact dimensions obtained from the chart may be specified, whereas if more conventional form paving is anticipated, the numbers should be rounded to the next highest inch. (See §§ 2.13, “Thickness Adjustment for Construction Method.”) It is recommended that in all cases the overlay thickness be greater than 3 inches, even though the charts may indicate less. (Special attention should be given to overlays from 3 inches to 4 inches in thickness, since field experience in this range is limited.)

§ 3.2—Reinforcement Design

The design of the reinforcing steel, both longitudinally and transversely, for the CRCP overlay is the same as indicated in Section 2.2, “Reinforcement Design.” The friction factor for the asphalt stabilization in Figure 2.2-1 is recommended for use in this design analysis. The reinforcement layout will follow the same principles outlined in Subsection 2.25.
FIGURE 3.1-1—Design Chart for Overlay—No Bond Breaker
§ 3.3—Joints and Terminal Treatment

The principles for joints and terminal treatment for CRCP overlays are the same as those outlined in Section 2.4. In cases where an existing concrete pavement is used for a portion of the highway and new pavement is used elsewhere, a transverse construction joint will be required if the pavement thicknesses are different. If the new pavement has a thicker section than the overlay pavement and economics indicate the use of a different reinforcing design, the reinforcement pattern for the new pavement should be carried 20 feet or greater into the overlay pavement before transitioning. (See § 4.7.) From that point, the design may be transitioned into that required for the overlay pavement. The principles for lap staggering, etc., should be rigidly adhered to in this transition area.

§ 3.4—Pavement Structure Section

Examples of typical pavement structures for rural freeways, utilizing a CRCP overlay to upgrade an existing facility, are illustrated in Figure 3.1-4. The examples, in addition to general concept, illustrates two possible methods of widening a narrow existing facility previously overlaid with asphalt concrete. For the upper section in the figure, the pavement is widened by adding a 3-foot strip of asphalt concrete to each side of the pavement equal in depth to the existing concrete pavement. The stress relieving course and the CRCP are then added to the proper dimensions. For the example in lower part of the figure, the existing pavement structure was widened by stabilizing a subbase with an additive to a thickness that permits the CRCP overlay to be constructed to full depth (designed in accordance with §§ 2.11) in the area of additional width. Hence, the thickness of the section widening the original roadway is designed as new pavement, and the thickness for the portion overlaid, is designed from the overlay criteria. The CRCP overlay is then placed over the stress-relieving course to the proper dimensions. It is essential that extra care be taken in the design and construction of the widened area to avoid a stress concentration in the overlay directly above the construction joint. Stabilized subbase portland cement concrete, or asphalt concrete should be used to minimize the differential consolidation which would produce the undesirable stress concentration.

For both these examples, an additional thickness of asphalt concrete is added to one of the existing lanes to remove the pavement crown from the center line, thus directing surface water drainage away from the freeway median. Note also that the vertical alignment of construction joints in any layer is avoided.

It is recommended that a dense-graded bituminous material be used for the stress relieving course. Stability requirements in this layer are not as critical as one on or near the surface; therefore, the stability may be reduced to a Hvemc stabilometer value of 20 or Marshall stability of 500. The maximum size of the course aggregate will be dependent upon the thickness of the stress-relieving layer selected.
FIGURE 3.1-2—Design Chart for Overlay with One-Half to One Inch A.C.P. Bond Breaker
FIGURE 3.1.3—Design Chart for Overlay with Three Inches
A.C.P. Bond Breaker
FIGURE 3.1-4 Chart for design of CRCP Overlays for airports
SECTION 4
CONSTRUCTION

§ 4.0—General

Good practices and controls during construction including careful inspection and supervision are essential to the performance of all types of pavements. Many of the problems associated with CRCP in the past may be attributed to construction errors and poor construction practices.

After the subbase has been prepared, i.e., constructed and finished to the desired grade, the paving operation may commence. If concrete is placed by means other than a slipform paver, the paving operation is begun by setting the forms to the specified line and grade. After which the steel is placed. For slipform paving, the operation is started by setting the tightly drawn wire grade line or by planing a track path to the proper grade, depending on equipment type, after which the reinforcing steel is placed on the subbase.

It is not the intent of this manual to describe in detail the proper construction procedures, but rather to discuss pertinent items and possible problem areas. These, as discussed in the following sections are: steel placement, laps, construction joints, vibration, concrete placement, "leaveouts," CRCP overlay construction, and equipment.

§ 4.1—Steel Placement

Basically, the steel placement is a function of the design details. With prefabricated, welded, deformed wire mats, the continuous steel mat is formed by assembling and tying the mats together on the subbase in an appropriate manner. With prefabricated mats, most of the labor takes place in the shops and only a minimum is required to assemble the mats in the field. With deformed reinforcing bars, the steel mat is fabricated on the site by a combination of human hands and mechanical devices. In this case, most of the labor is required at the construction site unless the deformed bars are assembled and prefabricated in the shop.

The reinforcement mat may be assembled in front of the paving operations or as a part of the paving operations. For the first case, the reinforcement is supported by bar chairs so that the desired height of the reinforcement can be maintained during construction. The full thickness of the pavement slab is placed in one pass of the paving equipment. Figure 4.1-1 shows deformed wire fabric mats 4 feet wide being assembled on the subbase, and Figure 4.1-2 shows the fabric after assembly and being supported at the proper height by chairs. Generally one chair per 12 square feet of reinforcement gives adequate support. For the second case, the reinforcement may either be placed on top of the full-depth slab and vibrated to the desired depth or placed between pours by a double strike-off method. With the double strike-off method, the first pass of the paver places the concrete to a thickness that is about 1 inch greater than the desired height of the longitudinal reinforcing steel. The mats are then placed on top of the concrete, and a second pass of the paver brings the pavement to the desired thickness as shown in Figure 4.1-3. The use of two pavers is recommended with the double strikeoff method, along with a requirement that the second course be placed close enough behind the first course to avoid a plane of cleavage between layers. With slipform pavers, the first paver deposits the concrete to a width that is 8 inches (4 inches on each side) less than the plan width. The second paver then places the concrete at full depth and width. Regardless of the type of placement used, the final position of the longitudinal reinforcement should be within \( \pm \frac{1}{2} \) inch of the prescribed height.

The use of CRCP ramps at the intersection of CRC pavements at large angles requires special considerations during the placement. It is suggested that, in an area where the pavements are tied together, an inset about 4 feet wide be placed in the pavement edge for the entire width of the in-
FIGURE 4.1-1—Deformed Wire Fabric Mats Being Assembled on the Subbase

FIGURE 4.1-2—Assembled Mats in Place Ready for Concrete Placement
intersecting pavement. This procedure leaves exposed steel in the main lanes for the steel in the intersecting pavement to be tied directly to, hence providing a continuity condition for the two pavements.

§ 4.2—Laps

Lapping of the longitudinal reinforcement is important from the standpoint of bond development, which is essential for true continuity in the steel. The lap lengths should be equal to not less than 25 times the bar diameter for steel bars and 32 times the nominal wire diameter for the welded deformed wire mat.

Generally, not more than $\frac{1}{2}$ to $\frac{1}{2}$ of the longitudinal steel should be spliced in a single transverse plane across the pavement. It is recommended that the width of this plane be 2 feet if the $\frac{1}{2}$ figure is used, and 4 feet if the $\frac{1}{2}$ requirement is used. The latter case may be interpreted to read that any 4-foot length of pavement, not over $\frac{1}{2}$ of the longitudinal reinforcing members be spliced across the width of the pavement. Figure 4.1-2 shows a lap staggering pattern for deformed wire fabric mats that are 4 feet wide. For the prefabricated mats, tie wires are used to insure that the proper lap dimensions are maintained. These tie wires may be placed around the longitudinal wires or around the transverse wires if the design is such that the transverse wires for adjacent mats are vertically aligned. Figure 4.2-1 shows tie wires being placed around the longitudinal wires. If deformed bars are used, tie wires are placed at each lap of the longitudinal steel. These tie wires serve the purpose of joining the longitudinal laps and holding them in place during construction operations, but they add no structural strength to the mat.

With the prefabricated deformed wire mats, shingle laps are used to give the mats continuity. The position tolerance for the placement of the longitudinal steel, mentioned previously, will have to be relaxed at the laps. With the shingling effect, it is impossible to place the longitudinal steel within ± $\frac{1}{2}$ inch of the desired plane of placement; hence, the requirements must be relaxed in the vicinity of the laps. Figures 4.2-2 and 4.2-3 show lap-staggering techniques for the deformed wire fabric mats and deformed bars respectively.

§ 4.3—Construction Joints

Adequate performance of the construction joint, especially the transverse one, is the key to the longitudinal continuity of CRCP. Transverse construction joints have improved considerably as experience has been gained by both contractors and construction engineers. The essential to having a good construction joint is to have high quality concrete on both sides of the joint. Placement of the header for the transverse construction joint should be carefully planned. Haphazard header placement and finishing can lead to trouble. Use of the slipform paver and the hopper-type spreader have tended to eliminate the problem of poor quality concrete at the construction joint, but it is recommended that additional vibration be used on the new side. The transverse construction joint usually has additional longitudinal reinforcement as described in Section 2.42. Furthermore, it is usually specified that the transverse construction joint must be outside any splice or lap pattern in the longitudinal reinforcement. A recommended practice is to have the first longitudinal wire lap a minimum of 4 feet from the transverse construction joint, and then continue the normal lap staggering arrangement. The Plan View in Figure 2.2-5 illustrates these principles, and Figure 4.3-1 is a photograph of a transverse construction joint conforming to these principles.
FIGURE 4.1.3—Deformed Wire Fabric Mats Being Placed Using the Double Strike Off Technique

FIGURE 4.2.1—Placement of Tie Wires at the Longitudinal Laps
FIGURE 4.2-2—Lap Staggering Pattern for Deformed Wire Fabric Mats Six Feet Wide

FIGURE 4.2-3—Lap Staggering Pattern for Deformed Bars
The continuation of the construction operations from a transverse construction joint where the concrete has cured for periods greater than 10 days requires special procedures. This comes about because the pavement end has established a fluctuating movement pattern with temperature cycles. and this movement can cause damage and loss of concrete bond in the new slab if not provided for. The lower-friction subbases, such as the natural subgrades or crushed sandstones, are particularly troublesome (see Figure 2.2.1). The damaging movements may be neutralized by starting construction operations early in the morning to allow the concrete to acquire more of its initial strength prior to the contractive movements associated with cooling of the pavement as the sun sets. If a severe temperature drop is expected within 48 hours, the slab should not be placed. An alternative to these suggestions would be to stabilize the movement of the existing slab end by ponding water on it or by covering it with wet sand, wet straw, or wet cotton blankets. The length of slab to be covered varies with temperature and subbase type, but in general a minimum of 75 feet should be covered.

![Transverse Construction Joint with Additional Steel](image)

**FIGURE 4.3.1—Transverse Construction Joint with Additional Steel**

The longitudinal construction joint is used when more lanes are required than can be placed by a single pass of the paver, or at the intersection of ramp connections. In the past, a tongue and groove type section was popular, but experience has shown that the tongue and groove joint has resulted in structural failure of the pavement because of problems in construction, namely, poor consolidation of the concrete in the lower lip of the groove section and shear failure in the upper lip when removing the forms. Also edge loading of construction equipment before the additional lane or ramp is placed may cause the upper lip to fail in shear. The longitudinal construction joint is reinforced by tiebars, either single-unit or multiple-piece bars with couplings. If bent tie bars are used, the portion of the bar for tying into an adjacent slab may be wrapped with paper or cardboard to prevent bonding to the first placement. The bars may then be straightened and the bond-breaking material removed prior to placement of the adjacent slab.

§ 4.4—Vibration

Adequate vibration of paving concrete has proved to be a necessity. Usually, every agency that builds portland cement concrete pavements experiences vibration problems. Vibration of reinforced concrete pavements is complicated by the fact that the steel mat is usually placed first, forming an obstruction for the plastic concrete to flow through, which often results in poor consolidated concrete beneath the steel.
Of the two most common types of paving concrete vibrators—the internal or spud type and the surface or pan type—neither shows superiority to the other on the basis of any authentic data, although individual engineers will tend to favor one or the other based on their individual experience. Figures 4.4-1 and 4.4-2 illustrate the use of internal and surface vibrators, respectively.

Pan-type vibrators will give good results on slabs less than 10 inches thick. On slabs thicker than 10 inches, internal vibration should be used exclusively or in combination with pan-type vibrators. A spacing of 14 to 24 inches of the internal vibrators is required for adequate coverage. The vibrating elements for the pan-type should be high amplitude and low frequency—the pan 3000 to 4500 impulses per minute. The immersion type should operate in excess of 7000 impulses per minute.

When pavements are inadequately vibrated, failure occurs, beginning with closely spaced transverse cracks, usually in the vertical plane of the transverse reinforcement. Thereafter, severe spalling and consequent loss of structural integrity occur. Therefore, it is very important that the vibration equipment be checked regularly for its specified output and the proper coverage of the slab.

Internal or spud-type vibrators should not be allowed to touch the reinforcing steel for extensive periods since this can cause excessive mortar around the steel, resulting in insufficient bond strength. On the other hand, the surface or pan-type vibrators may cause excessive mortar to be worked to the pavement’s surface, resulting in a non-durable wearing surface. With a non-durable wearing surface, the pavement may lose its skid resistance, spall at cracks, and even scale in certain environmental conditions.

With low-slump concrete normally used in paving operations, there is little danger of overvibration. Experience has shown that the probability of problems due to undervibration greatly exceeds that of overvibration. Overvibration may be detected by the appearance of excessive surface water and mortar without coarse aggregate. If this condition exists, it is suggested that the amount of concrete slump be reduced rather than the amount of vibration. Vibration periods of 5 to 15 seconds for an area are generally adequate. Therefore, the longitudinal speed of the equipment and the number of vibrations should be controlled to provide the suggested vibration period.

With the double strike-off method of placement, the entire depth of the new layer should be vibrated. The vibrator should extend into the first lift to insure that a monolithic slab is obtained. This is possible since the steel mats will generally penetrate an inch or more into the first layer.

An internal vibrator should be inserted at each edge of the slab even if pan vibrators are used. This will insure proper consolidation of the concrete at the edge around the exterior longitudinal bars where honeycombing frequently occurs.

The above-stated principles are also applicable to concrete made with lightweight coarse aggregate. There is a tendency for lightweight aggregates to float to the surface of the fresh concrete if overvibrated, making surface finishing difficult. If this occurs, the frequency of vibrators must be decreased and the amplitude increased.

§ 4.5—Placement

As with all types of construction, the concrete in CRCP construction should be deposited on the subgrade in a systematic pattern to provide good coverage. The operator should avoid placing the concrete in piles or windrows and depending on the spreader or screed to provide coverage, as this produces unequal densities and honeycombing in heavily reinforced slabs in addition to aggregate segregation. Isolated drops of concrete batches at a distance in front of the normal paving operations has resulted in isolated honeycombing of concrete beneath the steel, due to a rapid set.
FIGURE 4.4-1—Internal Vibrators

FIGURE 4.4-2—Surface Vibrators
Placement operations should be monitored closely during periods of high temperature (greater than 90°F), low relative humidity (less than 50 percent), and high winds. These conditions can cause a rapid initial set of the concrete in an unconsolidated condition prior to vibration around the reinforcement, in addition to the more usual problems. The normal preventive measures of hot-weather concreting, such as use of cool materials, dampening subgrade and forms, and careful work schedules, should be rigidly adhered to.

§ 4.6—Leaveouts, Coring, and Utility Cuts

"Leaveouts" of a section of the slab during construction operations for haul roads, cross traffic, etc., should be avoided wherever possible. Experience shows that indiscriminate use of leaveouts can cause problems if not handled properly. The free ends at each end of the leaveout will establish a movement pattern during curing. When the leaveout is completed, this movement has to be halted, something which may be difficult for fresh concrete, unless the following precautions are taken.

If possible, the leaveout should be longer than 100 feet. The procedure for placement of the leaveout should include controlling the movement of the free ends to a minimum. One way to limit the free end movement is to reduce variations in the slab temperature during a daily cycle for a distance of approximately 75 feet on each side of the leaveout area. The temperature stabilization should be initiated 24 hours prior to the concrete placement and continued for 60 hours after placement. The temperature stabilization may be achieved by the use of wet straw or cotton mats, moist sand, or water ponding on each of the existing pavement ends.

Construction operations in urban areas sometimes require the cross traffic be carried through major intersections. This requirement may be handled by using leaveout procedures described previously. Some of the intersections could be constructed during normal operations, and after proper curing they could be opened to traffic so that other intersections could be closed to complete the leaveout. An alternate to this is to construct the intersection first as shown in Figure 4.6-1. One side of the intersection is placed, and after proper curing, traffic is detoured onto it so that the other side may be constructed. After all the intersections are completed, normal paving operations could commence. Temperature stabilization of the intersection would not be as critical since end movement would be small due to the short length.

In order to maintain the continuity of the pavement structure, cutting and coring of the slab should be held to a minimum. All required coring should be performed with a core drill that does not exceed 2 inches in diameter, and if possible, the cores should not cut the reinforcing steel. When the cutting of the slabs becomes a necessity, the replacement procedures should be such as to provide full restoration of the slab continuity. One successful method is to cut out only half the slab at a time, replacing the steel and concrete within a 12-hour period. After five to ten days of curing, the other half is cut out and replaced in the same way. As an alternative, the temperature stabilization described previously may be used. The minimum width of the transverse cut should be 5 feet. Experience on Illinois Experimental Port at Vandalia showed that short patches did not perform well. A minimum length of 10 feet was established.

If traffic detector pads are required, the thin type (2-inch total depth) should be used in lieu of the full slab depth type, as installation of the latter type has caused problems. As shown in Figure 4.6-2, the area for the thin type may be formed during construction by placing a form board of proper dimensions in the surface. This may be removed at a later date and the detector pad installed.
FIGURE 4.6-1—Placement Plan for Handling Cross Traffic at Intersections

FIGURE 4.6-2—Suggested Installation of Traffic Detector Devices
Figure 4.6-8 is a photograph of a "leaveout" where the steel has been reassembled and is ready for final placement. This leaveout was on an Interstate Highway in Texas at a concrete batching plant to allow circulation of traffic. Note the moist sand on each of the pavement terminals that was used for temperature stabilization. Figure 4.6-4 is a photograph of the leaveout after placement and during concrete curing.

§ 4.7—CRCP Overlay Construction

Basically, the construction of a CRCP overlay over an old jointed concrete pavement is the same as the construction of an entirely new CRC pavement. The old jointed pavement in many cases has to be prepared for the overlay if badly broken up. This preparation includes leveling up the jointed concrete pavement with hot-mix asphaltic concrete. This level-up includes bringing the pavement to a desired grade and cross slope so that a good working platform is provided for subsequent paving operations. The asphaltic concrete level-up also serves to cover old cracks and joints in the jointed pavement that might otherwise tend to cause planes of weakness in the CRCP overlay and lead to reflection cracking in the overlay. Knowledge of overlay projects on highways in Texas and an airport overlay in Illinois indicates that no reflection cracking is present.

The old jointed pavements that have been overlaid thus far with continuously reinforced concrete pavement have been narrower than the width of the new overlay. Usually the jointed pavements are 20 to 22 feet wide while the CRCP overlays are 24 feet wide. Thus, the placement of a 24-foot slab over a narrower one requires careful consideration in design and extreme caution in construction. One method of widening the jointed concrete pavement is full-section widening with asphalt concrete on both sides of the pavement. For example, a 20-foot JCP may be widened to 26 feet by adding 3 feet of full section depth of asphaltic concrete along each side of the pavement. This type of widening provides a very firm support for the CRCP overlay which is usually thinner than a continuously reinforced concrete pavement on new location.

Another method of overlay construction which has been used successfully is to increase the thickness of the overlay in the widened area to match the thickness required for a new pavement. This requires excavating the shoulder to the proper depth. To avoid longitudinal cracking over the thickness transition, it is suggested that the soil beneath the widened area be stabilized by an additive.

A suggested treatment for junctures of a regular CRCP and a CRCP overlay is shown in Figure 4.7-1. The longitudinal steel should be at mid-depth in both slabs with a height transition over a distance of 10 feet or more. The heavier longitudinal steel (generally new pavement) should be extended into the pavement with the lighter mat (generally overlay). The normal procedure for transverse construction joints (§ 4.3) should be used with the steel extending a minimum of 20 feet into the slab (see § 3.3) before picking up the normal lap staggering pattern. Since the longitudinal steel for the two mats will probably not match up, a double lap should be used for additional strength.

Basically, all the items mentioned in the discussion on the construction of new pavements apply to CRCP overlays. Construction joints, steel placements, and vibration may be more critical with overlays, since overlays are usually thinner than new CRCP.

§ 4.8—Equipment

The engineer should make provisions in the specifications to permit the contractor to utilize the slipform paver and the central mix plant in order to achieve the most economical product. Slip form pavers produce a smoother riding surface in many cases and equipment is available to construct up to 48 feet in one pass. If the slipform paver is to be operated to full potential, central mixing must be utilized to supply the required quantity of concrete. Furthermore, central mix plants produce a uniform, high-quality concrete which is a necessity for CRCP.
FIGURE 4.6.3—Leaveout with Steel Reassembled and Ready for Placement

FIGURE 4.6.4—Leaveout After Concrete Placement
SECTION 5

EXAMPLE PROBLEM FOR NEW PAVEMENT

In this section, the concepts and procedures discussed in the previous sections are used to illustrate a typical design problem starting from the subgrade soil. Figure 5.0-1 is a flow diagram for a pavement design problem that graphically illustrates the sequential design steps and the figures required for each step. In accordance with Section 1.0, “Materials” and Subsection 2.11, “Fatigue Method for Pavement Thickness Determination,” the required information as to load variables, structural variables, and material properties are developed as follows:

Load Variables
Total equivalent 18-kip axle loads = 3,650,000 applications.

Structural Variables
1. Poor subgrade (k value = 100) not stabilized.
2. Average daily traffic predictions require a pavement three lanes wide (36 feet).

Materials Properties
Tests on concrete proposed for project indicate the following properties:
1. Modulus of elasticity = 4.5 x 10^6 psi
2. Flexural strength = 690 psi
3. Tensile strength = 0.4 x 690 = 276 psi

Longitudinal and transverse steel:
1. Deformed wire mats: ASTM A-497
2. Yield strength = 70,000 psi
3. Working stress = 70,000/1.33 = 52,500 psi

Tie bar steel:
1. Deformed bars—½ inch diameter:
   ASTM A-615 (Grade 40)
2. Yield strength = 40,000 psi
3. Working stress = 30,000 psi

Step 1:
Figure 2.3-1 indicates that an 8-inch minimum subbase thickness is required for poor subgrade support. Figure 2.3-2 indicates a stabilized subbase is required for a poor subgrade if the subgrade material is not treated with a stabilizing agent. On the basis of a survey of the materials available and economic considerations for a particular project, a cement-stabilized subbase is selected. Referring again to Figure 2.3-1, a compressive strength of 600 psi at 7 days is established. Figure 2.2-1 indicates that a typical cement stabilized subbase will have a friction factor of 1.80.

Step 2:
Entering Figure 2.1-1 with the total equivalent wheel loads, the concrete flexural strength, concrete modulus of elasticity, and subgrade modulus, a pavement thickness of 7.4 inches is obtained. If conventional forms are anticipated on the construction project, a pavement thickness of 8 inches will be used. If slipform pavers are anticipated, a pavement thickness of 7½ inches will be adequate.
Step 3:
Entering Figure 2.2.2 with a steel working stress of 52,500 psi, the concrete modulus of elasticity, concrete tensile strength, and the subbase friction factor from Step 1, the required cross-sectional area of the longitudinal steel is found to be 0.5 percent steel.

Step 4:
Entering Figure 2.2.3 with the appropriate pavement width, the subbase friction factor from Step 1, and allowable working stress, a cross-sectional area for the transverse steel is found to be 0.066 percent.

Also entering Figure 2.2.3 with a working stress of 30,000 psi, a cross-sectional area of 0.108 percent is found for the tie bar steel. The percentage of transverse steel at the longitudinal joint and the longitudinal lap may be reduced in accordance with the procedure outlined in Subsection 2.24 since neither is at the centerline.

\[ P_1 = 2 \cdot 0.108 \cdot \frac{12}{36} = 0.072\% \]

Step 5:
Figure 2.2.4 may be used to determine the spacing requirements for the reinforcement. If the 4x12-inch grid for the longitudinal and transverse wires, as illustrated in Figure 2.2.5, is used, then the appropriate deformed wire size may be determined from Figure 2.2.4. If deformed bars were used, then the bar size would be fixed and the appropriate spacing would be determined.

Entering Figure 2.2.4 with the longitudinal wire spacing of 4 inches, a pavement thickness of 8 inches, and a cross-sectional area of 0.5 percent longitudinal steel as indicated in Step 3, a wire size of 0.16 square inch (i.e. D-16) is found to be required.

A check of the bond area to concrete volume ratio finds:

\[ Q = \frac{4P}{D} = \frac{4 \times 0.005}{0.452} = 0.044 \text{ in}^2/\text{in}^3 > 0.03 \text{ in}^2/\text{in}^3 \]

Therefore, the proposed spacing and wire size are satisfactory.

Entering Figure 2.2.4 with the transverse wire spacing of 12 inches, an 8-inch pavement thickness, and a value of 0.066 percent for the cross-sectional area determined from Step 4, the required dimension for the transverse wires is found to be 0.063 square inches. Also entering Figure 2.2.4 with a bar area of 0.20 square inches, an 8-inch thickness, and a percentage of 0.072 from Step 4, the required tie bar spacing is 35 inches. The tie bar length would be 20 inches (40D).

Step 6:
Figure 2.4.2 shows that two anchor lugs are required at all pavement terminals for a cement stabilized subbase when the allowable end movement is ±1/4 inch. The use of a polymer type joint seal or a preformed compression seal is recommended.

Step 7:
A detail for the prefabricated deformed wire mat or for deformed bars would be prepared as illustrated in Figure 2.2.5. The mat dimensions and spacings may be adjusted to fit the special conditions of the job. The principles outlined in Section 4, "Construction," would be considered in formulating this design detail. In addition, many of the concepts presented in that section would be included as special notes or specifications.
Figure 5.0-1 Flow Diagram for a Pavement Design Problem

1. Sequential numbering of design steps

2. Terminal Treatment
   Fig. 24-1

3. % Longitudinal Steel
   Fig. 22-2

4. % Transverse Steel
   Fig. 22-3

5. Wire Spacing & Size
   Fig. 22-4

6. Cross Section & Reinforcement Layout
   Fig. 22-4

7. -

8. Load Variables
   Design Wheel Load

9. Subbase Type
   Thickness and Friction Factor

10. Pavement Thickness
    Figs. 21-1 & 21-2

11. Moduli of Support
    Subbase Pavement Width

12. Structural Variables
    Fig. 21-1 or 21-2

13. Concrete Tensile Strength
    Flexural Strength

14. Steel Modulus of Elasticity
    Type Yield Point

15. Material Properties
    Concrete-D Steel
SECTION 6

EXAMPLE PROBLEM FOR CRCP OVERLAY

In this section, a typical design problem for a CRCP overlay on an existing portland cement concrete pavement is presented. The flow diagram presented in Figure 5.0-1 is also applicable to the design of CRCP overlays. In accordance with Section 1, “Materials”, and Section 3, “Design of Overlays”, the required information as to load variable, structural variables and material properties are developed as follows:

Load Variables
A loadometer survey of the traffic on the proposed facility indicates the average of the ten heaviest wheel loads is equal to 13,500 pounds. Applying a 33 percent growth factor, a wheel load of 18,000 pounds is used for design.

Structural Variables
1. Soil samples of the subgrade beneath the existing pavement indicate the subgrade modulus to be 135 psi (k value) or a resilient modulus equal to 3,000 psi. Therefore, the existing subgrade is classified as poor.
2. The average daily traffic predictions require only two lanes and the existing pavement is 24 feet wide.
3. The condition survey indicates the pavement structure may be classified as “intact”. (use Figure 2.1-2). Measurements of cores from the pavement show the existing pavement thickness to be 6 inches.

Material Properties
Cores from the existing portland cement concrete pavement were tested and the following properties found:
1. Modulus of elasticity = 4,000,000 psi
2. Splitting tensile strength = 485 psi
3. Flexural strength = 485 psi x 1.33 = 650 psi
   (Refer to Reference 44 for conversion of splitting tensile strength to flexural strength.)
4. Tensile strength = 0.4 x 650 = 260 psi

Longitudinal and Transverse Steel:
1. Deform wire mats ASTM A 497.
2. Yield strength equals 70,000 psi.
3. Working stress equals 70,000/1.33 = 52,500 psi.

Tie Bar Steel:
1. Deformed bars ½ inch diameter: ASTM A 615 (grade 40).
2. Yield strength equals 40,000 psi.
3. Working stress equals 40,000 divided by 1.33 equals 30,000 psi.

Step 1:
Only the selection of the thickness for the stress relieving course applies here since subbase design is not applicable to overlay pavement design. The pavement profile of the existing pavement is such that a 1-inch surface bituminous material is satisfactory. A stabilometer value (Hveem or Marshall) should be prescribed that is somewhat less than used on surface courses since stability requirements are less. Figure 2.2-1 indicates the bituminous material would have a friction factor of 1.80.

Step 2:
Entering Figure 3.1-2, with an allowable working stress of 325 psi, a poor subgrade, and an existing pavement thickness of 6 inches, a CRCP overlay thickness of 5 inches is required.
Step 3:
Entering Figure 2.2-2, with an allowable steel working stress of 52,500 psi, concrete tensile strength, and the subbase of the friction factor from Step One, the required cross-sectional area of the longitudinal steel is found to be 0.485 percent steel.

Step 4:
Entering Figure 2.2-3 with a 24-foot pavement, the allowable working stress, and friction factor from Step one, the required cross-sectional area for the transverse steel is found to be 0.041 percent.

Step 5:
A 4 x 12 inch grid for the longitudinal and transverse wires as illustrated in Figure 2.2-5 is selected for use. For these spacings, Figure 2.2-4 is entered, and it is found that wire sizes of 0.097 square inches and 0.025 square inches are required for the longitudinal and transverse wires, respectively. A check of the bond area to concrete value ratio finds:

\[ Q = \frac{4P}{D} = \frac{4 \times 0.00485}{0.352} = 0.055 \text{ in}^2/\text{in}^3 \]

\[ > 0.03 \text{ in}^2/\text{in}^3 \]

therefore, the proposed spacing and bar size are satisfactory.

Step 6:
This step is omitted since anchor lugs are not required with CRCP overlays.

Step 7:
A detail for prefabricated deformed wire mat or for deformed bars would be prepared as illustrated in Figure 2.2-5.
REFERENCES