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TECHNICAL MANUAL

RIGID PAVEMENTS FOR AIRFIELDS

DEPARTMENTS OF THE AIR FORCE AND THE ARMY
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RIGID PAVEMENTS FOR AIRFIELDS

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CHAPTER 1
INTRODUCTION

1-1. Purpose and Scope

The purpose of this manual is to provide information and criteria for designing rigid airfield pavements for U.S. Army and Air Force construction. Included in this manual are criteria for subsurface exploration; subgrade and base requirements; criteria for stabilized layers; pavement thickness design; jointing details; and criteria for strengthening existing rigid pavements.

1-2. Related Criteria

Additional criteria related to the design of rigid airfield pavements may be found in the following applicable publications:

Subject	*Source*
Aircraft loadings	TM 5-824-1/AFM 88-6, chapter 1; TM 5-803-4
Airfield geometric design	TM 5-824-1/AFM 88-6, chapter 1; TM 5-803-4; TM 5-803-7/AFR 86-14; AFR 86-5; AFM 86-2
Airfield pavement drainage	TM 5-820-1; TM 5-820-2; TM 5-820-3/AFM 88-5, chapters 1, 2, and 3
Airfield pavement evaluation	TM 5-827-1/AFM 88-24, chapter 1; TM 5-827-2/AFM 88-24, chapter 2; TM 5-827-3/AFM 88-24, chapter 3; TM 5-818-3/AFM 88-24, chapter 4; TM 5-826-1; TM 5-826-2; TM 5-826-3; TM 5-826-4
Concrete materials	TM 5-822-7/AFM 88–6, chapter 8
Frost design	TM 5-818-2/AFM 88-6, chapter 4
Other materials	TM 5-825-2/AFM 88-6, chapter 2
Soil stabilization	TM 5-822-4/AFM 88-7, chapter 4
Soil mechanics	TM 5-818-1/AFM 88-3, chapter 7

1-3. Airfield and traffic categories

Criteria for airfield types and traffic areas have been established by the Army and Air Force and are a necessary supplement to this manual. For definitions of airfield types and traffic areas, see TM 5-824-1/AFM 88-6, Chap. 1 for the Air Force and TM 5-803-4 for the Army.

1-4. Types of pavements

A rigid pavement is considered to be any pavement system that contains portland cement concrete as one element. The following pavements are considered to be rigid pavements:

- Plain concrete pavements. A nonreinforced jointed rigid pavement constructed on a base course and/or subgrade.
- Reinforced concrete pavements. A jointed rigid pavement that has been strengthened with deformed bars or welded wire fabric.
- Continuously reinforced concrete pavement. A rigid pavement that is constructed without joints and uses reinforcing steel to maintain structural integrity across contraction cracks that form in the pavement.
- Fibrous concrete pavement. A rigid pavement that has been strengthened by the introduction of randomly mixed, short, small-diameter steel fibers.
- Prestressed concrete pavement. A rigid pavement that has been strengthened by the application of a significant horizontally applied compressive stress during construction.
- Rigid overlay pavement. A rigid pavement used to strengthen an existing flexible or rigid pavement.
- Nonrigid overlay pavement. A flexible pavement (either all-bituminous or bituminous with base course) used to strengthen an existing rigid pavement.

1-5. Design parameters

The procedures in this manual express pavement thickness in terms of five principal parameters:

- Design load (generally stated in the design directive).
- Foundation strength.
- Concrete properties.
- Traffic intensity.
- Traffic areas.

The foundation strength and concrete properties normally depend upon many factors that must be evaluated. The values for use in design should be selected only after tests to determine the pertinent properties have been completed, all applicable previous tests have been reviewed, and consideration has been given to the records of performance of similar construction.

1-6. Definitions

Terms used in this manual are defined as follows:

Aircraft pass: the passage of an aircraft on the pavement facility being designed. For a runway, passes are considered to be the number of design aircraft takeoffs, excluding touch–and–go operations. For taxiways and aprons, passes are considered to be the number of design aircraft movements that traffic the taxiway or apron. At single-runway bases, the pass level for the runway, taxiway, and apron should be the same.

Base pavement: an existing pavement (either rigid or flexible) on which an overlay is to be placed.

Coverage: a measure of the number of maximum stress repetitions that occur at a particular location in a pavement as a result of the design aircraft pass level.

Design aircraft pass level: the number of aircraft passes for which an airfield pavement is to be designed.

Inlay pavement: rigid pavement used to replace the center portion of existing runways or taxiways as a method of rehabilitation or upgrading of existing pavement.

Jet-fuel-resistant (JFR) materials: materials, such as pavement joint fillers, which are designed to resist the effects of fuels used in jet-operated aircraft.

Modified soil: a soil which has improved construction characteristics through the use of additives. However, the additives do not improve the strength of the soil sufficiently to qualify it as a stabilized soil (TM 5-822-4/AFM 88-7, Chap. 4).

Pass-per-coverage ratio: the number of passes required to produce one coverage.

Stabilized soil: a soil which has improved load-carrying and durability characteristics through the addition of admixtures. Lime, cement, and fly ash, or any combinations of these, and bitumens are the commonly used additives for soil stabilization.

1-7. Investigations preliminary to pavement design

The importance of accurate information pertaining to the characteristics of the pavement foundations and materials that will be used in the pavement section cannot be overemphasized. The design of rigid pavements and overlay pavements must be based on complete and thorough investigations of the subgrade conditions, borrow areas, and sources of base course, concrete aggregates, and other materials. Explorations and laboratory classification tests, similar to those described in TM 5-825-2/NavFac DM 21.3/AFM 88-6; MIL-STD-619; and MIL-STD-621, will be used as appropriate to establish the pertinent material characteristics and any peculiarities of the proposed site that might affect the behavior of the pavement. While the maximum use of previous investigations should be used to establish those characteristics, it is emphasized that sufficient additional investigations must be made at the time of the pavement design to assure that the previous results are valid.

1-8. Subgrade

a. Exploration. In all instances, field and laboratory tests will be conducted to determine the classification, moisture-density relations, expansion characteristics, and strength of the subgrade. If stabilization of the subgrade is to be considered, other tests as required by TM 5-822-4/AFM 88-7, Chap. 4, will be made, as well as chemical analysis and clay mineralogy determination. In order to give consideration to all factors that may affect the performance of the pavement, a careful study of existing pavements on similar subgrades in the locality will be made to determine the conditions that may develop in the subgrade after it has been used under a pavement. The engineer is cautioned that such factors as ground water, surface water infiltration, soil capillarity, topography, drainage, rainfall, and frost conditions may affect the future support rendered by the prepared subgrade or base course. Experience has shown that the subgrade will often reach near saturation, even in semiarid and arid regions, after a pavement has been constructed. If conditions exist that will cause the subgrade soil to be affected adversely by frost action, the subgrade will be treated in accordance with the requirements of TM 5-818-2/AFM 88-6, Chap. 4. Subgrades and base courses are grouped into three types with respect to behavior during saturation: low plastic soils exhibiting little or no swell; swelling soils; and cohesionless sands and gravels. Special cases of subgrade soil are discussed in TM 5-825-2/NAVFAC DM 21.3/AFM 88-6.

b. Compaction requirements. Compaction improves soil strength and ensures that densification with resulting voids under the concrete slab does not occur. Subgrade soils that gain strength when remolded and compacted will be prepared in accordance with the following criteria.

(1) Compacting fill sections. Fills composed of soil having a plasticity index (PI) greater than 5 or a liquid limit (LL) greater than 25 will be compacted to not less than 90 percent of CE-55 maximum density. Fills composed of soil having a PI equal to or less than 5 and an LL equal to or less than 25 will be compacted as follows: the top 6 inches will be 100 percent of CE-55 maximum density; the remaining depth of fill will be 95 percent of CE-55 maximum density. Large fills on natural soil should be analyzed for bearing capacity and settlement using conventional soil mechanics.

(2) Compacting cut sections. The top 6 inches of subgrades composed of soil having a PI greater than 5 or an LL greater than 25 will be compacted to not less than 90 percent of CE-55 maximum density. If the natural subgrade exhibits densities equal to or greater than 90 percent of CE-55 maximum density, no compaction is necessary other than that required to provide a smooth surface. Soils having a PI equal to or less than 5 and an LL equal to or less than 25 will be compacted as follows: the top 6 inches will be 100 percent of CE-55 maximum density; the 18 inches below the top 6 inches will be 95 percent of CE-55 maximum density. Again, if the natural subgrade exhibits densities equal to or in excess of the specified densities, no compaction will be necessary other than that required to provide a smooth surface; in most cases, these densities can be obtained by surface rolling only.

(3) Permissible variations in field density. The above criteria should be considered as minimal values. Also, it is emphasized that it is often difficult to correlate field densities with those obtained in laboratory compaction tests. Therefore, the design density will be the maximum that can be obtained by practical compaction procedures in the field. Higher densities should result in higher foundation strengths and thus thinner pavements which may offset the added cost of compaction. Experience has shown that the highest densities for all but the special cases (that is, soils that lose strength when remolded, become "quick" when remolded, or have expansive characteristics) result in lower permanent deformations, less susceptibility to pumping, and improved overall performance.

(4) Evaluation. Evaluation of the subgrade support will be determined in accordance with paragraph 1-11.

1-9. Base courses

a. General. Base courses may be required for one or more of the following reasons: (a) to provide uniform bearing surface for the pavement slab; (b) to replace soft, highly compressible, or expansive soils; (c) to protect the subgrade from detrimental frost heaving (in areas subject to frost action, design will be in accordance with TM 5-818-2/AFM 88-6, Chap. 4); (d) to produce a suitable surface for operating construction equipment during unfavorable weather; (e) to improve the foundation strength (modulus of soil reaction or modulus of elasticity); (f) to prevent subgrade pumping; and (g) to provide drainage of water from under the pavement. A minimum base course thickness of 4 inches will be required over subgrades that are classified as CH, CL, MH, ML, and OL (MIL-STD-619) for protection against pumping except in arid climates where experience has shown no need for the base course to prevent pumping. In certain cases of adverse moisture conditions (high water table or poor drainage), SM and SC soils may also require base courses to prevent pumping. Engineering judgment must be exercised in the design of base course drainage to ensure that water is not trapped directly beneath the pavement, which invites the pumping condition that the base course is intended to prevent. In addition, base courses in inlay sections should be constructed so as to drain toward the outside edge. Daylighting of the base course may also be required. Care must also be exercised when selecting base course materials to be used with slipform construction of the pavement. Generally, slipform pavers will operate satisfactorily on materials meeting base course requirements. However, cohesionless sands, rounded aggregates, etc., may not provide sufficient stability for slipform operation and should be avoided if slipform paving is to be a construction option. The designer should consider extending the base course 5 to 10 feet outside the edge of the pavement to provide a working platform for construction equipment.

b. Material requirements. A complete investigation will be made to determine the source, quantity, and characteristics of available materials. The base course may consist of natural materials or processed materials, as defined in TM 5-825-2/NAVFAC DM 21.3/AFM 88-6. In general, the unbound base material will be a well-graded, high-stability material. All base courses to be placed beneath airfield rigid pavements will conform to the following requirements in addition to those requirements in base course guide specifications (sieve designations are in accordance with American Society for Testing and Materials (ASTM) E 11):

— Well -graded, coarse to fine.
— Not more than 85 percent passing the No. 10 sieve.
— Not more than 15 percent passing the No. 200 sieve.
— PI not more than 8 perrcent.

However, when it is necessary that the base course provide drainage, the requirements set forth in TM 5-820-2/AFM 88-5, Chap. 2 will be followed.

c. Compaction requirements. High densities are essential to keep future consolidation to a minimum, but thin base courses placed on yielding subgrades are difficult to compact to high densities. Therefore, the design density in the base course materials should be the maximum that can be obtained by practical compaction procedures in the field but not less than:

— 95 percent of CE-55 maximum density for base courses less than 10 inches thick.
— 100 percent of CE-55 maximum density in the top 6 inches and 95 percent of CE-55 maximum density for the remaining thickness for base courses 10 inches or more in thickness.

d. Evaluation. The supporting value of base courses will be determined in accordance with paragraph 1-11.

1-10. Soil stabilization or modification

a. General. The stabilization or modification of the subgrade and/or base course materials using either chemicals or bitumens has been found desirable in many geographic areas. Principal benefits include the reduction of rigid pavement thickness requirements, provision of an all-weather construction platform, decreased swell potential, and reduction of the susceptibility to pumping as well as the susceptibility of strength loss due to moisture. Normally, the decision to stabilize or modify a soil will be based upon the economics involved, but in certain instances, such as the construction of inlay pavements, stabilization of the foundation will be required to facilitate construction. A lean concrete base is considered a stabilized layer and must meet the strength and durability requirements for a stabilized layer.

b. Requirements. To be considered a stabilized layer with a reduction in rigid pavement thickness, the stabilized material must be a minimum of 6 inches in thickness and meet the strength and durability requirements contained in TM 5-822-4/AFM 88-7, Chap. 4. Otherwise, the layer is considered to be a modified soil. The design of the stabilization or modification will be in accordance with TM 5-822-4/AFM 88-7, Chap. 4, and TM 5-818-2/AFM 88-6, Chap. 4. Where lean concrete base courses are being used, the mix proportioning, control, and testing of the lean concrete will be the same as for concrete. Since lean concrete bases are designed specifically to provide economy in pavement construction, emphasis must be placed on economy when arriving at the design mix. Experience has demonstrated that cement contents in the 225 to 375 pounds per cubic yard range yield economical lean concrete mixed with good workability. Pavement designs that result in a nonstabilized (pervious) layer sandwiched between a stabilized or modified soil (impervious) layer and the pavement present the danger of entrapped water with subsequent instability in the nonstabilized layer. These designed will not be used unless the nonstabilized layer is positively drained, and their use will require the approval of the Commander, U.S. Army Corps of Engineers (CEED-EG), Washington, DC 20314-100, or the appropriate MACOM.

Table 1-1. Typical values of modulus of soil reaction.

Type of material	Modulus of soil reaction (pci) for moisture content percentage: 1 to 4	5 to 8	9 to 12	13 to 16	17 to 20	21 to 24	25 to 28	Over 28
Silts and clays, LL greater than 50 (OH, CH, MH)	—	175	150	125	100	75	550	25
Silts and clays LL less than 50 (OH, CL, ML)	—	200	175	150	125	100	75	50
Silty and clayey sands (SM and SC)	300	250	225	200	150	—	—	—
Sand and gravelly sands (SW and SP)	350	300	250	—	—	—	—	—
Silty and clayey gravels (GM and GC)	400	350	300	250	—	—	—	—
Gravel and sandy gravels (GW and GP)	500	450	—	—	—	—	—	—

Notes:
1. Values of k shown are typical for materials having dry densities equal to 90 to 95 percent of the maximum. For materials having dry densities less than 90 percent of the maximum, values should be reduced by 50 pci, except that a k of 25 pci will be the minimum used for design.
2. Values shown may be increased slightly if density is greater than 95 percent of the maximum, except that a k of 500 pci will be the maximum used for design.
3. Frost-melting-period k values are given in TM 5-818-2/AFM 88-6, chapter 4.

c. Evaluation. The foundation support provided by modified soil layers will be evaluated by the modulus of soil reaction, k, determined after the modifying agent has been added using the procedure outlined in paragraph 1-11. For stabilized soils, the evaluation of the supporting value will depend upon the type of pavement being designed. For pre-stressed concrete pavements on stabilized layers, and other rigid pavement types on a bituminous stabilized layer, a composite modulus of soil reaction, k_c, as described in paragraph 1-11, will be used. For plain, reinforced, and fibrous concrete pavements, the stabilized layer will be considered to be a low-strength base pavement, and the design will be accomplished using a modification of the partially bonded rigid overlay equation as described in chapters 2, 3, and 4. In both cases, the thickness and flexural modulus of elasticity of the stabilized material will be determined at the same age as for the design flexural strength of the concrete. The flexural modulus of elasticity of cement-, lime-, and fly ash-stabilized material will be determined by ASTM C 78; whereas, for bituminous-stabilized material, the flexural modulus will be determined in accordance with appendix B of this manual.

1-11. Evaluation of foundation support

a. Modulus of soil reaction. the modulus of soil re-

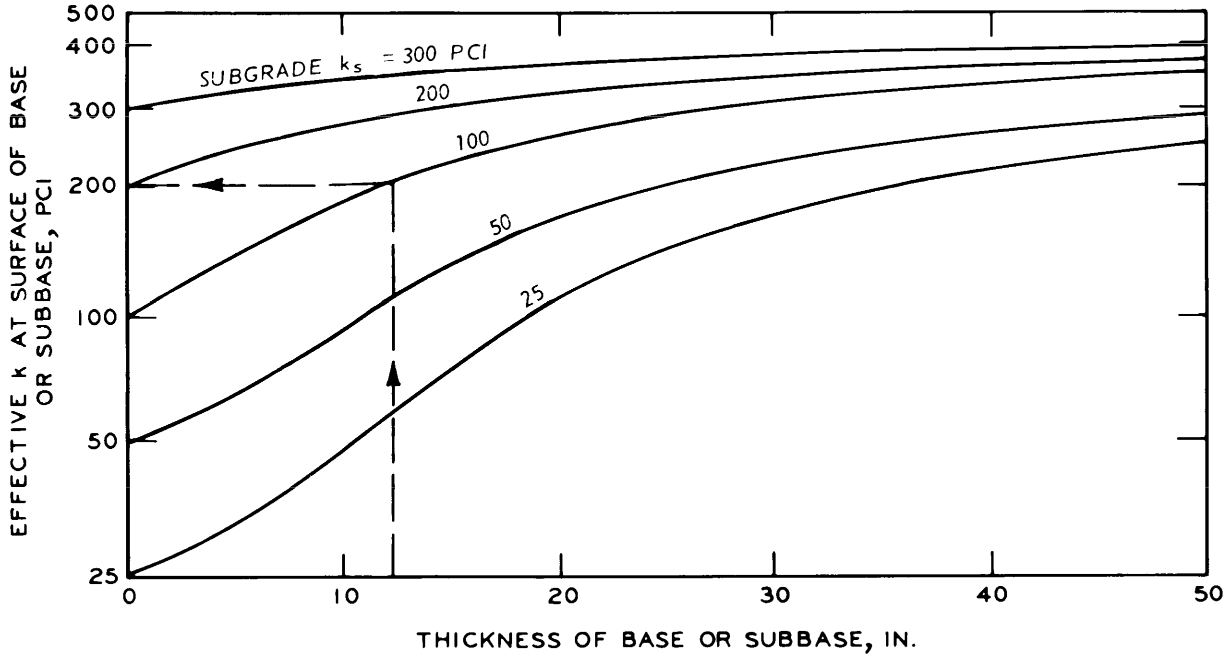


Figure 1-1. Effect of base course thickness on modulus of soil reaction.

action, k, expressed in pounds per cubic inch (pci), will be used to define the supporting value of all unbound subgrade and base course materials and all soils that have been additive-modified (TM 5-822-4/AFM 88-7, Chap. 4.). The k value will be determined by the field plate-bearing test as described in MIL-STD-621, Test Method 104.

(1) Subgrade. The field plate-bearing test will be performed on representative areas of the subgrade, taking into consideration such things as changes in material classification, fill or cut areas, and varying moisture (drainage) conditions which would affect the support value of the subgrade. While it is not practical to perform a sufficient number of field plate–bearing tests to make a statistical analysis of the k value, a sufficient number must be performed to give confidence that the selected value will be representative of the in–place conditions. This means that at least two tests for each significantly different subgrade condition should be conducted. Considering the limited number of measured k values that can be obtained, maximum use of other pertinent soil data must be made to aid in the selection of the design k value. The pavement thickness is not affected appreciably by small changes in k values. Therefore, the assignment of k values in increments of 10 pci for values up to and including 250 pci and in increments of 25 pci for values exceeding 250 pci should be sufficient. A maximum k value of 500 pci will be used. Typical values of k for different soil types and moisture contents are shown in table 1-1.

(2) Base courses. The modulus of soil reaction, k, of the unbound base courses will be determined by field plate-bearing tests performed on the surface of the compacted base course or by tests on the subgrade and from figure 1-1. If both methods are used, the lower value obtained by the two methods will be used for the pavement design. As with the subgrade, sufficient field plate-bearing tests must be performed to permit a realistic assignment of design k values, taking into consideration variations in the base course thickness, type of material, and subgrade strength. Figure 1-1 yields an effective k value at the surface of the base course as a function of the subgrade k value and base course thickness. These relationships have been generated by field testing. If the design k value is selected from figure 1-1, it should be verified in the field.

(3) Special conditions. Test Method 104 of MIL-STD-621 requires a correction of the field plate-bearing test results to account for saturation of the soil after the pavement has been constructed. Most fine-grained soils exhibit a marked reduction in the modulus of soil reaction with an increase in moisture content, and a saturation correction is applicable. However, in arid regions or regions of low water table (10 feet or more below ground level throughout the year), the degree of saturation that may result after the pavement has been constructed may be less than that on which the saturation correction is based. If examination of existing pavements (highway or airfield) in the near vicinity indicates that the degree of saturation of the subgrade is less than 95 percent and if there is no indication of excessive loss of subgrade support at joints due to erosion or pumping, the correction for saturation may be deleted.

b. Composite modulus of soil reaction. For the design of continuously reinforced and prestressed pavements on a stabilized foundation and all other rigid pavements which incorporate a bituminous stabilized layer directly under the pavement, the foundation strength will be defined as a composite modulus of soil reaction k_c. The k_c value is a function of the modulus of soil reaction of the foundation materials directly beneath the stabilized layer and the thickness and flexural mod-

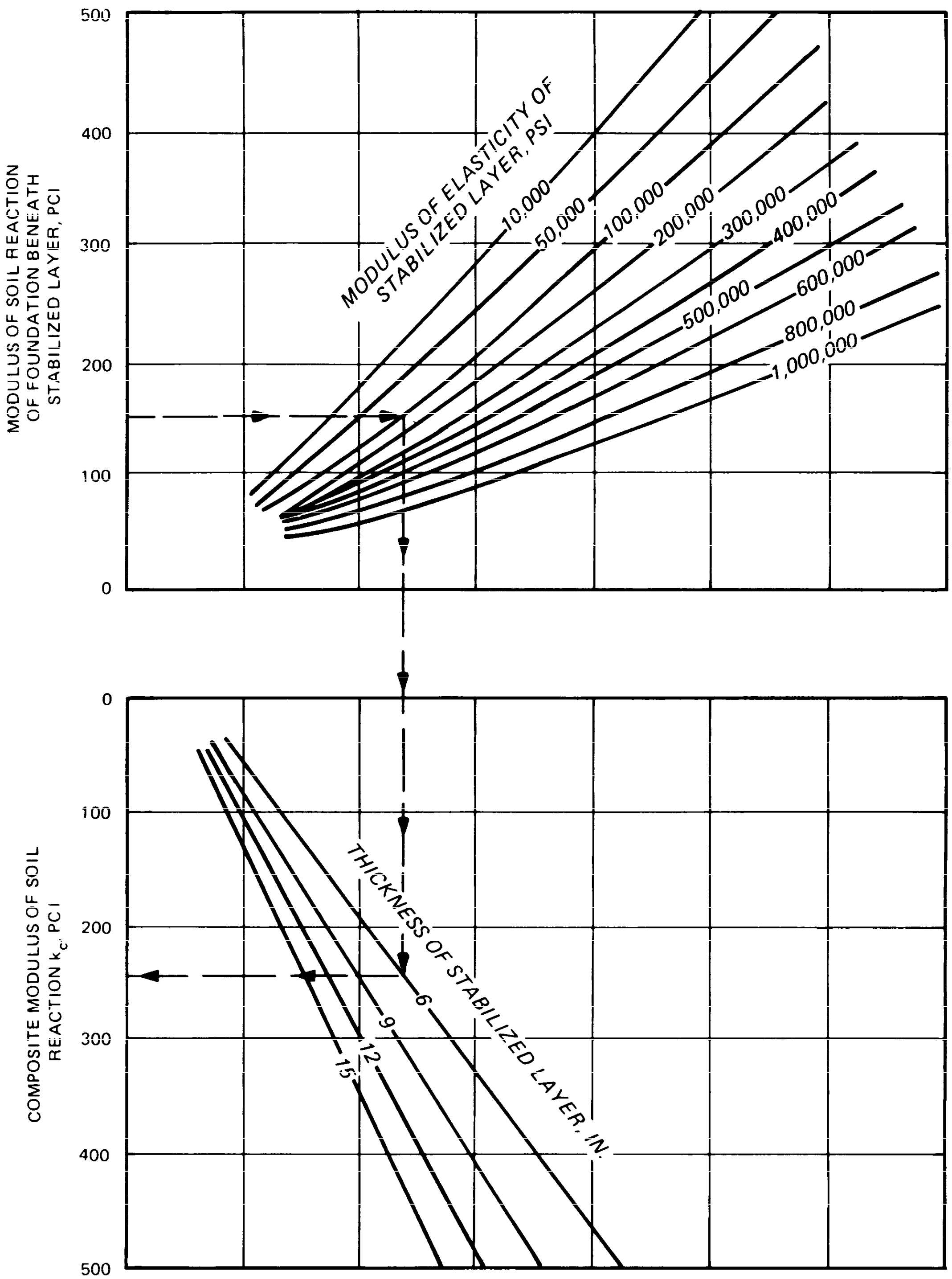


Figure 1-2. Composite modulus of soil reaction.

ulus of elasticity of the stabilized layer. The flexural modulus of stabilized materials will be determined from ASTM C 78 nor from appendix B for bituminous materials. With these properties, the k_c value is determined from figure 1-2.

c. Foundation support in frost areas. The procedure for evaluating foundation support in frost areas is presented in TM 5-818-2/AFM 88-6, Chap. 4.

1-12. Concrete

a. Stresses. The design of a concrete pavement is based on the critical tensile stresses produced within the slab by the aircraft loading. However, a common and sometimes important source of stress is temperature and/or moisture differential within the slab. The location and intensity of critical stresses produced by a wheel load will vary from point to point depending on the location of the load. Correlations of theory, model studies, and full-scale test results have indicated that the critical concrete tensile stress occurs when the load is adjacent to an edge or joint of the pavement. The stress due to

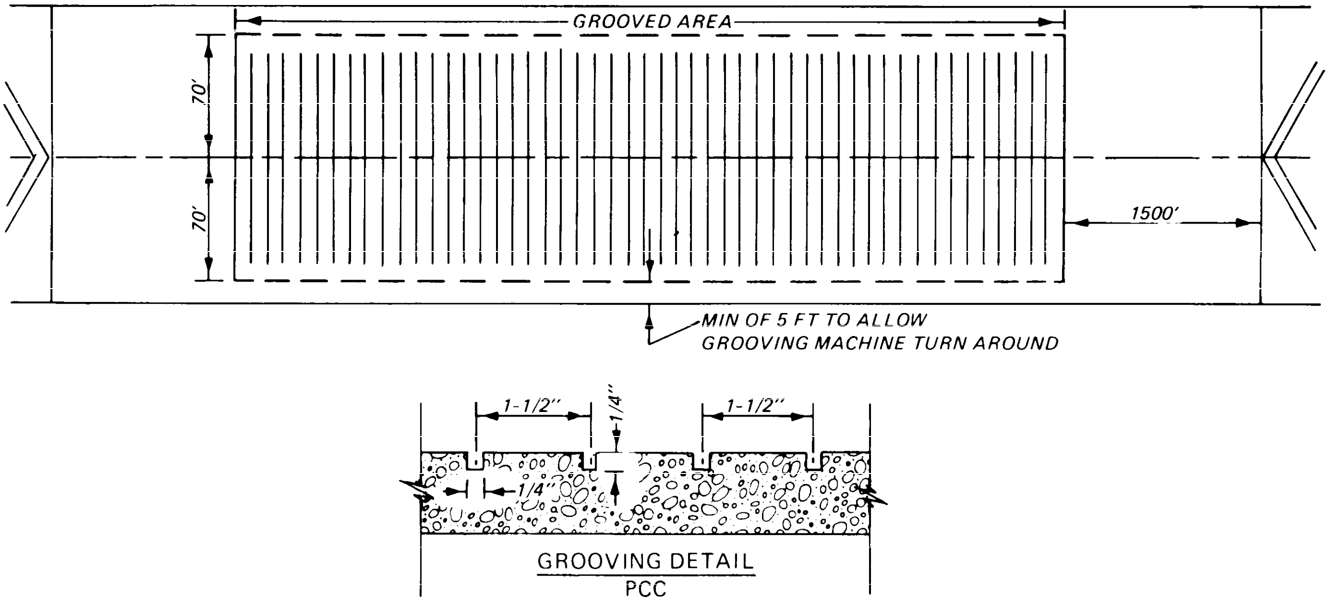


Figure 1-3. Recommended grooving requirements.

temperature and moisture variation reverses cyclically from top to bottom and may add to or subtract from the stress due to the applied load. Although not considered independently, the overall effect of these cyclic stresses has been considered in the thickness criteria presented herein.

b. Mix proportioning and control. Proportioning of the concrete mix and control of the concrete for pavement construction will be in accordance with TM 5-822-7/ AFM 88-6, Chap. 8. Normally, a design flexural strength at 90-day age will be used for the pavement thickness determination. Should it be necessary to use the pavements at an earlier age, consideration should be given to the use of a design flexural strength at the earlier age or to the use of high early-strength cement, whichever is the more economical. Fly ash gains strength more slowly than cement, so that if used it may be desirable to select a strength value at a period other than 90 days if time permits.

c. Testing. The flexural strength and the modulus of elasticity in flexure of the concrete and lean concrete base will be determined in accordance with ASTM C 78. The standard test specimen will be a 6- by 6-inch section long enough to permit testing over a span of 18 inches. The standard beam will be used for concrete with the maximum size aggregate up to 2 inches. When aggregate larger than the 2-inch nominal size is used in the concrete, the cross-sectional dimensions of the beam will be at least three times the normal maximum size of the aggregate, and the length will be increased to at least 2 inches more than three times the depth.

d. Special conditions.

(1) Results of the concrete tests and anticipated weathering may require modification of the mix proportioning or an adjustment in the required pavement thickness as determined by procedures discussed in chapter 2. For example, some of the factors that would require an adjustment in the required pavement thickness are: less than predicted strength gain, retrogression in concrete strength, or unusually high or low flexural modulus of elasticity. All possible sources of information should be explored consistent with job conditions, and tests should be made to evaluate the effects of the variables on the concrete to be used on the job.

(2) The high temperatures and velocities of jet engine exhaust do not normally require special surfaces or surface treatment. Unique conditions, such as power check pads or temperature-susceptible siliceous aggregates, when encountered, will be considered on a case-by-case basis.

1-13. Grooving of runways

The grooving of runways is required to provide for safer aircraft performance. Figure 1-3 shows the area on the runway that should be grooved. In addition, figure 1-3 presents the details for grooving rigid pavements. In the following areas grooving should not be accomplished:

- Within 6 inches of transverse joints or transverse working cracks.
- Through neoprene compression seals. (For longitudinal joints, the top of the seal should be ⅛ inch below the bottom of the groove.)
- The first 1,500 feet form the thresholds.
- The first 300 feet either side of an arrest barrier cable which requires hook engagement for operation.
- Through in-runway lighting fixtures or similar items.

1-14. Paved areas requiring rigid pavement

The following areas on Air Force airfields require the use of rigid pavements:

- On all paved areas on which aircraft are regularly parked, maintained, serviced, or preflight checked.

- On runway ends (1,000 feet). Rigid pavements may be used from the runway end to 300 feet past the barrier, if needed to control hook skip.
- Primary taxiways.
- Dangerous cargo, power check, warmup, arm/disarm, holding and washrack pads.
- On all paved areas on which helicopters are regularly parked, maintained, or serviced.
- On any other area where it can be documented that flexible pavement will be damaged by jet blast or by spillage of jet fuel or hydraulic fluid.

CHAPTER 2
PLAIN CONCRETE PAVEMENT DESIGN

2-1. Basis of design

The thickness requirements for plain concrete pavements are based on the Westergaard edge loading analysis, which has been modified based upon full-scale accelerated traffic testing, small-scale model testing, and experience. The thickness design curves include an assumption that the stress at the edge of the loaded slab will be reduced 25 percent by the load transfer afforded by the joint designs required. A further assumption has been made that the flexural modulus of elasticity and Poisson's ration of the concrete remain constant at 4 x 10^6 pounds per square inch (psi) and 0.15, respectively. Analyses are availabe to accommodate other percentages of edge stress reduction, traffic volumes, and concrete properties than those used for preparation of the design curves and can be obtained from the Commander, U.S. Army Corps of Engineers (CEEC-EG), Washington, DC 20314-1000, or HQ Air Force Engineering and Services Center (AFESC/DEMP), Tyndall AFB, FL 32403-6001. In frost areas, special design requirements in addition to those stated in this chapter are in TM 5-818-2/AFM 88-6, Chap. 4.

2-2. Uses

Plain concrete pavements, meeting the requirements contained herein, can be used for any pavement facility. The selection of the pavement type should be based upon the economics involved. The only restriction to the use of plain concrete pavement pertains to unusual conditions that may require minimal reinforcement of pavement as outlined in chapter 3.

2-3. Thickness design

a. General. Figures 2-1 through 2-13 are design curves to be used in designing Army and Air Force plain concrete pavements as defined in TM 5-803-4 and TM 5-824-1/AFM 88-6, Chap. 1. Figures 2-1 to 2-3 are for Army Class I, II, and III airfield designs and figures 2-4 to 2-13 are for Air Force design. Figures 2-4 to 2-8 are mixed traffic design curves for the five basic airfield types defined in TM 5-824-1/AFM 88-6, Chap. 1. Figure 2-9 is a design curve for shoulder pavements applicable to all Army or Air Force airfields requiring shoulders. Figures 2-10 to 2-13 are individual design curves for various aircraft to be used in designing pavements for conditions other than those defined in TM 5-824-1/AFM 88-6, Chap. 1. In addition, the computer program discussed in chapter 9 may be used for the design of plain concrete pavements.

b. Plain concrete pavements on nonstabilized or modified soil foundations. For plain concrete pavements that will be placed directly on nonstabilized or modified base courses or subgrade, the thickness requirement will be determined from the appropriate design curve using the design parameters of concrete flexural strength, R; modulus of soil reaction, k; gross weight of aircraft; aircraft pass level; and pavement traffic area type (except for shoulder design). The design gross aircraft weight and pass level may vary depending upon the type of traffic area or pavement facility. When the thickness from the design curve indicates a fractional value, it will be rounded to the nearest full- or half-inch thickness. Values falling exactly on 0.25 or 0.75 inch will be rounded upward. The minimum thickness of plain concrete pavement will be 6.0 inches. When it is necessary to change from one thickness to another within a pavement facility, such as from one traffic area to another, the transition will be accomplished in one full paving lane width or slab length.

c. Plain concrete pavements on stabilized base and/or subgrade. Stabilized base and/or subgrade layers meeting the strength requirements of paragraph 1-10 and lean concrete base will be treated as low-strength base pavements, and the plain concrete pavement will be considered an overlay with a thickness determiend using the following modified, partially bonded rigid overlay pavement design equation:

$$h_O = \sqrt[1.4]{h_d^{1.4} - \left[\left(\sqrt[3]{\tfrac{E_b}{E_c}}\right) h_b\right]^{1.4}} \qquad \text{(eq 2-1)}$$

where

h_o = thickness of plain concrete overlay

h_d = design thickness of equivalent single slab placed directly on foundation

E_b = modulus of elasticity of base

E_c = modulus of elasticity of concrete, usually taken as 4 x 10^6 psi

h_b = thickness of stabilized layer or lean concrete base

The required thickness determined by this equation will be rounded to the nearest full- or half-inch thickness for construction.

2-4. Jointing

a. General. Joints are provided to permit contraction and expansion of the concrete resulting from temperature and moisture changes, to relieve warping and curling stresses due to temperature and moisture differentials, to prevent unsightly irregular breaking of the pavement, and as a construction expedient to separate sections or strips of concrete placed at different times. The three general types of joints — contraction, construction, and expansion — are shown in figures 2-14, 2-15, and 2-16, respectively. In addition, a slip joint is shown in figure 2-17. A typical jointing layout of the three types is illustrated in figure 2-18.

b. Contraction joints.

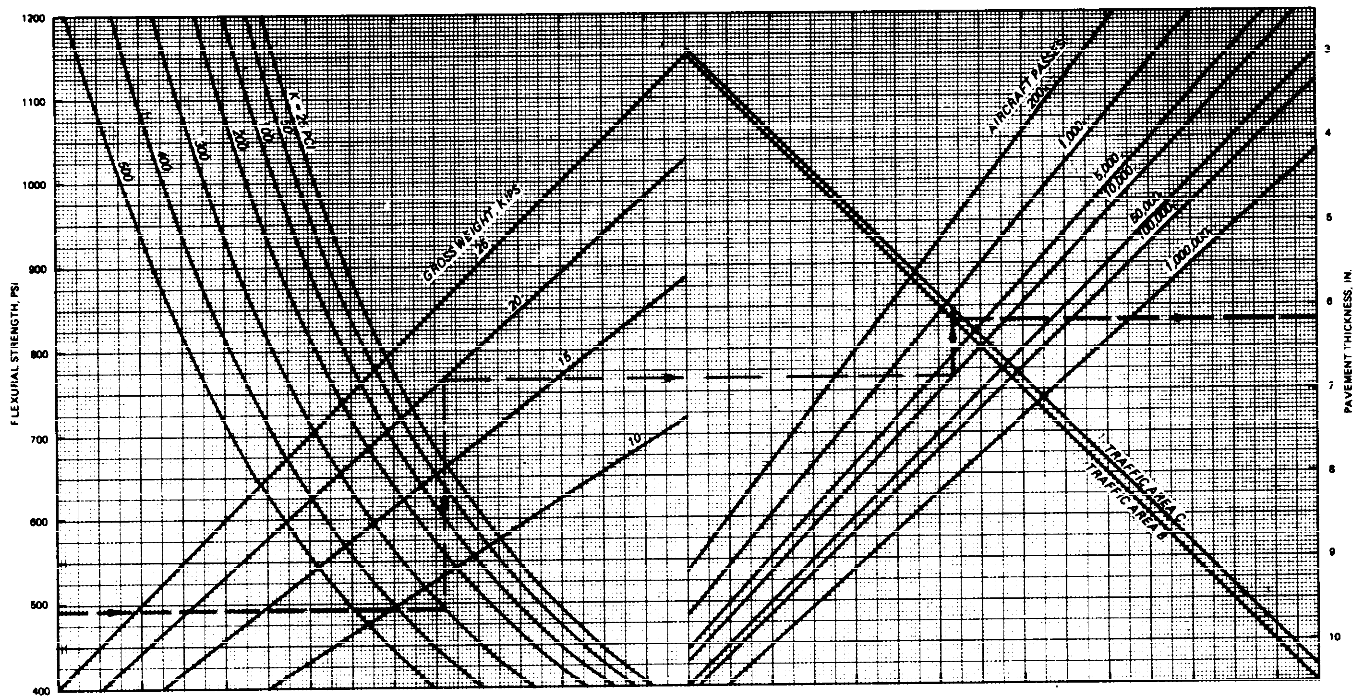


Figure 2-1. Plain concrete design curves for Army Class I airfields.

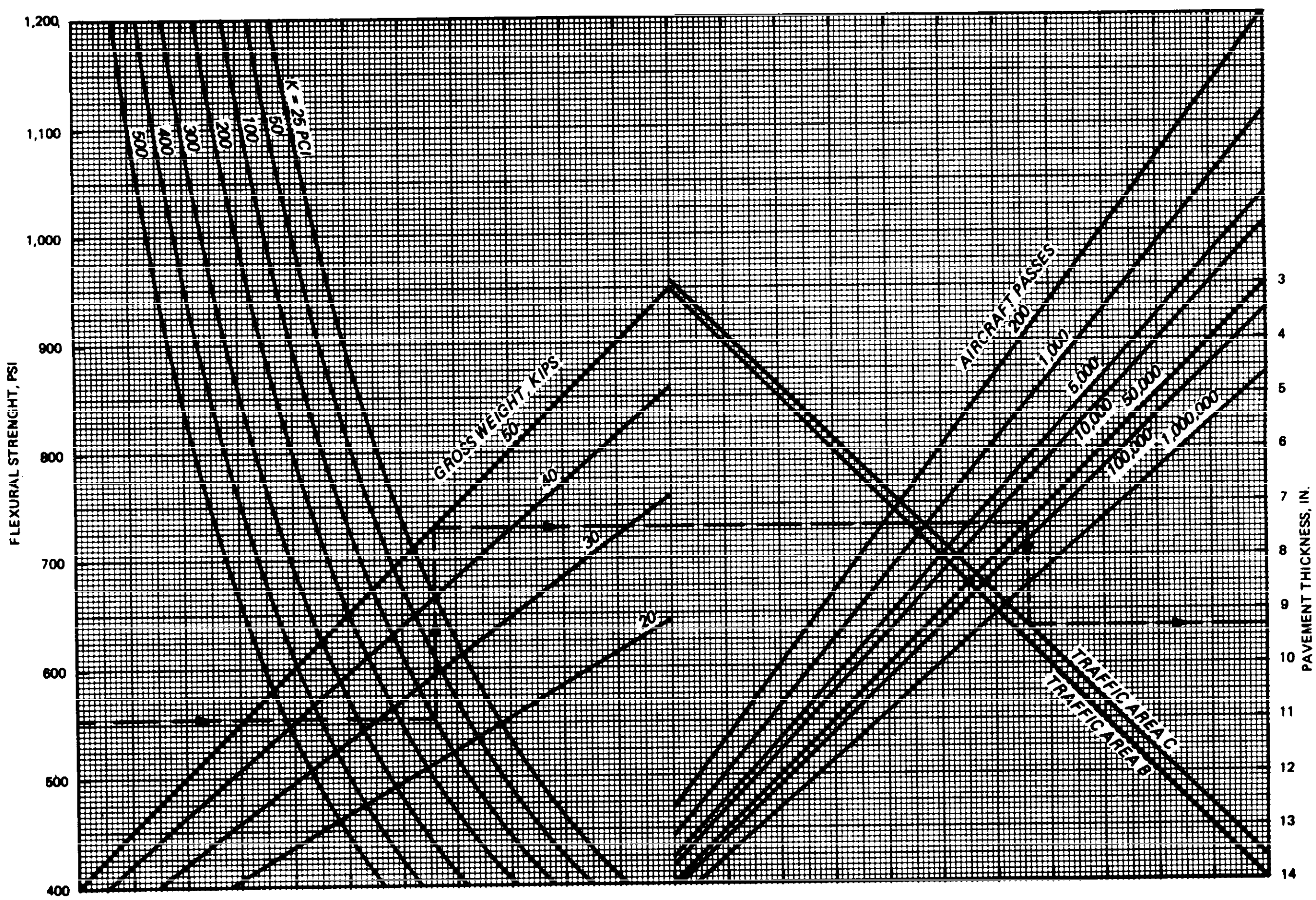


Figure 2-2. Plain concrete design curves for Army Class II airfields.

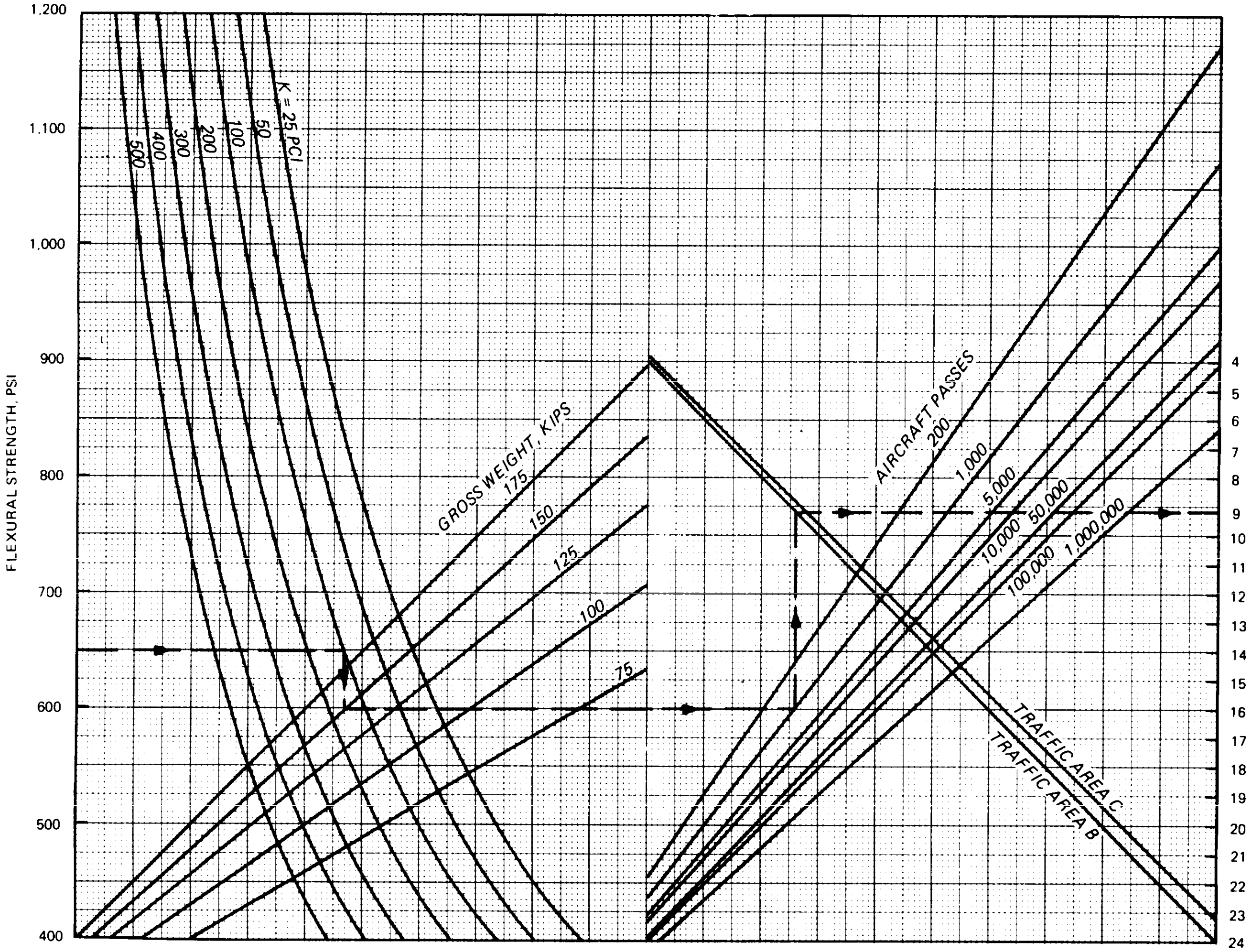


Figure 2-3. Plain concrete design curves for Army Class III airfields.

(1) General. Weakened-plane contraction joints are provided to control cracking in the concrete and to limit curling or warping stresses resulting from drying shrinkage and contraction and from temperature and moisture gradients in the pavement. Shrinkage and contraction of the concrete causes slight cracking and separation of the pavement at the weakened planes, which will provide some relief from tensile forces resulting from foundation restraint and compressive forces caused by subsequent expansion. Contraction joints will be required transversely and may be required longitudinally depending upon pavement thickness and spacing of construction joints. Instructions regarding the use of saw cuts or preformed inserts to form the weakened plane are contained in TM 5-822-7/AFM 88-6, Chap. 8.

(2) Width and depth of weakened plane groove. The width of the weakened plane groove will be a minimum of ⅛ inch and a maximum equal to the width of the sealant reservoir. The depth of the weakened plane groove must be great enough to cause the concrete to crack under the tensile stresses resulting from the shrinkage and contraction of the concrete as it cures. Experience, supported by analyses, indicates that this depth should be at least one-fourth of the slab thickness for pavements 12 inches or less, 3 inches for pavement greater than 12 and less than 18 inches in thickness, and one-sixth of the slab thickness for pavements greater than 18 inches in thickness. In no case will the depth of the groove be less than the maximum nominal size of aggregate used. Concrete placement conditions may influence the fracturing of the concrete and dictate the depth of groove required. For example, concrete placed early in the day, when the air temperature is rising, may experience expansion rather than contraction during the early life of the concrete with subsequent contraction occurring several hours later as the air temperature drops. The concrete may have attained sufficient strength before the contraction occurs so that each successive weakened plane does not result in fracturing of the concrete. As a result, excessive opening may result where fracturing does occur. To prevent this, the depth of the groove will be increased to assure the fracturing and proper functioning of each of the scheduled joints.

(3) Width and depth of sealant reservoir. The width and depth of the sealant reservoir for the weakened plane groove will conform to dimensions shown in figure 2-19. The dimensions of the sealant reservoir are critical to satisfactory performance of the joint sealing materials.

(4) Spacing of transverse contraction joints. Transverse contraction joints will be constructed across each

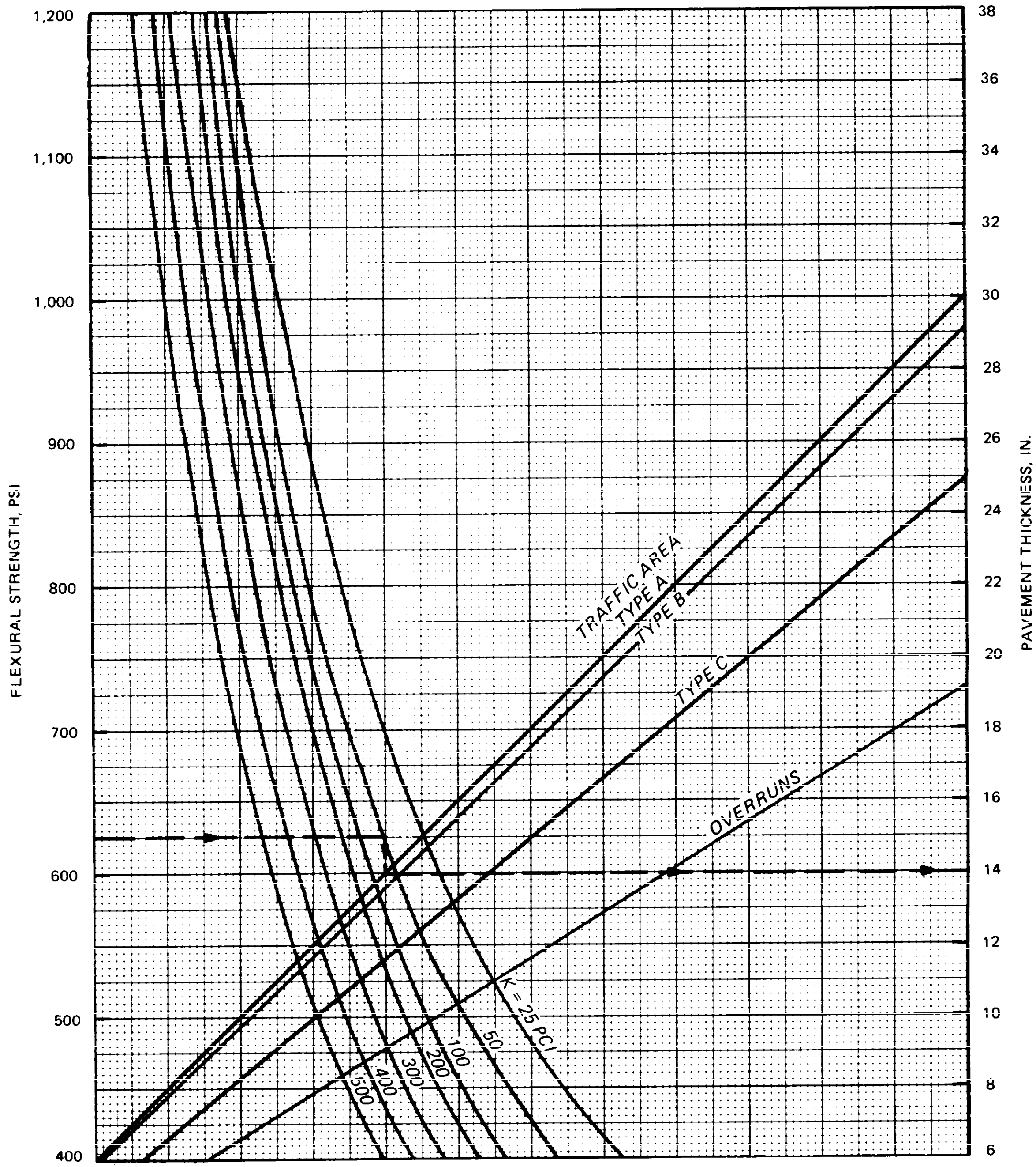


Figure 2-4. Plain concrete design curves for light-load pavements.

paving lane, perpendicular to the center line, at intervals of not less than 12½ feet and generally not more than 25 feet (20 feet for the Air Force). The joint spacing will be uniform throughout any major paved area, and each joint will be straight and continuous from edge to edge of the paving lane and across all paving lanes for the full width of the paved area. Staggering of joints in adjacent paving lanes can lead to sympathetic cracking and will not be permitted unless reinforcement is used. The maximum spacing of transverse joints that will effectively control cracking will vary appreciably depending on pavement thickness, thermal coefficient and other characteristics of the aggregate and concrete, climatic conditions, and foundation restraint. It is impractical to establish limits on joint spacing that are suitable for all conditions without making them unduly restrictive. The joint spacings in table 2-1 have given satisfactory control of transverse cracking in most instances and may be used as a guide, subject to modification based on available information regarding the performance of existing pavements in the vicinity or unusual properties of the concrete. For the best pavement performance, the number of joints should be kept to a minimum by using the greatest joint spacing that will satisfactorily control cracking. Experience has shown, however, that oblong slabs, especially in thin pavements, tend to crack into smaller slabs of nearly equal dimensions under traffic. Therefore, it is desirable, insofar as practicable, to keep the length and width dimensions as nearly equal as possible. In no case should the length dimension (in the direction of paving) exceed

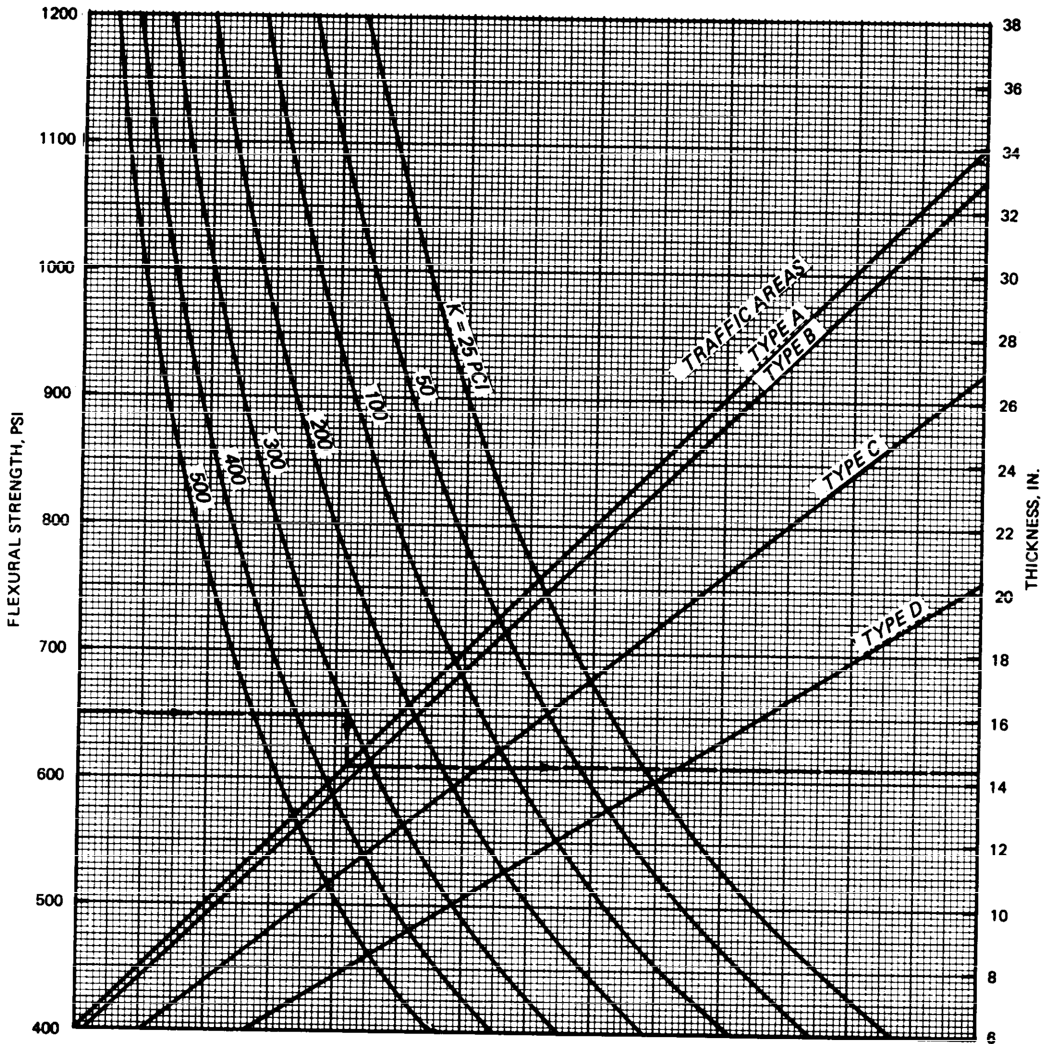


Figure 2-5. Plain concrete design curves for medium-load pavements.

the width dimension more than 25 percent. Under certain climatic conditions, joint spacings different from those in table 2-1 may be satisfactory. Where it is desired to change the joint spacing, a request will be submitted to the Commander, U.S. Army Corps of Engineers (CEEC-EG), Washington, DC 20314-1000, or the appropriate MACOM.

(5) Spacing of longitudinal contraction joints. Contraction joints will be placed along the center line of paving lanes that have a width greater than the determined maximum spacing of transverse contraction joints in table 2-1. Contraction joints may also be required in the longitudinal direction of overlays, regardless of overlay thickness, to match joints existing in the base pavement unless a bond-breaking medium is used between the overlay and base pavement or the overlay pavement is reinforced.

(6) Doweled and tied contraction joints. Dowels will be required in the last three transverse contraction joints back from the ends of all runways to provide positive load transfer in case of excessive joint opening due to progressive growth of the pavement. Similar dowel requirements may be included in the transverse contraction joints at the end of other long paved areas, such as taxiways or aprons where local experience indicates that excessive joint opening may occur. In rigid overlays in Air Force Type A traffic areas and Army Type B traffic areas, longitudinal contraction joints that would coincide with an expansion joint in the base pavement will be doweled. Dowel size and spacing will be as specified in table 2-2. Deformed tie bars, ⅝-inch diameter by 30 inches long, spaced on 30-inch centers, will be required in longitudinal contraction joints that fall 15 feet or less from the free edge of paved areas greater than 100 feet in width to prevent cumulative opening of these joints.

c. Construction joints

(1) General Construction joints may be required in both the longitudinal and transverse direction. Longitudinal construction joints (generally spaced 20 to 25 feet apart but may reach 50 feet apart depending on construction equipment capability) will be required to separate successively placed paving lanes. Transverse construction joints will be installed when it is necessary to stop concreted placement within a paving lane for a length of time that will allow the concrete to start to set. All transverse construction joints will be located in place of other regularly

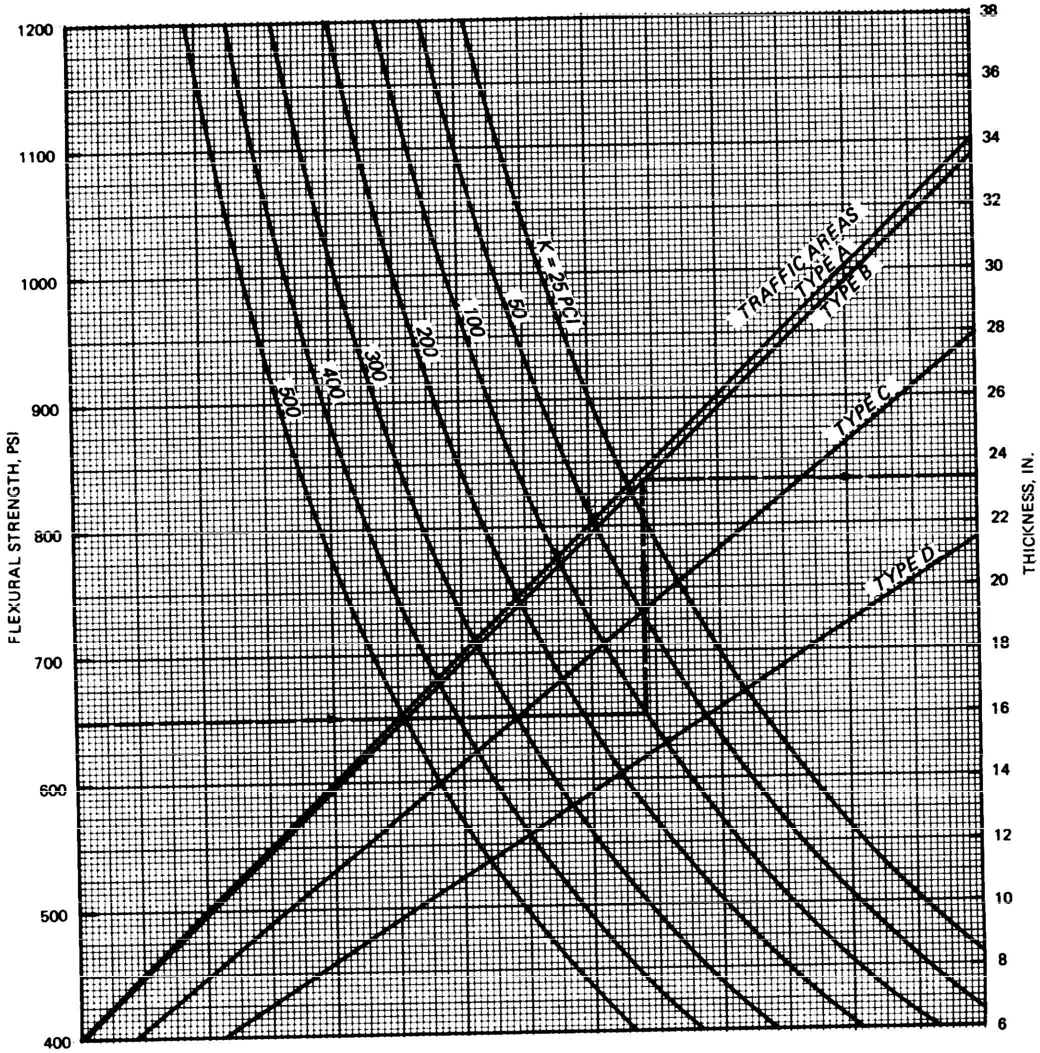


Figure 2-6. Plain conncrete design curves for heavy-load pavements.

spaced transverse joints (contraction or expansion types) and will normally be doweled butt joints. There are several types of construction joints available for use as shown in figure 2-15 and as described below. The selection of the type of construction joint will depend on such factors as the concrete placement procedure (formed or slipformed), airfield type (TM 5-803-4 or TM 5-824-1/AFM 88-6, Chap. 1), and foundation conditionns. Considering these factors, the types of construction joint that may be used are shown in figure 2-20.

(2) Doweled butt joint. The doweled butt joint is considered to be the best joint for providing load transfer and maintaining slab alinement. Therefore, it is the desirable joint for the most adverse conditions, such as heavy loading, high traffic intensity, and lower strength foundations. However, because the alinement and placement of the dowel bars are critical to satisfactory performance, this type of joint is difficult to construct, especially for slipformed concrete. The doweled butt joint is required for all transverse construction joints.

(3) Thickened-edge joint. Thickened-edge-type joints may be used in lieu of other types of joints employing load-transfer devices except as limited in figure 2-20. The thickened-edge joint is constructed by increasing the thickness of the concrete at the edge to 125 percent of the thickness determined from paragraph 2-3. The thickness is then reduced by tapering from the free-edge thickness to the design thickness at a distance 5 feet from the longitudinal edge. The thickened-edge butt joint is considered adequate for the load-in-

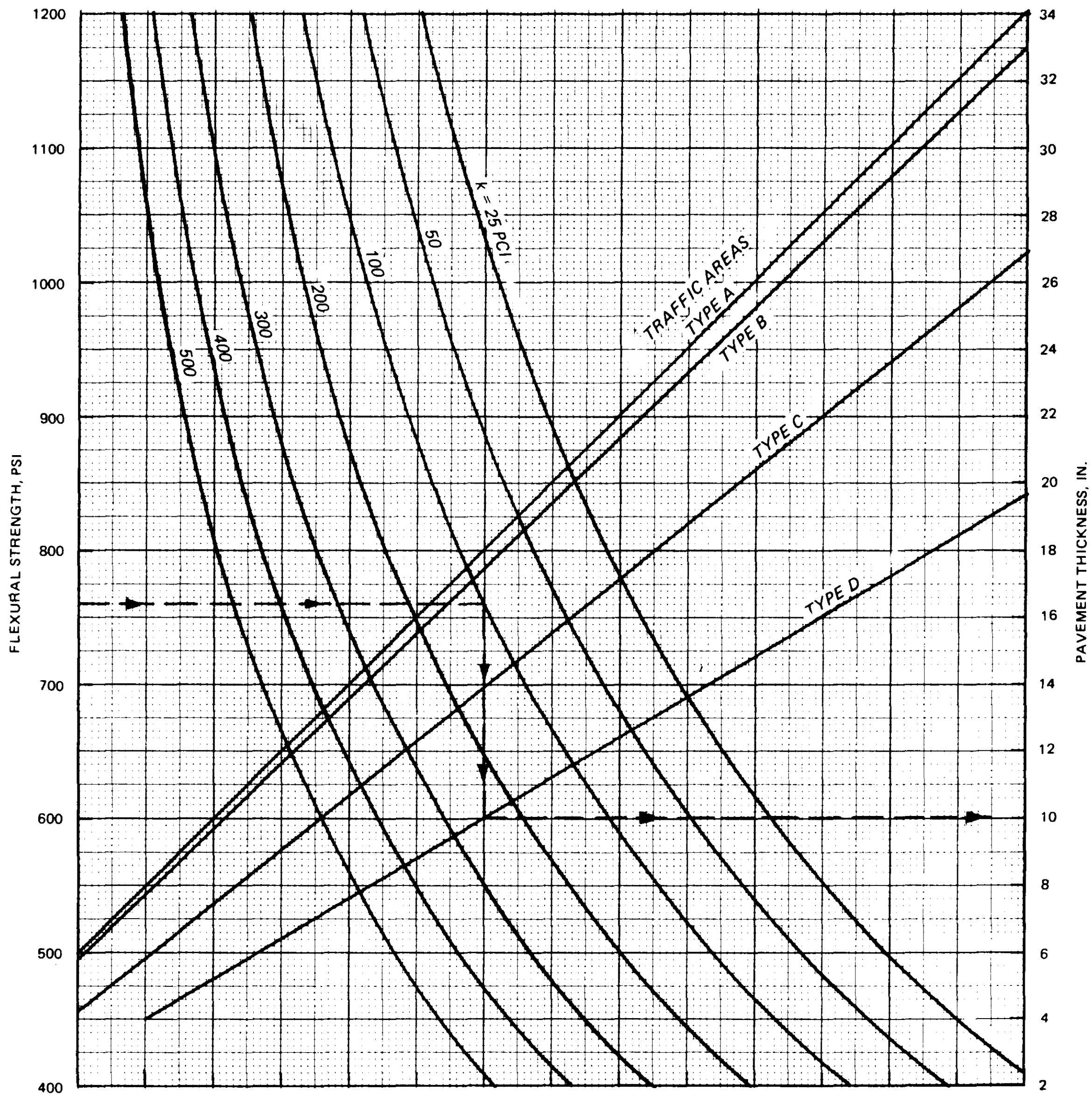


Figure 2-7. Plain concrete design curves for modified heavy-load pavements.

duced concrete stresses. However, the inclusion of a key in the thickened-edge joint provides some degree of load transfer in the joint and helps maintain slab alinement; although not required, it is recommended for pavement constructed on low- to medium-strength foundations. The thickened-edge joint may be used at free edges of paved areas to accommodate future expansion of the facility or where aircraft wheel loadings may track the edge of the pavement.

(4) Keyed joint. The keyed joint is the most economical method, from a construction standpoint, of providing load transfer in the joint. It has been demonstrated that the key or keyway can be satisfactorily constructed using either formed or slipformed methods. Experience has demonstrated that the required dimensions of the joint can best be maintained by forming or slipforming the keyway rather than the key. The dimensions and location of the joint (figure 2-15) are critical to its performance. Deviations exceeding the stated tolerances can result in failure in the joint. Experience has shown that the keyed joint does not perform adequately for high-volume medium and heavy loads in pavements constructed on low- and medium-strength foundations. Tie bars in the keyed joint will limit opening of the joint and provide some shear transfer that will improve the performance of the keyed joints. However, tied joints in pavement widths of more than 75 feet can result in excessive stresses and cracking in the concrete during contraction.

d. Expansion joints.

(1) General. Expansion joints will be used at all intersections of pavements with structures and may be required within the pavement features. A special expansion joint required at pavement intersections is the slip joint. The types of expansion joints are the thickened-edge, the thickened-edge slip joint, and the doweled type (figures 2-16 and 2-17). Filler material for the thickened-edge and doweled-type expansion joint will be a nonextruding type. The type and thickness of filler

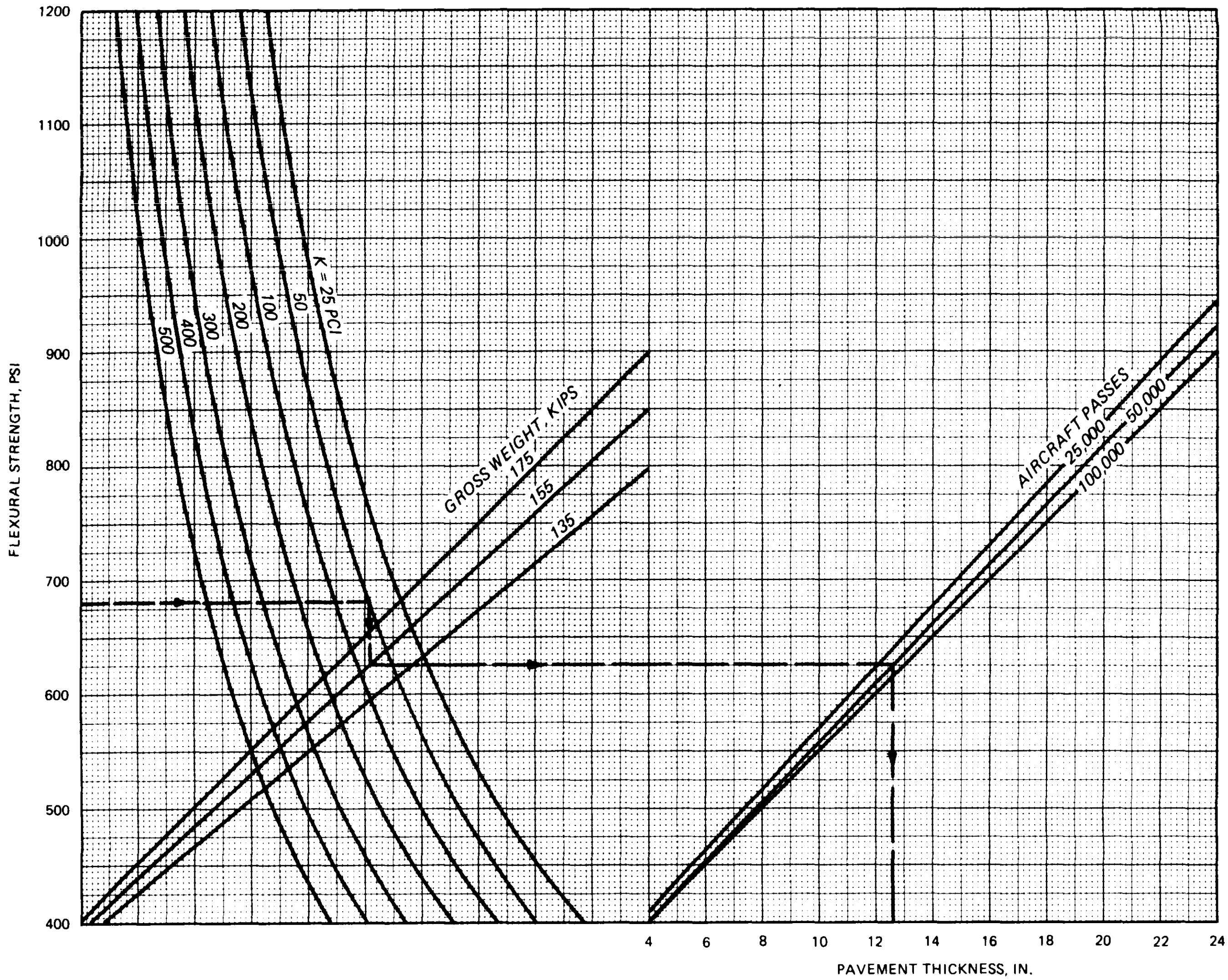


Figure 2-8. Plain concrete design curves for shortfield pavements.

material and the manner of its installation will depend upon the particular case. Usually a preformed material of ¾-inch thickness will be adequate, but in some instances a greater thickness of filler material may be required. Filler material for slip joints will be either a heavy coating of bituminous material not less than 1/16 inch in thickness when joints match or normal nonextruding-type material not less than ¼ inch in thickness when joints do not match. Where large expansions may have a detrimental effect on adjoining structures, such as at the juncture of rigid and flexible pavements, expansion joints in successive transverse joints back from the juncture should be considered. The depth, length, and position of each expansion joint will be sufficient to form a complete and uniform separation between the pavements and between the pavement and the structure concerned.

(2) Between pavement and structures. Expansion joints will be installed to surround, or to separate from the pavement, any structures that project through, into, or against the pavements, such as at the approaches to buildings or around drainage inlets and hydrant refueling outlets. The thickened-edge-type expansion joint will normally be best suited for these places.

(3) Within pavements.

(*a*) Expansion joints within pavements are difficult to construct and maintain, and they often contribute to pavement failures. Their use will be kept to the absolute minimum necessary to prevent excessive stresses in the pavement from expansion of the concrete or to avoid distortion of a pavement feature through the expansion of an adjoining pavement. The determination of the need for and spacing of expansion joints will be based upon: pavement thickness, thermal properties of the concrete, prevailing temperatures in the area, temperatures during the construction period, and the experience with concrete pavements in the area. Unless needed to protect abutting structures, expansion joints will be omitted in all pavements 10 inches or more in thickness and also in pavements less than 10 inches in thickness when the concrete is placed during warm weather since the initial volume of the concrete on hardening will be at or near the maximum. However, for concrete placed during cold weather, expansion joints may be used in pavements less than 10 inches thick.

(*b*) Longitudinal expansion joints within pave-

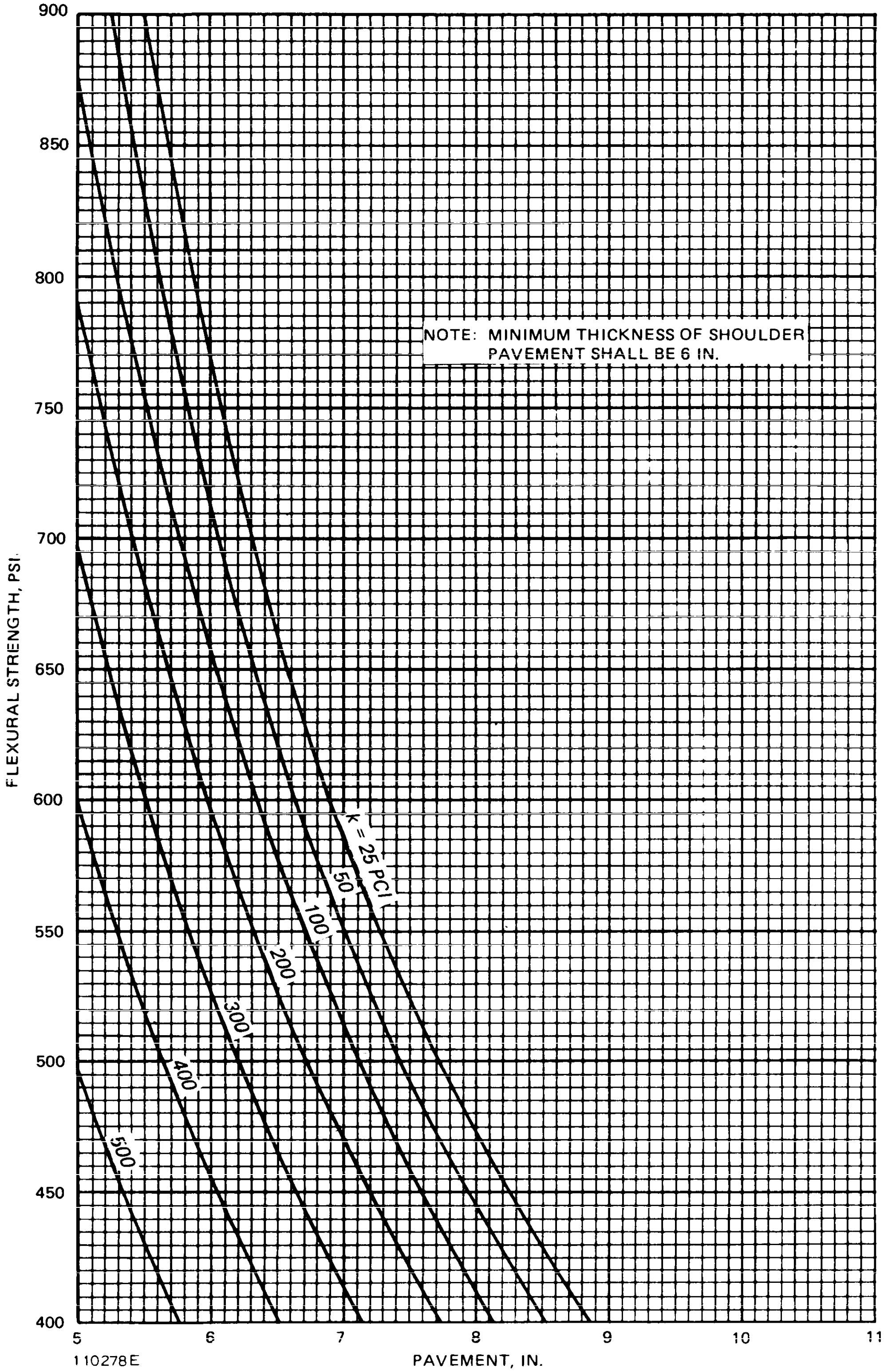


Figure 2-9. Plain concrete design curves for shoulders.

ments will be of the thickened–edge type (figure 2-16). Dowels are not recommended in longitudinal expansion joints because differential expansion and contraction parallel with the joints may develop undesirable localized strains and possibly failure of the concrete, especially near the corners of slabs at transverse joints.

(*c*) Transverse expansion joints within pavements will be the doweled type (figure 2–16). There may be instances when it will be desirable to allow some slippage in the transverse joints, such as at the angular intersection of pavements to prevent the expansion of one pavement from distorting the other. In these instances, the design of the transverse expansion joints will be similar to the thickened-edge slip joints (figure 2-17). When a thickened–edge joint (slip joint) is used at a free edge not perpendicular to a paving lane, a transverse expan-

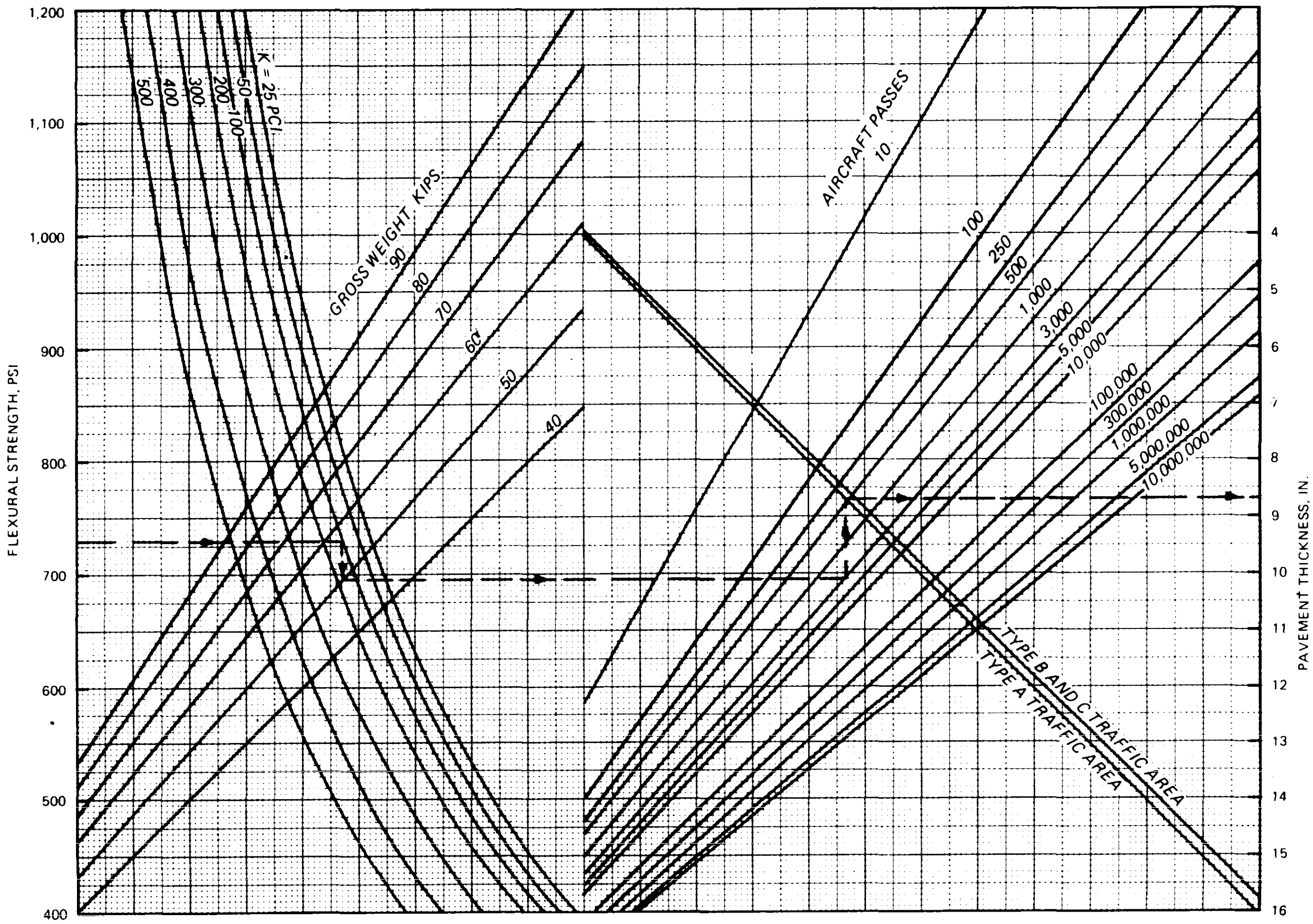


Figure 2-10. Plain concrete design curve for F-15 aircraft.

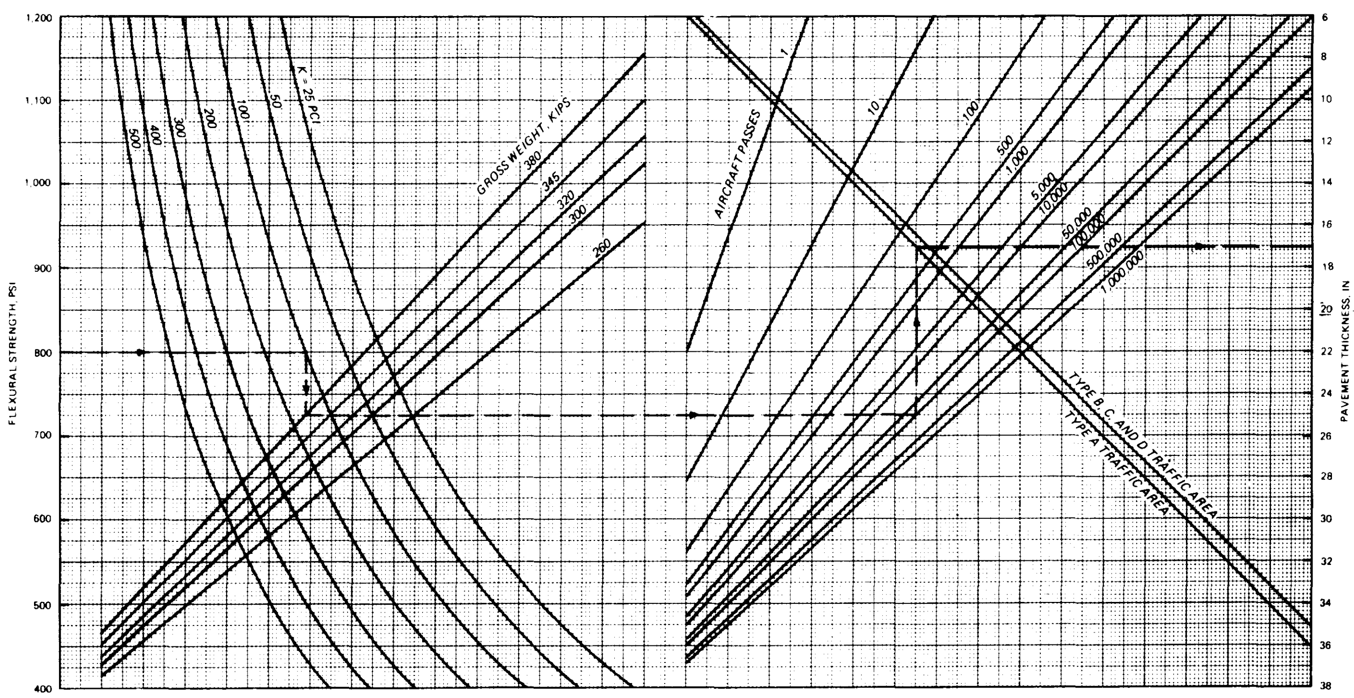


Figure 2-11. Plain concrete design curve for C-141 aircraft.

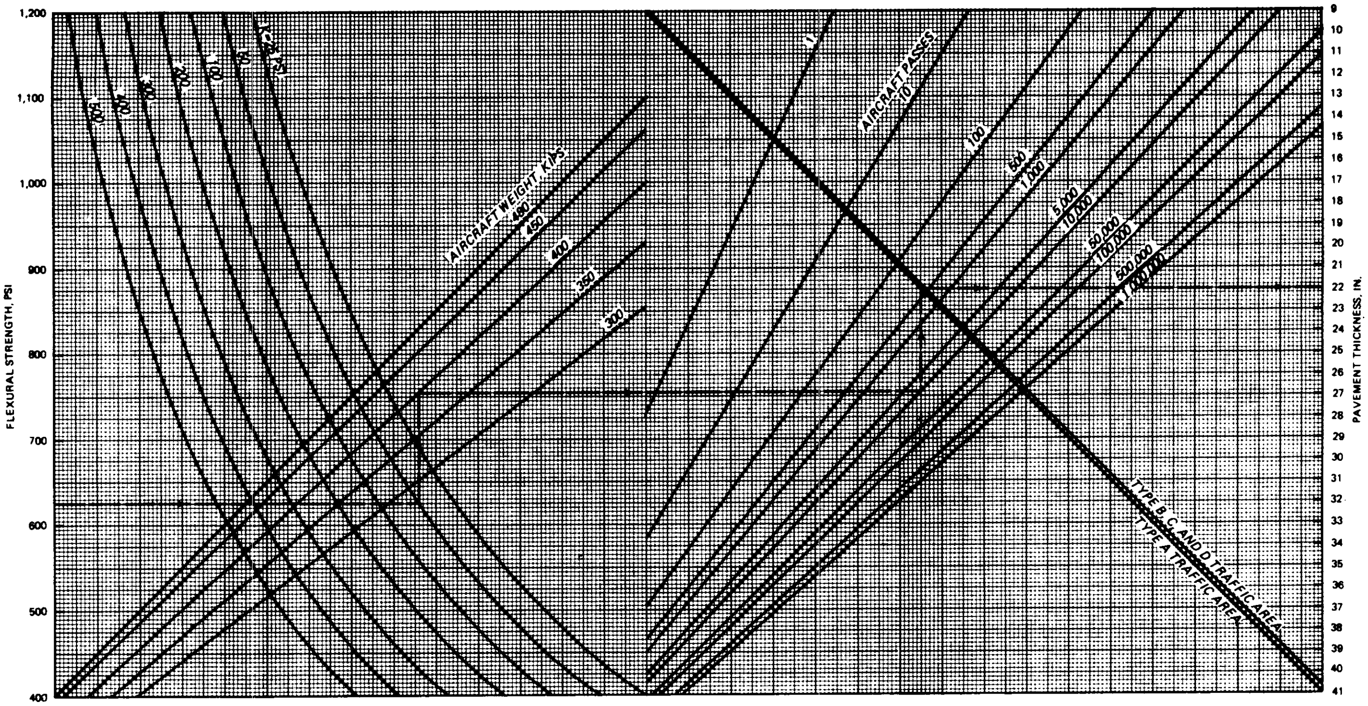
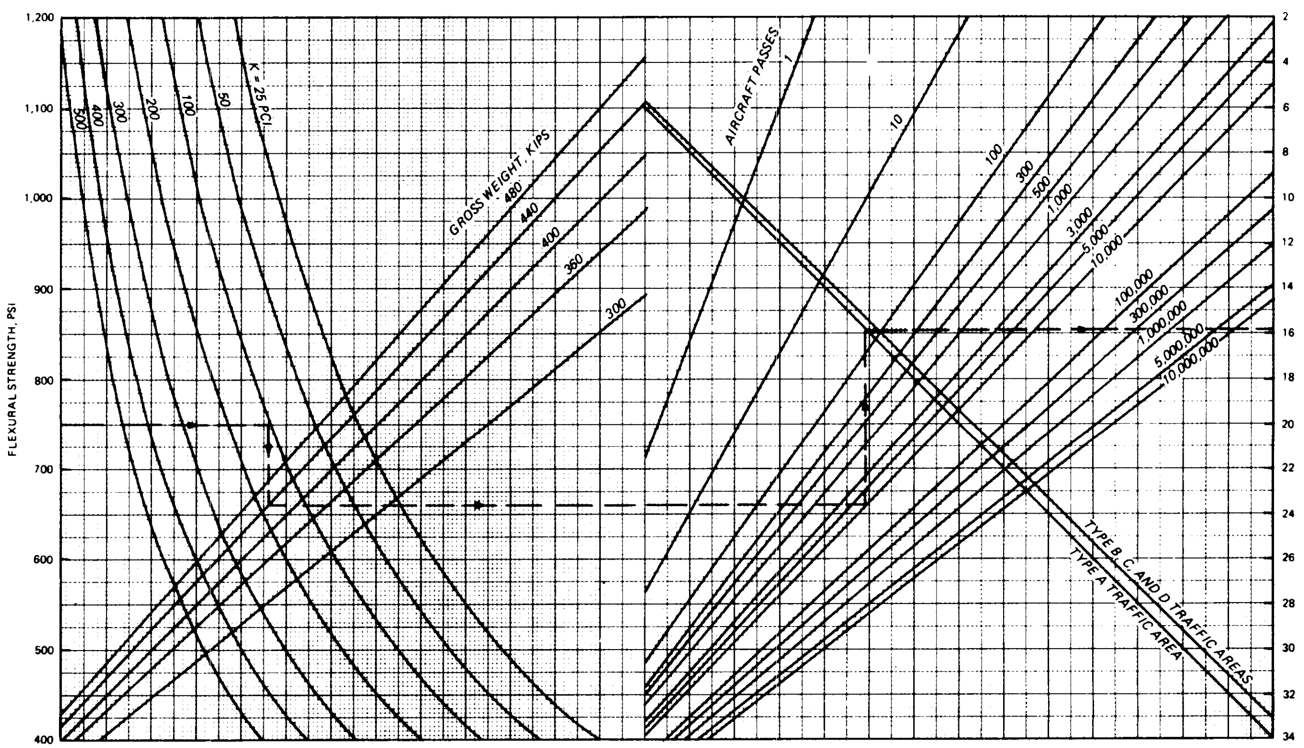


Figure 2-12. Plain concrete design curve for B-52 aircraft.



RIGID PAVEMENT DESIGN CURVE FOR B-1 AIRCRAFT

Figure 2-13. Plain concrete design curves for B-1 aircraft.

sion joint will be provided 75 to 100 feet back from the free edge.

e. Dowels. The important functions of dowels or any other load-transfer device in concrete pavements are: to help maintain the alinement of adjoining slabs, and to limit or reduce stresses resulting from loads on the pavement. Different sizes of dowels will be specified for different thicknesses of pavements (table 2-2). When extra-strength pipe is used for dowels, the pipe will be filled with either a stiff mixture of sand-asphalt or portland cement mortar, or the ends of the pipe will be plugged. If the ends of the pipe are plugged, the plug must fit inside the pipe and be cut off flush with the end of the pipe so that there will be no protruding material to bond with the concrete and prevent free movement of the dowel. Figures 2-14 through 2-16 show the dowel placement. All

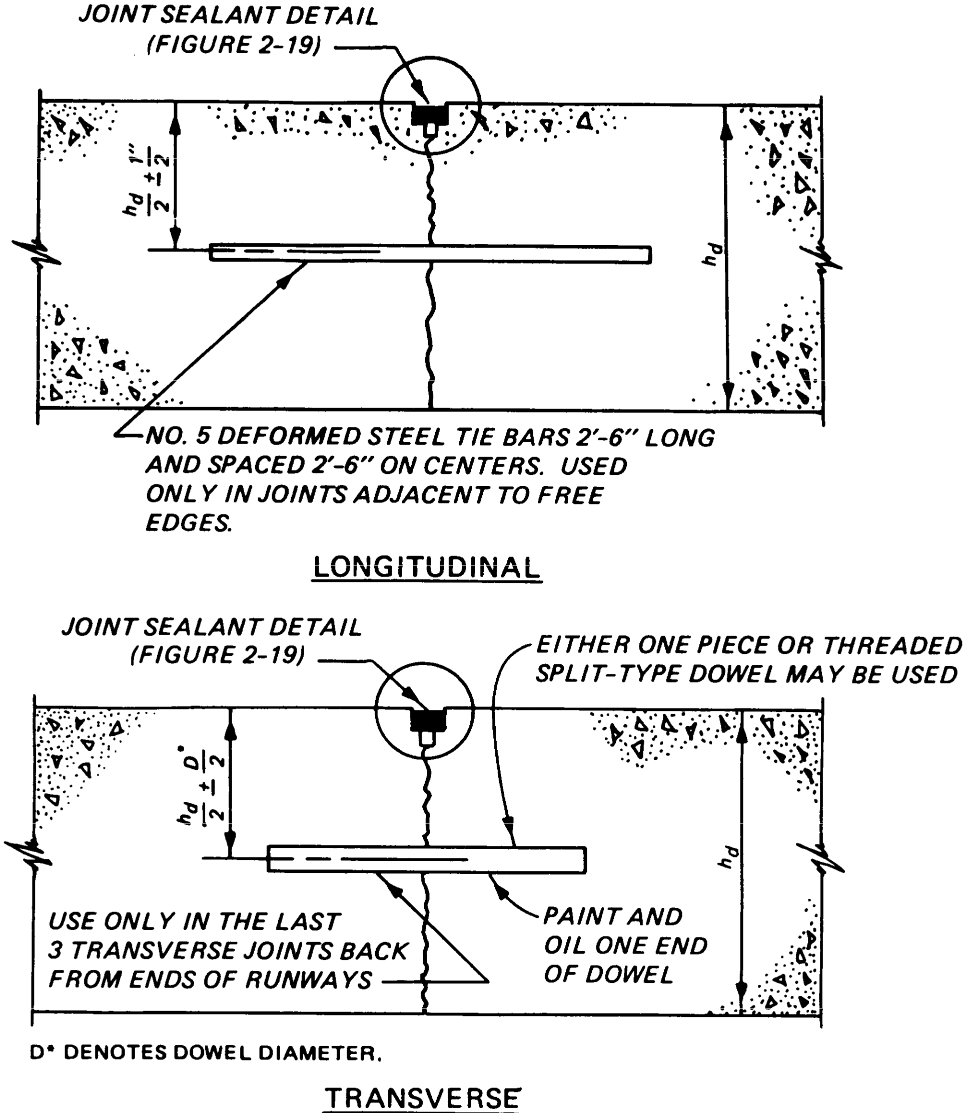


Figure 2-14. Contraction joints for plain concrete pavements.

dowels will be straight, smooth, and free from burrs at the ends. One end of the dowel will be painted and oiled to prevent bonding with the concrete. Dowels used at expansion joints will be capped at one end, in addition to painting and oiling, to permit further penetration of the dowels into the concrete when the joints close.

f. Special provisions of slipforming paving.

(1) Provisions must be made for slipform pavers when there is a change in longitudinal joint configuration. The thickness may be varied without stopping the paving train, but the joint configuration cannot be varied without modifying the side forms, which will normally require stopping the paver and installing a header. The requirements discussed as follows shall apply.

(2) The header may be set on either side of the transition slab with the transverse construction joint doweled as required. As an example, for the transition between the type A and type D areas on a medium-load pavement, the header could be set at the end of either type pavement. The dowel size and location in the transverse construction joint should be commensurate with the thickness of the pavement at the header.

(3) When there is a transition between a doweled longitudinal construction joint and a keyed longitudinal construction joint, the longitudinal construction joint in the transition slab may be either a keyed or doweled. The size and location of the dowels or keys in the transition slabs should be the same as those in the pavement with the doweled or keyed joint, respectively.

(4) When there is a transition between two keyed joints with different dimensions, the size and location of the key in the transition slab should be based on the thickness of the thinner pavement.

g. Joint sealing. All joints will be sealed with a suitable sealant to prevent infiltration of surface water and solid substances. Jet-fuel-resistant (JFR) sealants will be used in the joints of aprons, warm-up holding pads, hardstands, washracks, and other paved areas where fuel may be spilled during the operation, parking, maintenance, and servicing of aircraft. In addition, heat-resistant JFR joint sealant materials will be used for

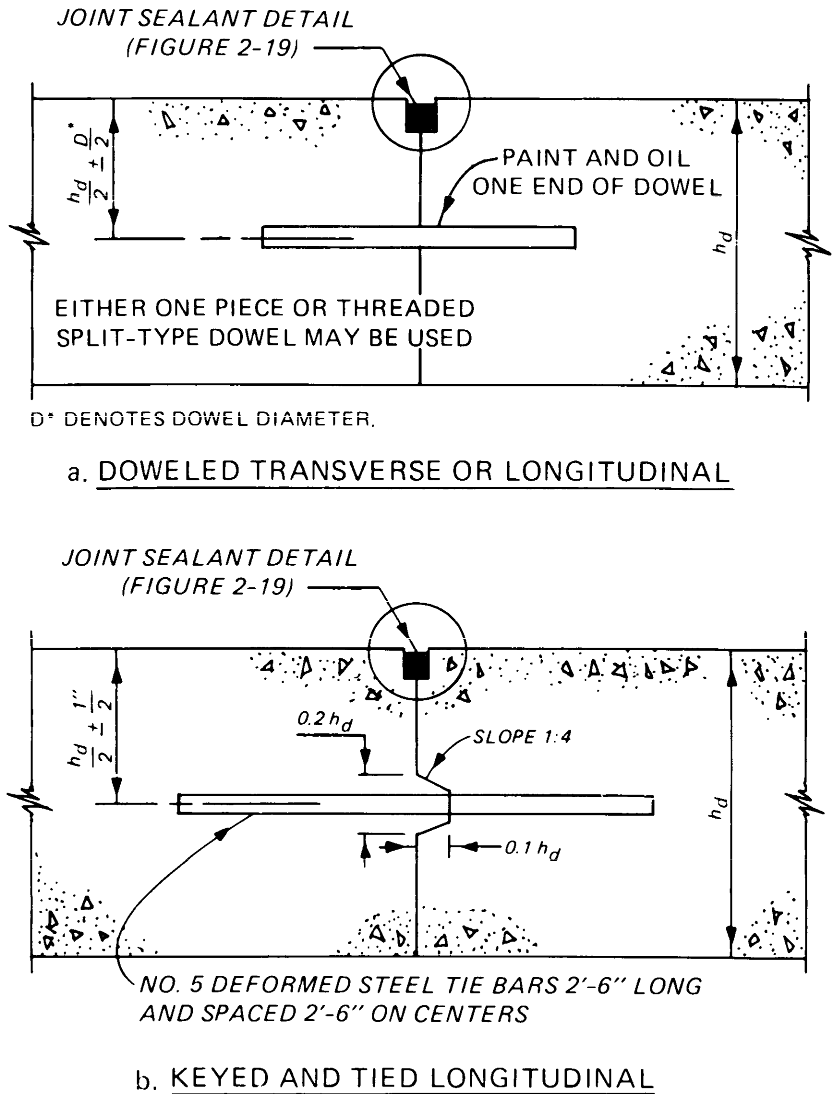


Figure 2-15. Construction joints for plain concrete pavements (Sheet 1 of 4).

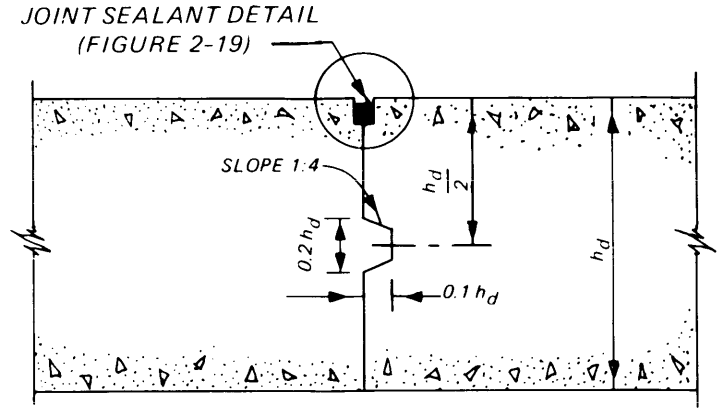
runway ends and other areas where the sealant material may be subject to prolonged heat and blast of aircraft engines. Non-JFR sealants will be used in the joints of all other airfield pavements. JFR sealants will conform to Federal Specifications SS-S-1614 and SS-S-200, and non-JFR sealants will conform to Federal Specification SS-S-1401. When heat- and blast-resistant JFR sealants are required, they will conform to Federal Specification SS-S-200. An optimal sealant, meeting both the heat- and blast-resistant JFR and non-JFR sealant requirements, is a preformed polychloroprene elastomeric material conforming to ASTM D 2628 and D 2835. As a general rule, compression-type preformed sealants must have an uncompressed width of not less than twice the width of the joint reservoir. However, the maximum and minimum dimensions for the seal width should be based on the joint opening and expected movement. The selection of a pourable or preformed sealant should be based upon the economics involved. Compression-type preformed sealants are recommended when the joint spacings exceed 25 feet and are required when joint spacings exceed 50 feet.

2-5. Special joints and junctures

a. General. Situations will develop where special joints or variations of the more standard type joints will be needed to accommodate movements that will occur and to provide a satisfactory operational surface. Some of these special joints or junctures are discussed in the following paragraphs.

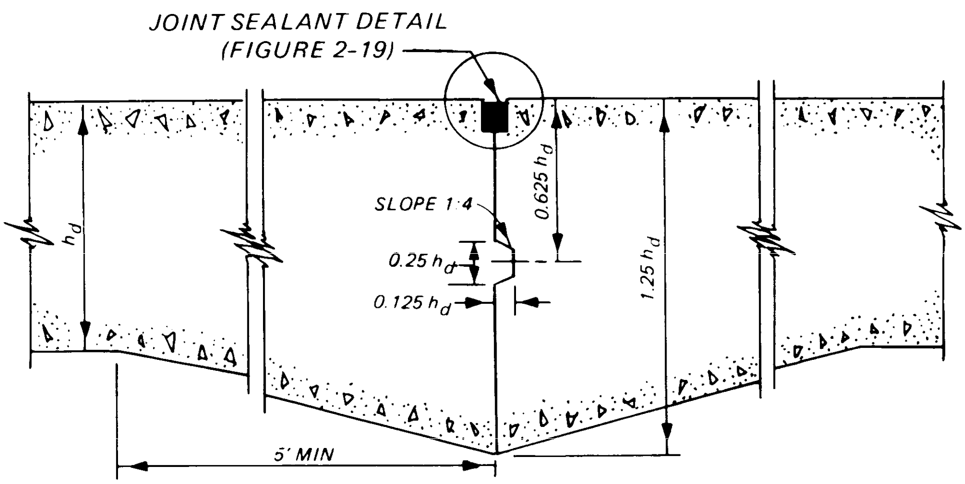
b. Juncture between rigid and flexible pavements. To minimize the occurrence of roughness at the juncture of rigid and flexible pavements, the juncture described in TM 5-825-2/NAVFAC DM 21.3/AFM 88-6, Chap. 2 will be used. When the juncture is installed during the construction of a new flexible pavement joining an existing rigid pavement, the existing rigid pavement will be drilled and doweled for the expansion joint. The dowels will be bonded in the existing rigid pavement with epoxy grout.

c. Slip-type joints. At the juncture of two pavement facilities, such as a taxiway and runway, expansion and contraction of the concrete may result in movements that occur in different directions. Such movements may cre-



NOTE: A TOLERANCE OF ±1/16" MAY BE ALLOWED FOR KEY DIMENSIONS AND LOCATION

c. KEYED LONGITUDINAL



NOTE: A TOLERANCE OF ±1/16" MAY BE ALLOWED FOR KEY DIMENSIONS AND LOCATION

d. KEYED THICKENED EDGE LONGITUDINAL

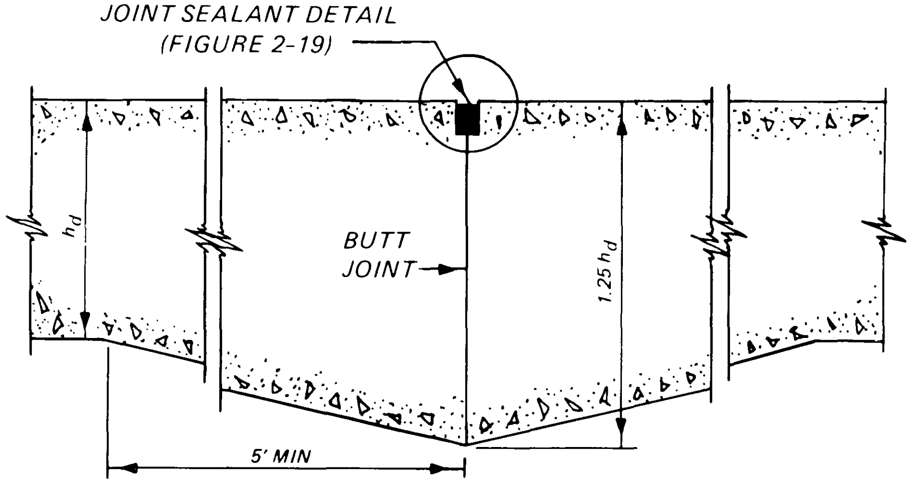
Figure 2-15. Construction joints for plain concrete pavements (Sheet 2 of 4).

ate detrimental stresses within the concrete unless provision is made to allow the movements to occur. At such junctures, the thickened–edge slip joint shall be used to permit the horizontal slippage to occur. The design of the thickened–edge slip joint will be similar to the thickened–edge construction joint (figure 2–17). The bond–breaking medium will be either a heavy coating of bituminous material not less than 1/16 inch in thickness when joints match or a normal nonextruding–type expansion joint material not less than 1/4 inch in thickness when joints do not match. The 1/16–inch bituminous coating may be either a low penetration (60 to 70 grade asphalt) or a clay–type asphalt-base emulsion similar to that used for roof coating (Military Specification MIL-R-3472) and will be applied to the face of the joint by hand brushing or spraying.

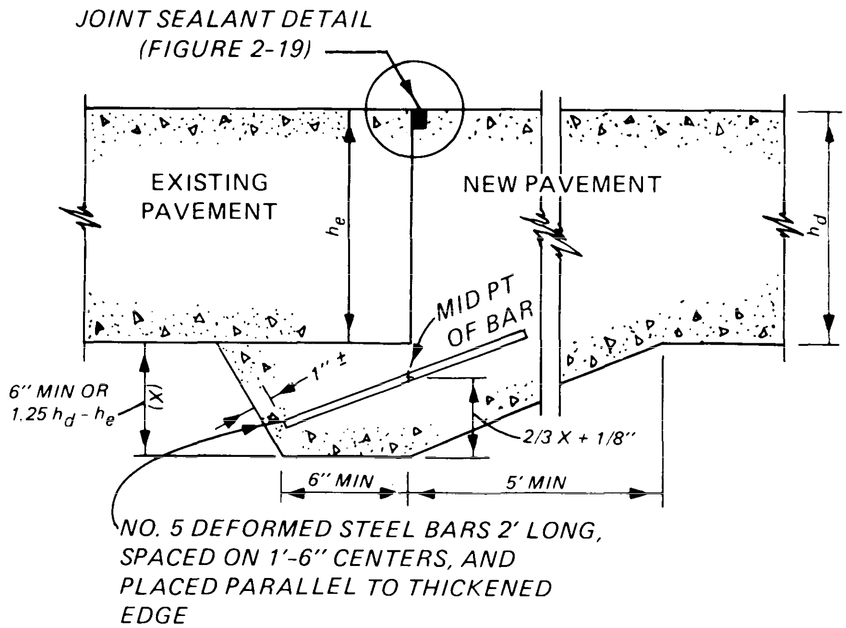
d. Special joint between new and existing pavements. A special thickened-edge joint design (figure 2-15) will be used at the juncture of new and existing pavements for the following conditions:

- When load-transfer devices (keyways or dowels) or a thickened edge was not provided at the free edge of the existing pavement.
- When load-transfer devices or a thickened edge was provided at the free edge of the existing pavement, but neither met the design requirements for the new pavement.
- For transverse contraction joints, when removing and replacing slabs in existing pavement.
- For longitudinal construction joints, when removing and replacing slabs in an existing pavement if the existing load-transfer devices are damaged during the pavement removal.
- Any other location where it is necessary to provide load transfer for the existing pavements.

The special joint design may not be required if a new



e. THICKENED EDGE LONGITUDINAL



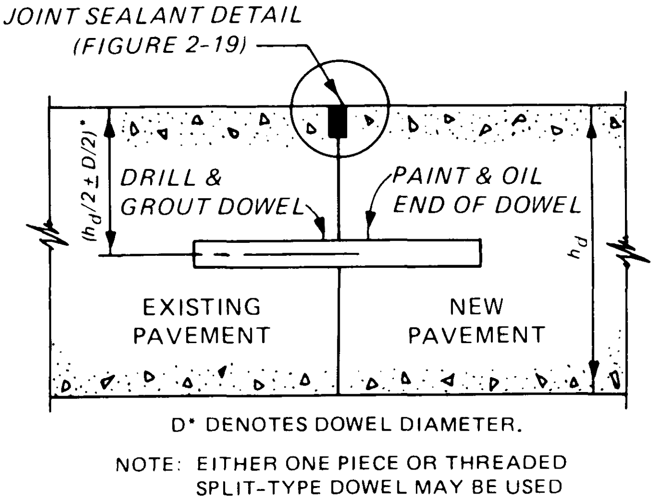
f. SPECIAL JOINT BETWEEN NEW AND EXISTING PAVEMENT TRANSVERSE OR LONGITUDINAL

Figure 2-15. Construction joints for plain concrete pavements (Sheet 3 of 4).

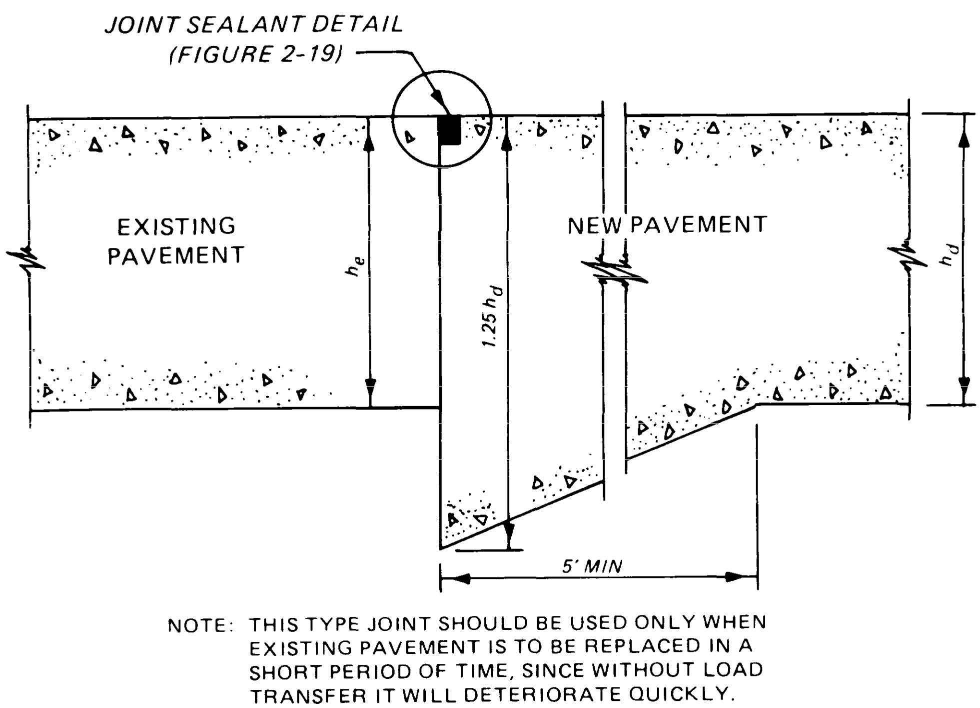
pavement joins an existing pavement that is grossly inadequate to carry the design load of the new pavement or if the existing pavement is in poor structural condition. If the existing pavement can only carry a load that is 75 percent or less of the new pavement design load, special efforts to provide edge support for the existing pavement may be omitted; however, if the provisions for edge support are omitted, accelerated failures in the existing pavement may be experienced. Any load-transfer devices in the existing pavement should be used at the juncture to provide as much support as possible to the existing pavement. The new pavement will simply be designed with a thickened edge at the juncture. Drilling and grouting dowels in the existing pavement for edge support may be considered as an alternative to the special joint, but a thickened-edge design will be used for the new pavement at the juncture.

2-6. Examples of plain concrete pavement design

a. General. It is required that an airfield be designed as a medium-load pavement. According to TM 5-824-1/AFM 88-6, Chap. 1, Type A and B traffic areas are designed for the F-15 at 81,000 pounds, the C-141 at 345,000 pounds, and the B-52 at 400,000 pounds. Type C and D traffic areas and overruns are designed for the F-15 at 60,750 pounds, the C-141 at 258,000 pounds, and the B-52 at 300,000 pounds. Type A, B, and C traffic areas are designed for 25,000 passes of the F-15, 100,000



g. DOWELED JOINT BETWEEN NEW AND EXISTING PAVEMENT



h. THICKENED EDGE JOINT BETWEEN NEW AND EXISTING PAVEMENT

Figure 2-15. Construction joints for plain concrete pavements (Sheet 4 of 4).

passes of the C-141, and 100 passes of the B-52. Type D traffic areas and overruns are designed for 250 passes of the F-15, 1,000 passes of the C-141, and 1 pass of the B-52. (Since the B-52 is included in the design, the runway must be 200 feet wide.) On-site and laboratory investigations have yielded the following data required for design: (a) the subgrade material is classified as a silty sand (SM); (b) the modulus of soil reaction, k, of the subgrade is 200 pci; (c) a nearby source of crushed gravel meets the requirements for base course; (d) frost does not enter subgrade material; and (e) 90-day concrete flexural strength, R, is 700 psi.

b. Example design, slab on grade. Figure 2-5 is entered with the subgrade k, concrete design flexural strength, and the pavement thickness is determined for the various traffic areas and overruns as follows:

Traffic Area	*Thickness, inches*
A	15.5 (15.5)*
B	15.0 (15.0)
C	11.9 (12.0)
D and overruns	8.6 (8.5)

* Values in parentheses are rounded values that would be used for design.

c. Example design, slab on unbound base. For comparison purposes, designs are developed below for three base course thicknesses. Field plate-bearing

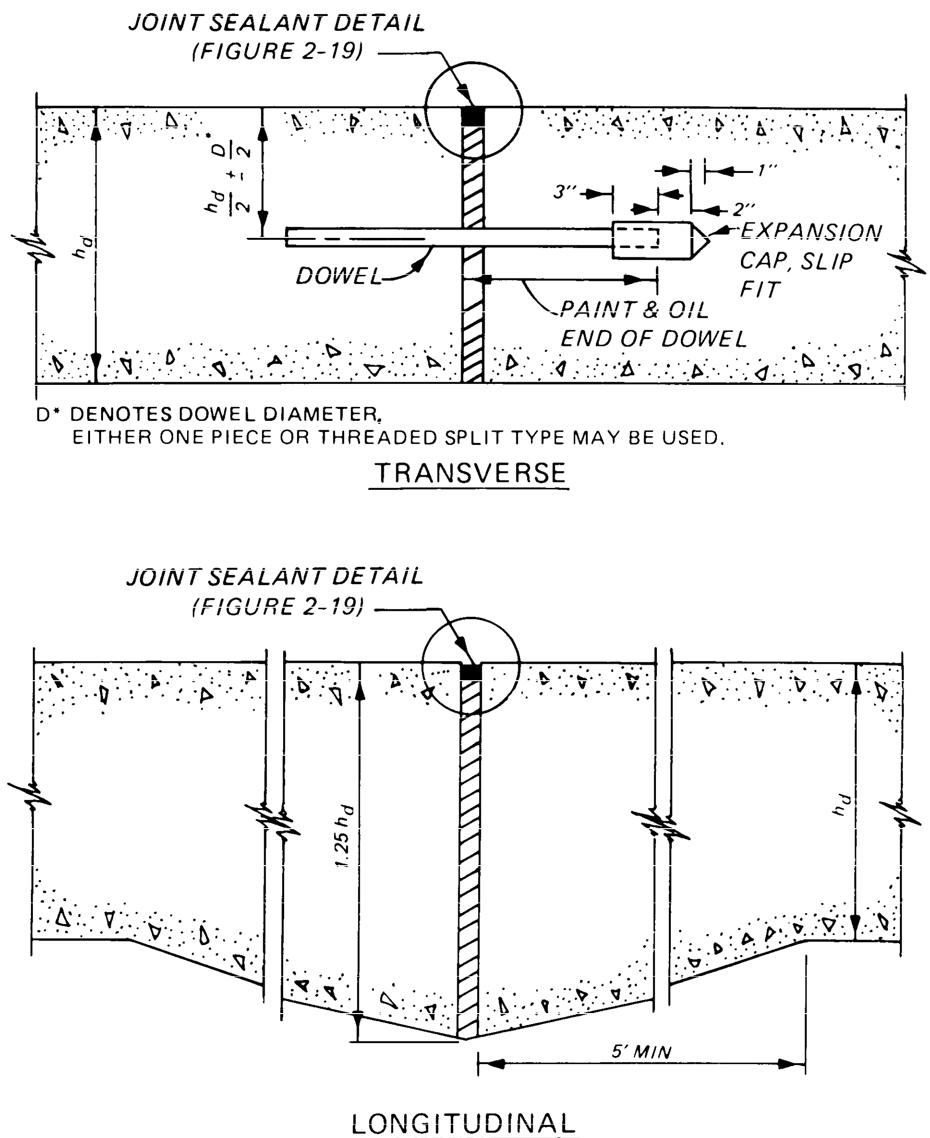


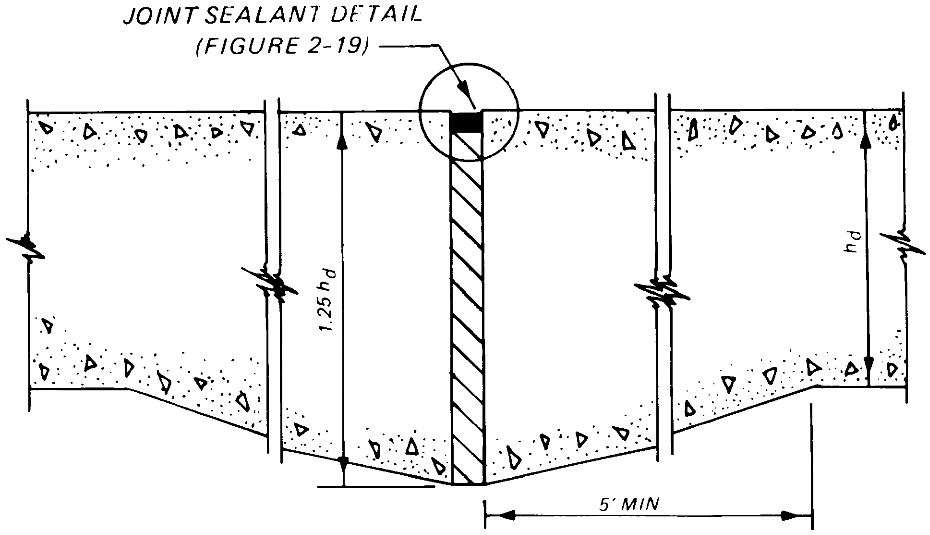
Figure 2-16. Expansion joints for plain concrete pavements.

tests conducted in a test section to establish the modulus of soil reaction for three thicknesses of base course give k values of 250 pci for a 6-inch base, 300 pci for a 12-inch base. These values are supported by figure 1-2 and are thus selected for design. Figure 2-5 is entered with the design flexural strength, modulus of soil reaction, and traffic areas to determine the required concrete pavement thicknesses. Thicknesses for shoulders were determined from figure 2-9. The thicknesses for this example are summarized as follows:

Foundation Condition	*Modulus of Soil Reaction pci*	*Thickness, inches Traffic Area* *A*	*B*	*C*	*D & Overruns*	*Shoulders**
6-inch base	250	14.4	13.9	11.0	7.9	6*
12-inch base	300	13.5	13.0	10.3	7.2	6*
18-inch base	350	12.7	12.2	9.6	6.7	6*

Note: Thickness should be rounded to the nearest half-inch for construction.
* Use minimum thickness of 6 inches for shoulders.
The final selection of concrete pavement thickness must be based upon a study of the cost of importing and placing base course versus savings in concrete pavements.

d. Example design, slab on stabilized base. Assume that a cement-stabilized base course will be used. Laboratory tests on base course material have shown that a cement content of 7 percent by weight will yield a compressive strength of 1,000 psi and a flexural modulus of elasticity, E_b, of 500,000 psi at an age of 90 days. According to TM 5-822-4/AFM 88-7, Chap. 4, the compressive strength of 1,000 psi qualifies as a stabilized layer (that is, permits a thickness reduction), and the design is made using the overlay equation given in paragraph 2-3c. The single slab thickness, h_d, of plain concrete is determined from figure 2-5 using R = 700 psi and k = 200 pci for the design load and pass level for each type traffic area. The thickness of plain concrete overlay determined with the equation in paragraph 2-3c for several thicknesses of stabilized layer are shown in the following tabulation:



NOTE: THE BOND-BREAKING MEDIUM WILL BE EITHER A HEAVY COATING OF BITUMINOUS MATERIAL NOT LESS THAN 1/16 INCH IN THICKNESS WHEN JOINTS MATCH OR A NORMAL NONEXTRUDING-TYPE EXPANSION JOINT MATERIAL NOT LESS THAN 1/4 INCH IN THICKNESS WHEN JOINTS DO NOT MATCH.

Figure 2-17. Slip joints for plain concrete pavements.

Type Traffic Area	*Thickness of Stabilized Layer, h_b inches*	*Thickness of Slab on grade inches*	*Overlay Thickness inches*
A	6	15.5	14.3 (14.5)
	12	15.5	12.4 (12.5)
	18	15.5	9.8 (10.0)
B	6	15.0	13.8 (14.0)
	12	15.0	11.9 (12.0)
	18	15.0	9.2 (9.5)
C	6	11.9	10.6 (11.0)
	12	11.9	8.4 (8.5)
	18	11.9	5.3 (6.0)
D & Overrun	6	8.6	7.1 (7.0)
	12	8.6	6.0 (6.0)*
	18	8.6	6.0 (6.0)*

Note: Values in parentheses are rounded values.
* Minimum thickness of plain concrete pavement.

The final selection of plain concrete pavement and stabilized base thicknesses will be based upon the economics involved.

e. Design example for mixed traffic.

(1) General. The design of rigid airfield pavements has been based on a standard definition of aircraft mixture, load, and pass levels. However, pavements may be designed for a mixture of aircraft type, loadings, and repetitions other than the standard. This design example presents a procedure for the design of pavements which will be subjected to a mixture of traffic types and loadings based upon equivalent aircraft loadings.

(2) Procedure. The design of a concrete pavement to accommodate a mixture of aircraft traffic is accomplished using the following steps:

(a) Determine the aircraft traffic that is anticipated to use the pavements during the life of the pavements. Arrange this traffic in accordance with aircraft type, gross weight, and number of passes.

(b) Select the pavement thickness required for each aircraft at the design gross weight, pass level, and pavement characteristics.

(c) Select the controlling aircraft as the one requiring the maximum thickness.

(d) Evaluate the controlling thickness in terms of allowable passes for each aircraft in the design mix using the appropriate design curves from figures 2-1 to 2-13. Those curves are entered from the left with the flexural strength, modulus of subgrade reaction, and load and from the right with controlling thickness and traffic. The intersection point of these two lines will estimate the allowable number of passes of an aircraft. An example of this operation is shown in figure 2-21.

(e) Determine the number of each aircraft equivalent to one pass of the controlling aircraft by dividing the allowable passes of each aircraft by the allowable pass level of the controlling aircraft.

(f) The number of design passes for each aircraft is then divided by the equivalent passes to determine the total number of equivalent passes of the controlling aircraft to be considered for final design.

(3) Example problem solution.

(a) Determine the thickness of pavement required for a taxiway having the mixture of aircraft, gross weights, and number of passes as shown in columns 1-3 in table 2-3. The concrete design flexural strength, R, is 650 psi, and the modulus of soil reaction, k, is 200 pci.

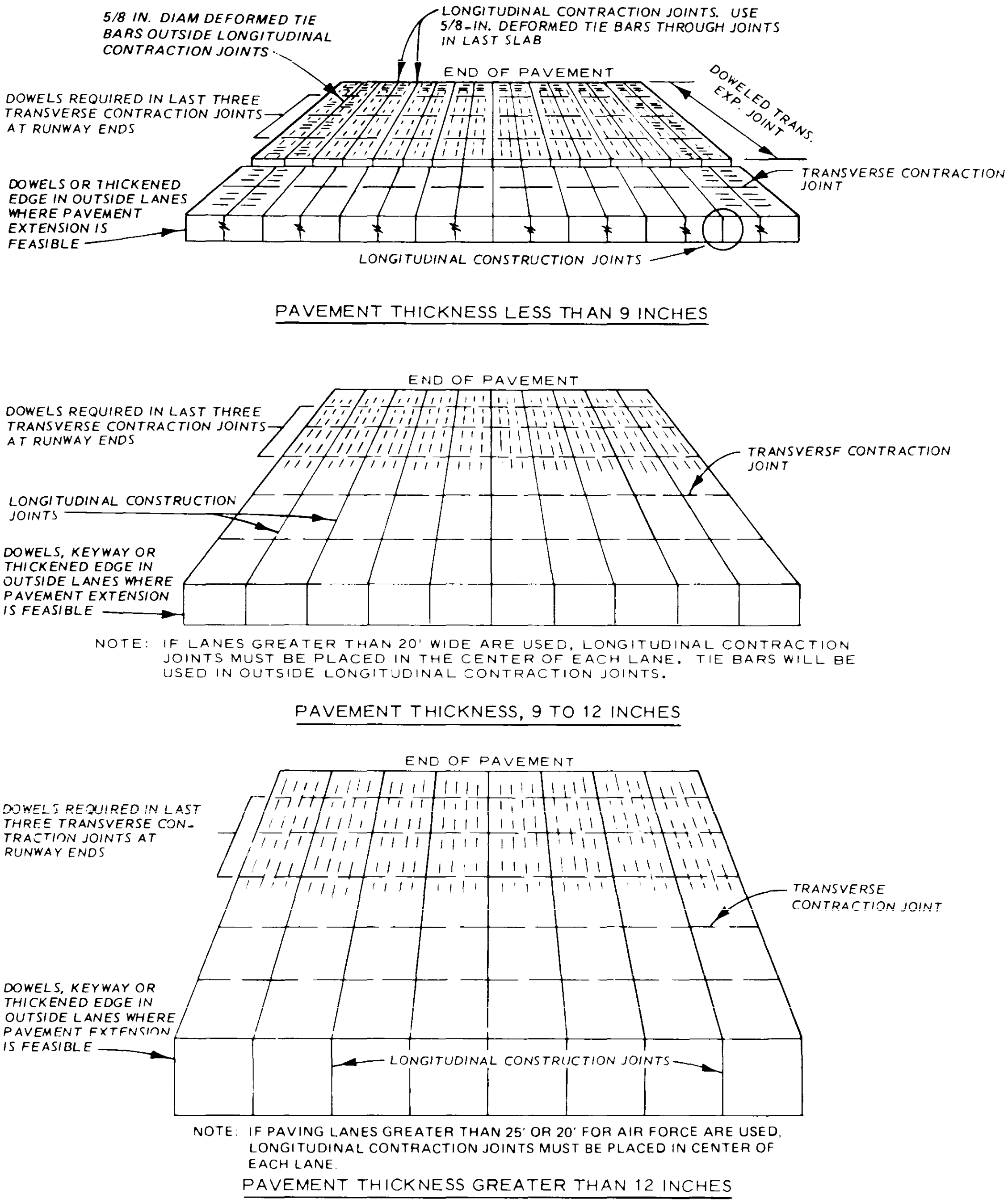


Figure 2-18. Typical jointing.

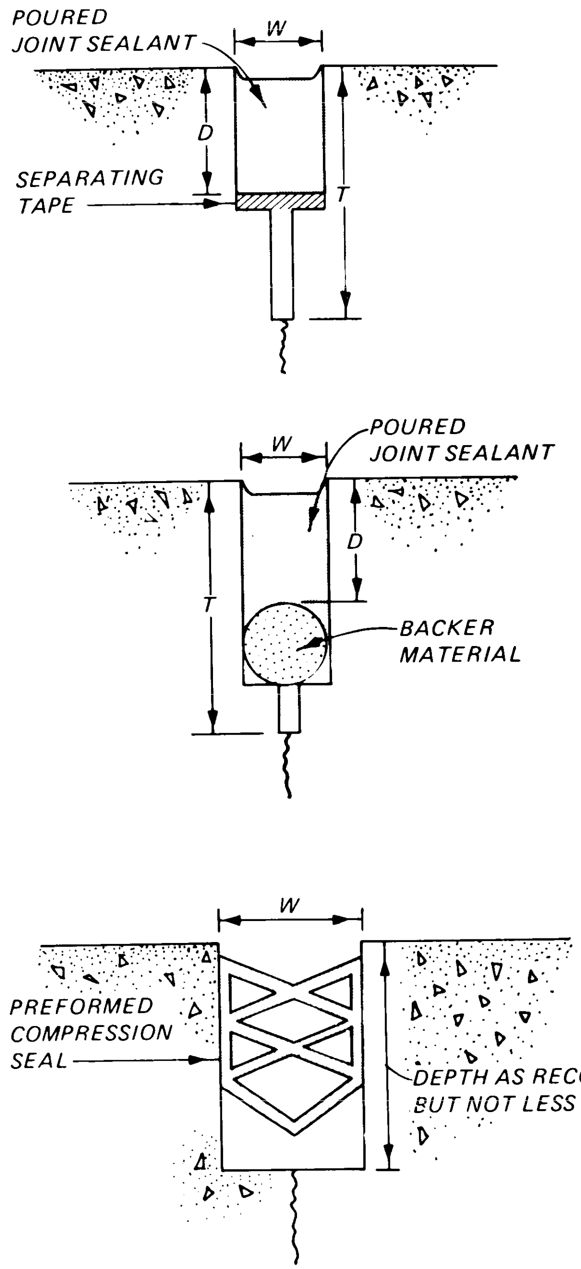
(b) The pavement thickness required for each aircraft is shown in column 4 as determined from appropriate design curves. (Figures 2-1, 2-3, 2-10, 2-11, and 2-12)

(c) Determine the allowable number of passes of each aircraft for the controlling thickness in column 4 (14.5 inches for the B-52). These allowable passes are determined from the aircraft respective design curve and listed in column 5. An example of this procedure is shown in figure 2-14.

(d) Divide the allowable number of passes (column 5) by the allowable number of passes for the B-52 (300). This gives the number of equivalent passes of each aircraft in terms of one pass of the B-52 and is shown in column 6. For example, one pass of the B-52 is equivalent to 40 passes of the C-141 at the design weights.

(e) Divide the number of design passes in column 3 by the number of equivalent passes in column 6 to determine the total number of equivalent B-52 passes for design. These values are shown in column 7.

(f) Determine the total number of equivalent B-52 passes by totaling the values in column 7. Enter the B-52 design curve (figure 2-12) with the total number of equivalent passes (556), the design load of 400 kips, R of 650 psi, k of 200 pci, and traffic area A to determine the final design thickness of 15.2 inches. This value will round off to 15.0 inches.



W = WIDTH OF SEALANT RESERVOIR (SEE TABLE)
D = DEPTH OF SEALANT; 1.0 TO 1.5 TIMES W
T = DEPTH OF INITIAL SAWCUT, 1/4 OF THE SLAB THICKNESS FOR PAVEMENT LESS THAN 12 IN.; 3 IN. FOR PAVEMENTS 12-18 IN.; OR 1/6 OF THE SLAB THICKNESS FOR PAVEMENTS OVER 18 IN.

TABLE

JOINT SPACING, FT	W, IN. MIN	W, IN. MAX
<25	1/2	5/8
25 TO 50	3/4	7/8
>50	1	1-1/8

NOTES: 1. SEPARATING TAPE OR BACKER MATERIAL REQUIRED TO PREVENT JOINT SEALANT FROM FLOWING INTO SAWCUT, TO SEPARATE NONCOMPATIBLE MATERIALS, AND TO PREVENT SEALANT FROM BONDING TO BOTTOM OF RESERVOIR.
2. TOP OF SEALANT WILL BE 1/8 IN. TO 1/4 IN. BELOW TOP OF PAVEMENT.
3. COMPRESSION SEAL MUST BE IN COMPRESSION AT ALL TIMES.

Figure 2-19. Joint sealant details for plain concrete pavements.

Pavement thickness, inches	Spacing, feet
Less than 9	12-1/2 to 15
9 to 12	15 to 20
Over 12*	20 to 25

* 20-foot maximum spacing for Air Force pavements.

Table 2-1. Recommended spacing of transverse contraction joints.

Pavement thickness inches	Maximum dowel length inches	Maximum dowel spacing inches	Dowel diameter and type
Less than 8	16	12	3/4-inch bar
8 - 11.5	16	12	1-inch bar
12 - 15.5	20	15	1- to 1-1/4-inch bar or 1-inch extra-strength pipe
16 - 20.5	20	18	1- to 1-1/2-inch bar or 1- to 2-1/2-inch extra-strength pipe
21 - 25.5	24	18	2-inch bar or 2-inch extra-strength pipe
Over 26	30	18	3-inch bar or 3-inch extra-strength pipe

Table 2-2. Dowel size and spacing for construction, contraction, and expansion joints.

FOUNDATION CONDITIONS \ TRAFFIC AREAS (B, C, D OVERRUNS AND SHOULDERS / A)	AIR FORCE AIRFIELD				ARMY AIRFIELDS	
	LIGHT LOAD	MEDIUM LOAD	HEAVY LOAD AND MODIFIED HEAVY LOAD	SHORTFIELD	CLASS I AND II	CLASS III
LOW STRENGTH K < 100 PCI	(hatched)	1	1	NA / 1	(hatched)	1
MEDIUM STRENGTH K OF 100 - 200 PCI	(hatched)	1, 2^a, 3^a, 4	1	NA / 1, 2^a, 3^a, 4	(hatched)	1, 2^a, 3^a, 4
HIGH STRENGTH K > 200 PCI	(hatched)	1, 2^a, 3^a, 4, 5^c	1, 2^a, 3^a, 4, 5^c	NA / 1, 2^a, 3^a, 4, 5^c	(hatched)	1, 2^a, 3^a, 4, 5^c
CHEMICALLY OR BITUMINOUS STABILIZED SOIL OR EXISTING FLEXIBLE PAVEMENT	(hatched)	1, 4, 5^c	1, 4, 5^c	NA / 1, 4, 5^c	(hatched)	1, 4, 5^c
EXISTING RIGID PAVEMENT	1, 4, 5 / 1, 4, 5	1, 4, 5 / 1	1, 4^b, 5^b / 1	NA / 1, 4, 5	1, 4, 5 / 1, 4, 5	1, 4, 5 / 1, 4, 5

TYPE CONSTRUCTION JOINT

1 DOWELED BUTT
2 THICKENED EDGE KEYED
3 THICKENED EDGE BUTT
4 KEYED WITH TIE BARS (LIMITED TO 75-FT PAVED WIDTH AND PAVEMENTS 9 IN. OR MORE IN THICKNESS)
5 KEYED (LIMITED TO PAVEMENTS 9 IN. OR MORE IN THICKNESS)
◁ TYPE 1,2,3,4, OR 5 JOINTS MAY BE USED

NOTE: a APPROVAL CONTINGENT UPON ADEQUATE BASE COURSE DRAINAGE
b TYPE D TRAFFIC AREAS, OVERRUNS, AND SHOULDERS ONLY
c USED ON OUTER LANES NOT SUBJECT TO CONCENTRATED MAIN GEAR TRAFFIC

Figure 2-20. Use of longitudinal construction joints.

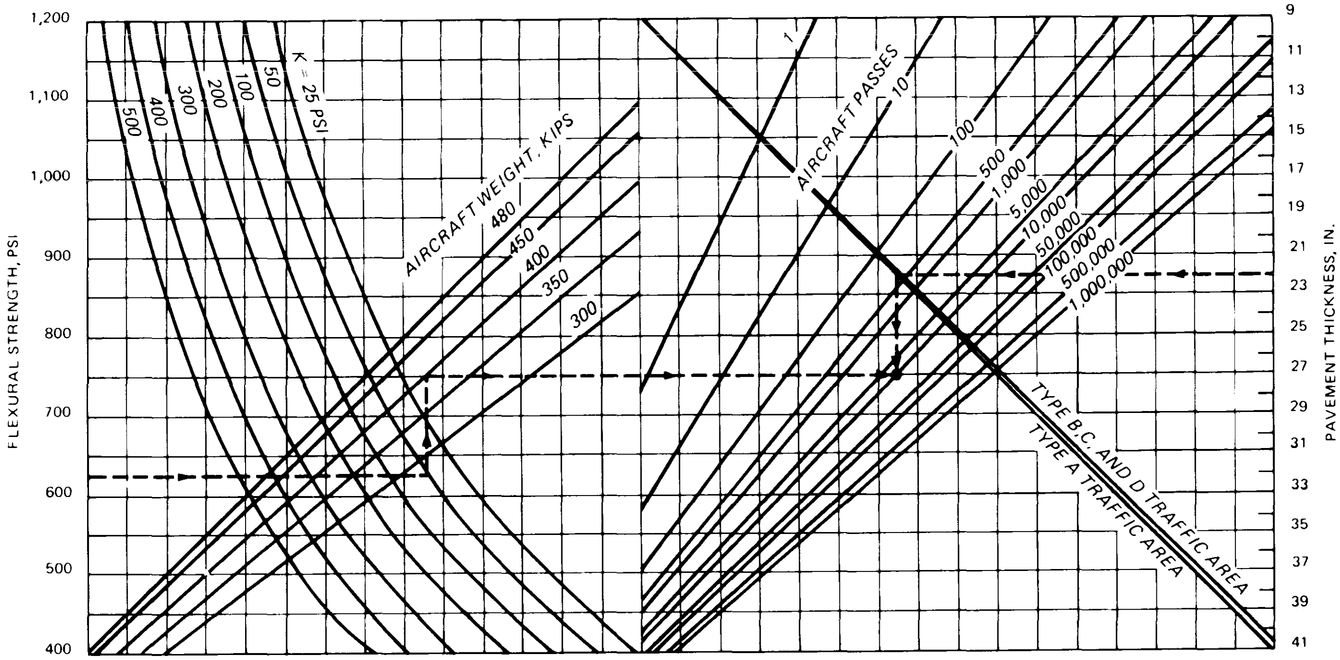


Figure 2-21. Example of allowable coverage determination.

Aircraft	Gross weight, kips	Aircraft passes	Preliminary thickness, in.	Allowable passes at 14.5 in.	Column 5 divided by 300	Column 3 divided by Column 6
B-52	400	300	14.5	300	1	300.0
C-141	345	10,000	14.3	12,000	40	250.0
C-130	155	5,000	9.3	1,000,000+	3,330	1.5
F-15	68	100,000	12.5	7,000,000	23,330	4.3
OV-1	18	1,000,000	6.4	Unlimited	--	--
					Total Passes on basis of B-52 aircraft	556

Table 2-3. Example of mixed traffic design

CHAPTER 3
REINFORCED CONCRETE PAVEMENT DESIGN

3-1. Basis of design

Steel reinforcement in the concrete provides improved continuity across the cracks that develop because of environmental factors or induced loads. The improved crack continuity results in better performance under traffic and less maintenance than an equal thickness of plain concrete pavement. Thus, for equal performance, the thickness of reinforced concrete pavement can be less than the thickness of plain concrete pavements. The design procedure presented herein yields the thickness of reinforced concrete pavement and the percentage of steel reinforcement required to provide the same performance as a predetermined thickness of plain concrete pavement constructed on the same foundation condition. The procedure has been developed from full-scale accelerated traffic testing. Failure is considered to be severe spalling of the concrete along the cracks that develop during traffic.

3-2. Uses

Reinforced concrete pavement may be used as slabs on grade or as overlay pavements for any traffic area of the airfield. Reinforcement may be used to reduce the required thickness and permit greater spacing between joints. Its selection should be based upon the economics involved. In certain instances, reinforcement will be required to control cracking that may occur in plain concrete pavements without any reduction in thickness requirements.

3-3. Reduced thickness design

a. General. The greatest use of reinforcement to reduce the required plain concrete pavement thickness will probably be to provide a uniform thickness for the various traffic areas and to meet surface grade requirements. This is especially true for rigid overlays where it is necessary to provide different thicknesses for the various types of traffic areas as different structural conditions of the base pavement. Since these changes in thickness cannot be made at the surface, reinforcement can be used to reduce the required thickness and thereby avoid the necessity for removal and replacement of pavements, or overdesigns. There are other instances in which reinforcement to reduce the pavement thickness may be warranted and must be considered, but the economic feasibility for the use of reinforcement must also be considered. The design procedure consists of determining the percentage of steel required, the thickness of the reinforced concrete pavement, and the maximum allowable length of slabs. In addition, the computer program discussed in chapter 9 may be used for the design of reinforced concrete pavement.

b. Determination of required percent steel and required thickness of reinforced concrete pavement. It is first necessary to determine the required thickness of plain concrete pavement using the design loading and physical properties of the pavement and foundation. When the reinforced concrete pavement is to be placed on stabilized or nonstabilized bases or subgrades, the procedure outline in chapter 2 will be used to determine the thickness of plain concrete. The thickness of plain concrete is then used to enter figure 3-1 to determine the required percent steel and the required thickness of reinforced concrete pavement. Since the thickness of reinforced concrete and percent steel are interrelated, it will be necessary to establish a desired value of one and determine the other. The resulting values of reinforced concrete thickness and percent steel will represent a reinforced concrete pavement that will provide the same performance as the required thickness of plain concrete pavement. In all cases, when the required thickness of plain concrete pavement is reduced by the addition of reinforcing steel, the design percentage of steel will be placed in each of two directions (transverse and longitudinal) in the slab. For construction purposes, the required thickness of reinforced concrete must be rounded to the nearest full- and half-inch increment. When the indicated thickness is midway between full- and half-inch, the thickness will be rounded upward.

c. Determination of maximum reinforced concrete pavement slab size. The maximum length or width of the reinforced concrete pavement slabs is dependent largely upon the resistance to movement of the slab on the underlying material and the yield strength of the reinforcing steel. The latter factor can be easily determined, but very little reliable information is available regarding the sliding resistance of concrete on the various foundation materials. For this design procedure, the sliding resistance has been assumed to be constant for a reinforced concrete pavement cast directly on the subgrade, on a stabilized or nonstabilized base course, or on an existing flexible pavement. The maximum allowable width, W, or length, L, of reinforced concrete pavement slabs will be determined from the following:

$$W \text{ or } L = 0.0777 \sqrt[3]{h_d(y_s S)^2} \qquad \text{(eq 3-1)}$$

where

h_d = design thickness of reinforced concrete

y_s = yield strength of reinforcing steel, normally 60,000 psi

S = percent reinforcing steel

The formula above has been expressed on the nomograph (figure 3-1) for a steel yield strength, y_s, of 60,000 psi, and the maximum length or width can be obtained from the intersection of a straight line drawn between the values of design thickness and percent steel that will be used for the reinforced concrete pavement. The width of reinforced concrete pavement will generally be controlled by the concrete paving equipment and will normally be 25 feet, unless smaller widths are necessary to meet dimensional requirements.

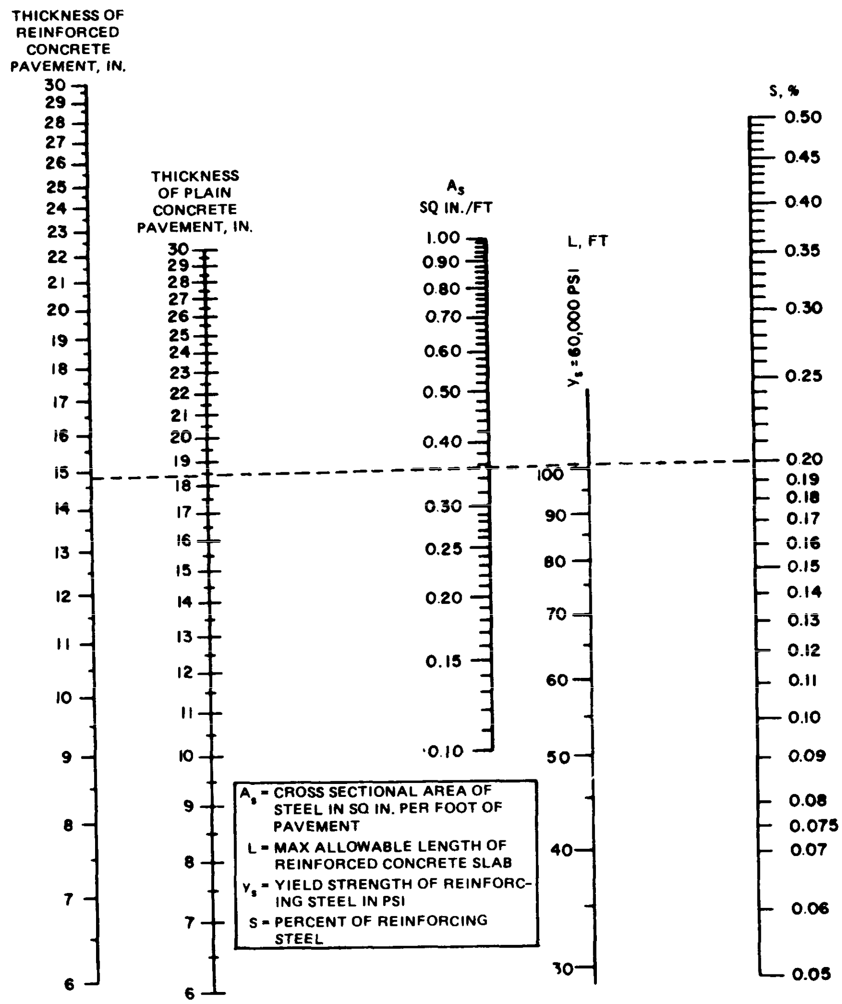


Figure 3-1. Reinforced concrete pavement design.

d. Limitations to reinforced concrete pavement design procedure. The design procedure for reinforced concrete pavements presented herein has been developed from a limited amount of investigational and performance data. Consequently, the following limitations are imposed:

(1) No reduction in the required thickness of plain concrete will be allowed for percentages of steel reinforcement less than 0.05.

(2) No further reduction in the required thickness of plain concrete pavement will be allowed over that indicated for 0.5 percent steel reinforcement in figure 3-1 regardless of the percent steel used.

(3) The maximum width or length of reinforced concrete pavement slabs will not exceed 100 feet regardless of the percent steel used or slab thickness.

(4) The minimum thickness of a reinforced concrete pavement or overlay will be 6 inches.

3-4. Reinforcement to control pavement cracking

a. General. Reinforcement is mandatory in certain pavement areas to control or minimize the effects of cracking. The reinforcing steel holds cracks tightly closed, thereby preventing spalling at the edges of the cracks and progression of the cracks into adjacent slabs. For each of the following conditions, the slabs or portions of the slabs will be reinforced with 0.05 percent steel in two directions normal to each other unless otherwise specified. No reduction in thickness will be allowed for this steel.

b. Odd-shaped slabs. It is often necessary in the design of pavement facilities to resort to odd-shaped slabs. Unless reinforced, these odd-shaped slabs often crack and eventually spall along the cracks, producing debris that is objectionable from operational and maintenance viewpoints. In addition, the cracks may migrate across joints into adjacent slabs. In general, a slab is considered to be odd-shaped if the longer dimension exceeds the shorter one by more than 25 or if the joint pattern does not result in essentially a square or rectangular slab. Figure 3-2 presents typical examples of odd-shaped slabs requiring reinforcement. Where practicable, the number of odd-shaped slabs can be minimized by using a sawtooth fillet and not reinforcing.

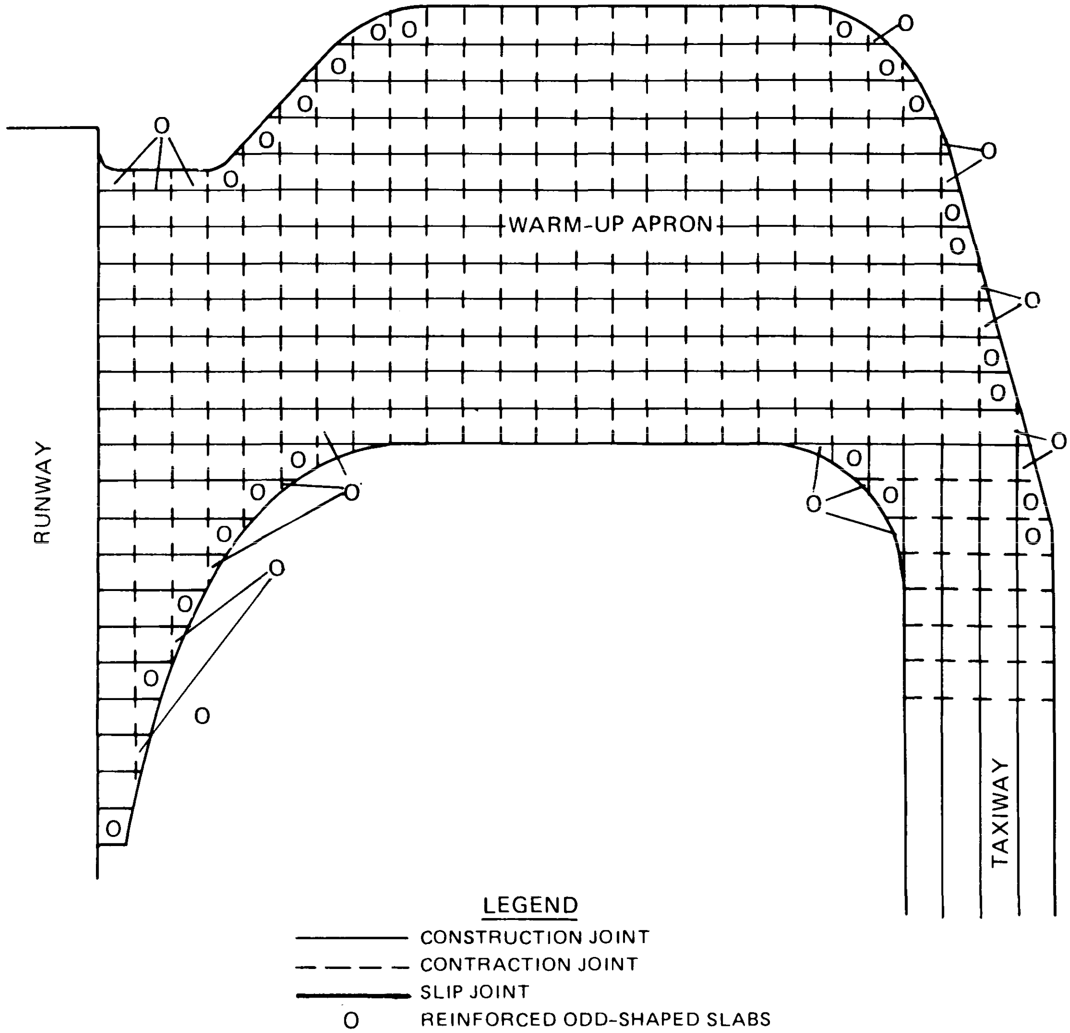


Figure 3-2. Typical layouts showing reinforcement of odd-shaped slabs and mismatched joints. (Sheet 1 of 2)

c. Mismatched joints. Steel reinforcement in the slabs is mandatory to prevent migration of cracks into adjacent pavements for the following two conditions of mismatched joints:

(1) Where joint patterns of abutting pavement facilities do not match, partial reinforcement of slabs may be necessary. In such a condition, the mismatch of joints can cause a crack to form in the adjacent pavement unless there is sufficient width of bond-breaking medium installed in the joint. The determination relative to using reinforcement at mismatched joints in such junctures is based upon the type of joint between the two pavement sections. A partial reinforcement of the slab, as described below, is required when the joint between the abutting pavement is one of the following: (a) doweled construction joint, (b) keyed construction joint, (c) thickened-edge butt joint without a bond-breaking medium, (d) doweled expansion joint, and (e) thickened-edge slip joint with less than ¼-inch bond-breaking medium. Reinforcement is not required if the joint between the abutting pavement facilities is either a thickened-edge expansion joint or a thickened-edge slip joint with ¼ inch or more of bond-breaking medium, except for a mismatch of joints in the center 75-foot width of runway where reinforcement of the slabs of mismatched joints will be required regardless of the type of joint between the facilities. When reinforcement at mismatched joints is required, the slab in the pavement facility directly opposite the mismatched joint will be reinforced with the minimum 0.05 percent steel. The reinforcing steel will be placed in two rectangular directions for a distance 3 feet back from the juncture and for the full width or length of the slab in a direction normal to the mismatched joint. When a new pavement is being constructed abutting an existing pavement, the new slabs opposite mismatched joints will be reinforced in the manner described above. When two abutting facilities are being constructed concurrently, the slabs on both sides of the juncture opposite mismatched joints will be reinforced in the manner described above. For this condition shown in figure 3-2 the slip joint bond-breaking medium can be specified to be a full ¼ inch thick, and the reinforcing may be omitted.

(2) The second condition of mismatched joints where reinforcement is required occurs in the construction of a plain concrete overlay on an existing rigid pave-

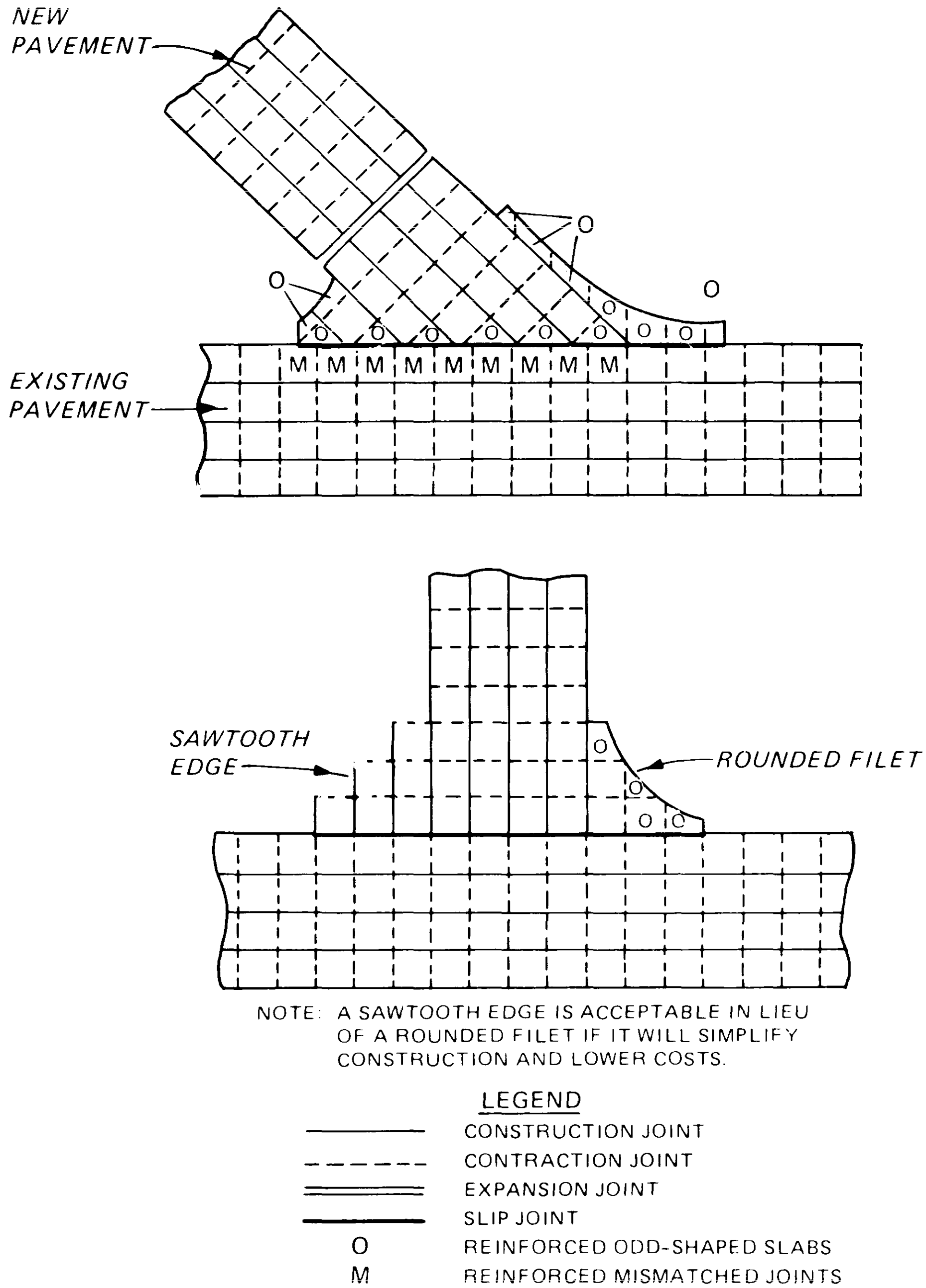


Figure 3-2. Typical layouts showing reinforcement of odd-shaped slabs and mismatched joints. (Sheet 2 of 2)

ment. Joints in the overlay should coincide with joints in the base pavement. Sometimes this is impracticable due to an unusual jointing pattern in the existing pavement. When necessary to mismatch the joints in the overlay and the existing pavement, the overlay pavement will be reinforced with the minimum 0.05 percent steel. The steel will be placed in two rectangular directions for a distance of at least 3 feet on each side of the mismatched joint in the existing pavement. The steel will, however, not be carried through any joint in the overlay except as permitted or required by paragraph 3-7. If the joint pattern in the existing pavement is highly irregular or runs at an angle to the desired pattern in the overlay, the entire overlay will be reinforced in both the longitudinal and transverse directions. When a bond-breaker course is placed between the existing pavement and overlay, reinforcement of the overlay over mismatched joints is not required, except for mismatched expansion joints.

d. Reinforcement of pavements incorporating heating pipes. Plain concrete pavements, such as hangar floors that incorporate radiant heating systems within the concrete, are subject to extreme temperature changes. These temperature changes cause thermal gradients in the concrete that result in stresses of sufficient magnitude to cause surface cracking. To control such cracking, these pavement slabs will be reinforced with the minimum 0.05 percent steel placed in the transverse and longitudinal directions.

e. Reinforcement of slabs containing utility blockouts. The minimum 0.05 percent steel reinforcement is required in plain concrete pavement slabs containing utility blockouts, such as for hydrant refueling outlets,

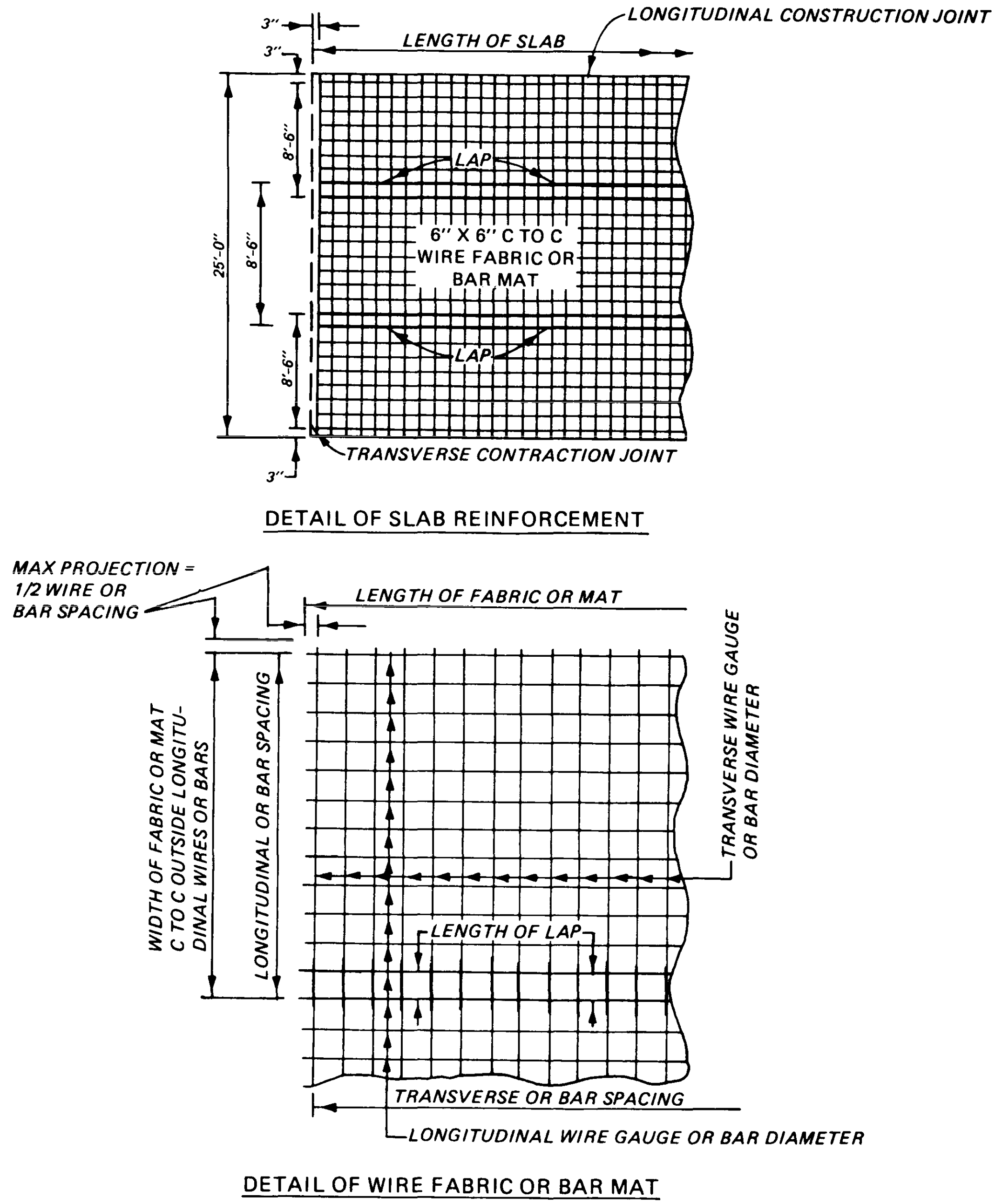


Figure 3-3. Reinforcing steel details. (Sheet 1 of 2)

storm drain inlets, and certain types of flush lighting fixtures. The entire slab or slabs containing the blockouts will be reinforced in two rectangular directions.

3-5. Reinforced concrete pavements in frost areas

Normally, plain concrete pavements in frost areas will be designed in accordance with TM 5-818-2/AFM 88-6, Chap. 4, and reinforcement will be unnecessary. There may, however, be special instances when it will be directed that the pavement thickness be less than required by frost design criteria. Two such instances are: the design of new pavements to the strength of existing pavement when the existing pavement does not meet the frost design requirements, and the design of an inlay section of adequate strength pavement in the center portion of an existing runway when the existing pavement does not meet the frost design requirements. In such instances, the new pavements will be reinforced with a minimum of 0.15 percent steel. The minimum 0.15 percent steel will be placed in each of two directions (transverse and longitudinal) in the slab. The reinforcing steel is required primarily to control cracking that may develop because of differential heaving. The pavement thickness may be reduced, and the maximum slab length, consistent with the percent steel, may be used. Longer slabs will help reduce roughness that may result from frost action. Greater percentages of steel reinforcement may be used when it is desired to reduce the pavement thickness more than is allowable for the required minimum percentage of steel.

3-6. Reinforcing steel

a. Type of reinforcing steel. The reinforcing steel may be either deformed bars or welded wire fabric. Deformed bars should conform to the requirements of ASTM A 615, A 616, or A 617. In general, grade 60 deformed bars should be specified, but other grades may be used if warranted. Fabricated steel bar mats should conform to ASTM A 184. Cold drawn wire for fabric reinforcement should conform to the requirements of ASTM A 82, and welded steel wire fabric to ASTM A 185.

b. Placement of reinforcing steel. The reinforcing steel will be placed at a depth of $\frac{1}{4}h_d$ + 1 inch from the surface of the reinforced slab. This will place the steel above the neutral axis of the slab and will allow clearance for dowel bars. The wire or bar sizes and spacing should be selected to give, as nearly as possible, the required percentage of steel per foot of pavement width or length. In no case should the percent steel used be less than that required by figure 3-1. Two layers of wire fabric or bar mat, one placed directly on top of the other, may be used to obtain the required percent of steel; however, this should only be done when it is impracticable to provide the required steel in one layer. If two layers of steel are used, the layers must be fastened together (either wired or clipped) to prevent excessive separation during concrete placement. When the reinforcement is installed and concrete is to be placed through the mat or fabric, the minimum clear spacing between bars or wires will be 1-½ times the maximum size of aggregate. If the strike-off method is used to place the reinforcement (layer of concrete placed and struck off at the desired depth, the reinforcement placed on the plastic conrete, and the remaining concrete placed on top of the reinforcement), the minimum spacing of wires or bars will not be less than the maximum size of aggregate. Maximum bar or wire spacing shall not exceed 12 inches of the slab thickness. Figure 3-3 shows the typical details of slab reinforcement with wire fabric or bar mats. The bar mat or wire fabric will be securely anchored to prevent forward creep of the steel mats during concrete placement and finishing operations. The reinforcement shall be fabricated and placed in such a manner that the spacing between the longitudinal wire or bar and the longitudinal joint, or between the transverse wire or bar and the transverse joint, will not exceed 3 inches or one-half of the wire or bar spacing in the fabric or mat (figure 3-3). The wires or bars will be lapped as follows.

(1) Deformed steel bars will be overlapped for a distance of at least 24 bar diameters, measured from the tip of one bar to the tip of the other bar. The lapped bars will be wired or otherwise securely fastened to prevent separation during concrete placement.

(2) Wire fabric will be overlapped for a distance equal to at least one spacing of the wire in the fabric or 32 wire diameters, whichever is greater. The length of lap is measured from the tip of one wire to the tip of the other wire normal to the lap. The wires in the lap will be wired or otherwise securely fastened to prevent separation during concrete placement.

3-7. Jointing

a. Requirements. Figures 3-4 through 3-6 present details of joints in reinforced concrete pavements. Joint requirements and types will be the same as for plain concrete except for the following:

(1) All joints, with the exception of thickened-edge-type joints and transverse construction joints, falling at a point other than at a regularly scheduled transverse contraction joint, will be doweled. One end of the dowel will be painted and oiled to permit movement at the joint.

(2) Thickened-edge-type joints (expansion, butt, or slip) will not be doweled. The edge will be thickened to $1.25h_d$.

(3) When a transverse construction joint is required within a reinforced slab unit, the reinforcing steel will be carried through the joint. In addition, dowels meeting the size and spacing requirements of table 2-2 for the design thickness, h_d will be used in the joint.

(4) Deleted.

b. Joint sealing. Joint sealing for reinforced concrete pavements will be the same as for plain concrete pavements.

3-8. Examples of reinforced concrete pavement design

a. A reinforced concrete pavement is to be used for a heavy-load airfield. Field and laboratory test programs have yielded design values of 700 psi for the concrete flexural strength, R, and 200 pci for the modulus of soil reaction, k, for the foundation.

b. Assuming that stabilization will not be used, it is first necessary to determine the required thicknesses of plain concrete pavement. By entering figure 2-6 with the design values of R and k, the required thicknesses of plain concrete are as shown in column 2 of table 3-1. At this point, it is necessary to decide whether to preselect the percentage of reinforcing steel and determine the required thickness of reinforced pavement, or to select a thickness of reinforced concrete and determine the percent steel. First, let it be assumed that S = 0.20 percent will be used and that it is desired to determine the required thickness. Figure 3-1 is entered with S = 0.20 percent and the thickness of plain concrete for each traffic area, and values of reinforced concrete pavement thickness determined as shown in column 3 of table 3-1. These thicknesses are rounded to the nearest ½-inch increment for construction (column 4). After the thicknesses are rounded, it is then necessary to reenter figure 3-1 to determine the percent steel commensurate with the rounded thickness values (column 5). Next, let it be assumed that type A, B, and C traffic areas are to be constructed to the same thickness (16 inched) of reinforced concrete pavement, and type D traffic areas are to be 9 inches. Figure 3-1 is entered with the thickness of plain concrete and selected values of reinforced concrete thickness to determine the required percent steel (column 7). The maximum length or width of a reinforced concrete pavement slab is a function of the yield strength of the steel, thickness of the slab, and percent steel and can be determined either from figure 3-1 or by the equation in paragraph 3-3c. Columns 6 and 8 of table 3-1 present the maximum allowable lengths or widths for the examples using a steel with a yield strength of 60,000 psi.

c. *Assume that a 6-inch lean concrete base course will be used.* The compressive strength of the lean concrete is 3,000 psi, and the flexural modulus of elasticity is 2×10^6 psi. As with the previous example, the required thicknesses of plain concrete pavement on both the nonstabilized and on the lean concrete base are determined and are shown in columns 2 and 3 of table 3-2. A value may then be selected for the required thickness of reinforced concrete or the percentage of reinforcing steel and determine the other using figure 3-1. If a percent steel value of 0.20 is selected, the values of reinforced concrete from figure 3-1 would be shown in column 4 of table 3-2. These values rounded for construction are listed in column 5. Then, reenter figure 3-1 with the rounded values of reinforced concrete to obtain the required percent steel shown in column 6. The allowable slab lengths are determined from the equation in paragraph 3-3c or figure 3-1 using a reinforcing steel with a yield strength of 60,000 psi (column 7). If a reinforced concrete thickness of 14 inches is selected for the type A, B, and C traffic areas and a thickness of 7.5 inches is selected for the type D traffic area, then the required percent steel determined from figure 3-1 would be as shown in column 8. Column 9 presents the allowable lengths or widths of slab for the reinforced concrete pavement.

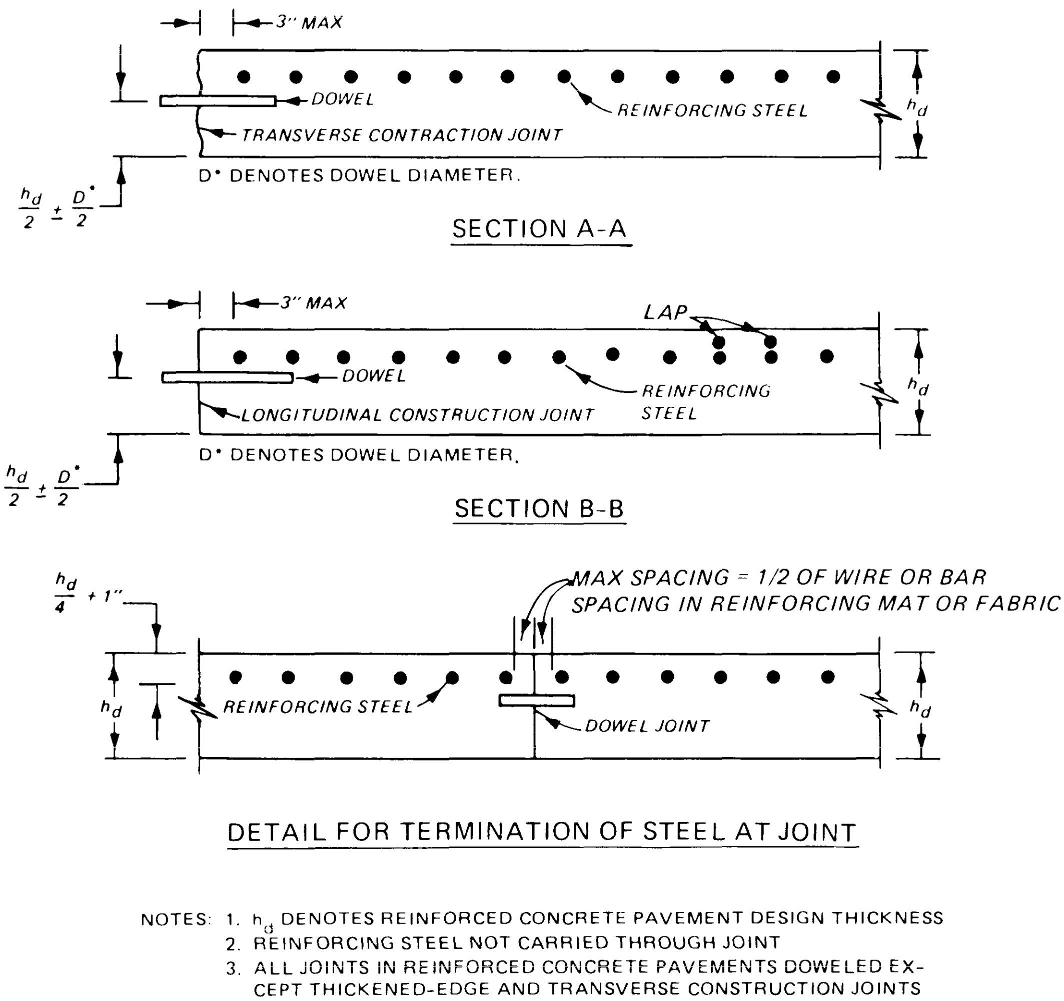


Figure 3-3. Reinforcing steel details. (Sheet 2 of 2)

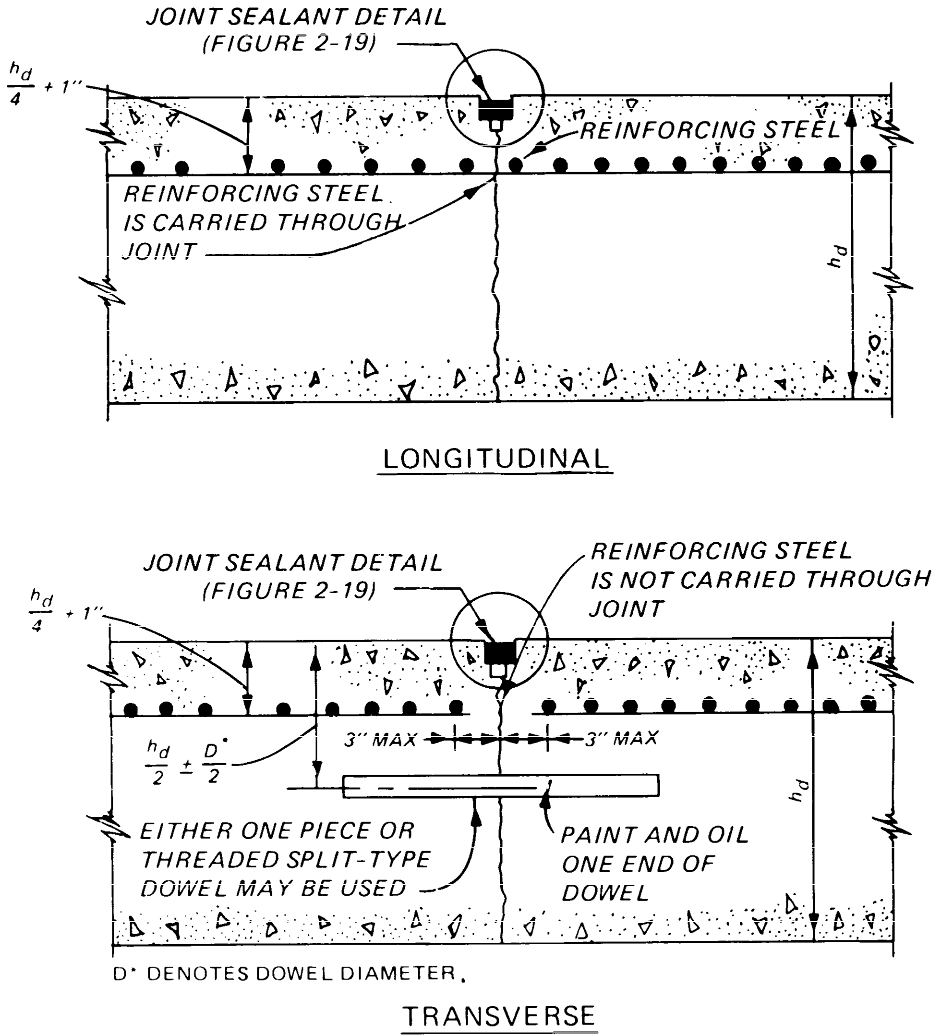
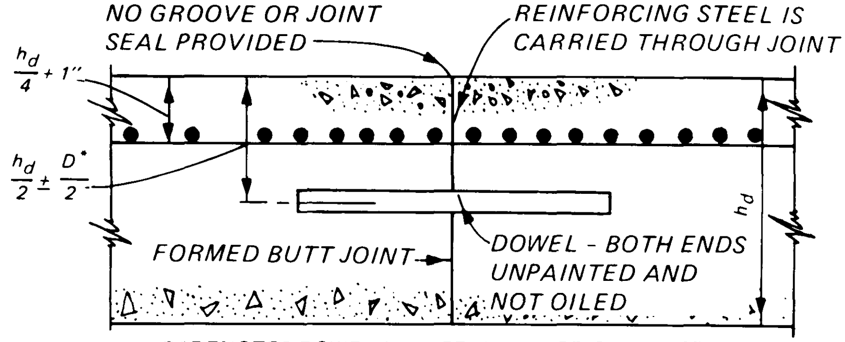


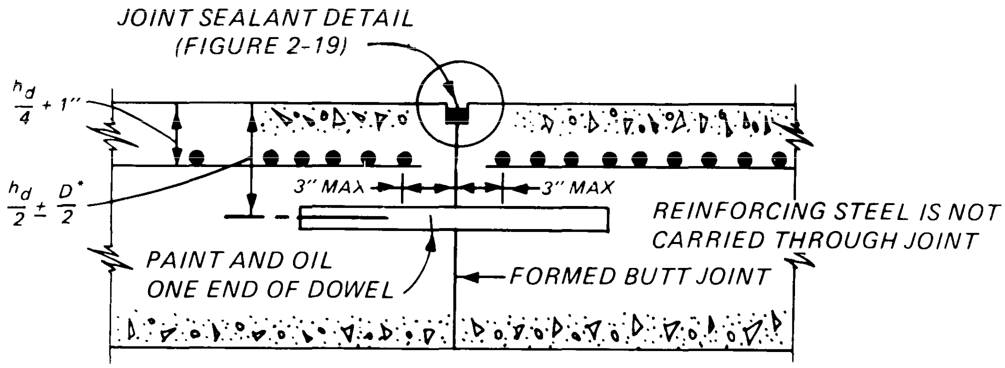
Figure 3-4. Contraction joints for reinforced concrete pavements.



D* DENOTES DOWEL DIAMETER. EITHER ONE PIECE OR THREADED SPLIT-TYPE DOWELS MAY BE USED.

NOTE: THIS DETAIL WILL BE USED ONLY WHEN A TRANSVERSE CONSTRUCTION JOINT IS REQUIRED AT A LOCATION OTHER THAN A REGULARLY SCHEDULED TRANSVERSE CONTRACTION JOINT.

DOWELED TRANSVERSE

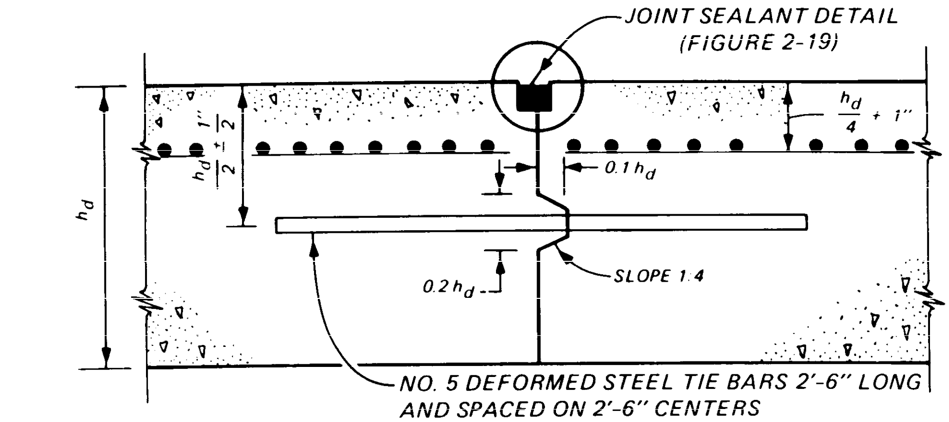


D* DENOTES DOWEL DIAMETER. EITHER ONE PIECE OR THREADED SPLIT-TYPE DOWELS MAY BE USED.

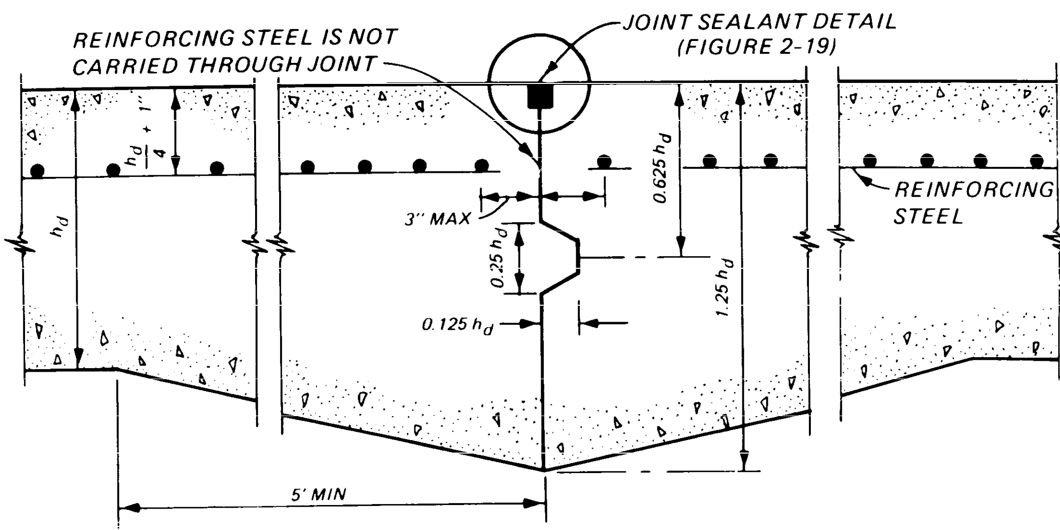
NOTE: THIS DETAIL WILL BE USED WHEN A TRANSVERSE CONSTRUCTION JOINT IS REQUIRED AT A REGULARLY SCHEDULED TRANSVERSE CONTRACTION JOINTS.

DOWELED TRANSVERSE OR LONGITUDINAL

Figure 3-5. Construction joints for reinforced concrete pavements. (Sheet 1 of 4)



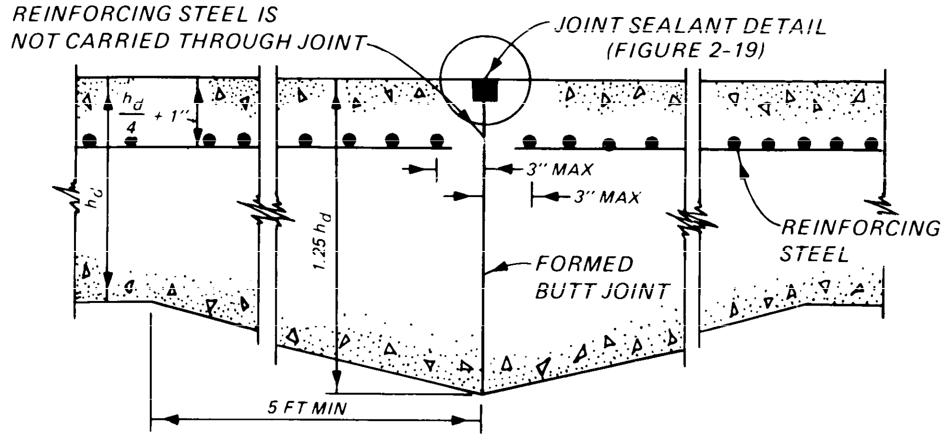
KEYED AND TIED LONGITUDINAL



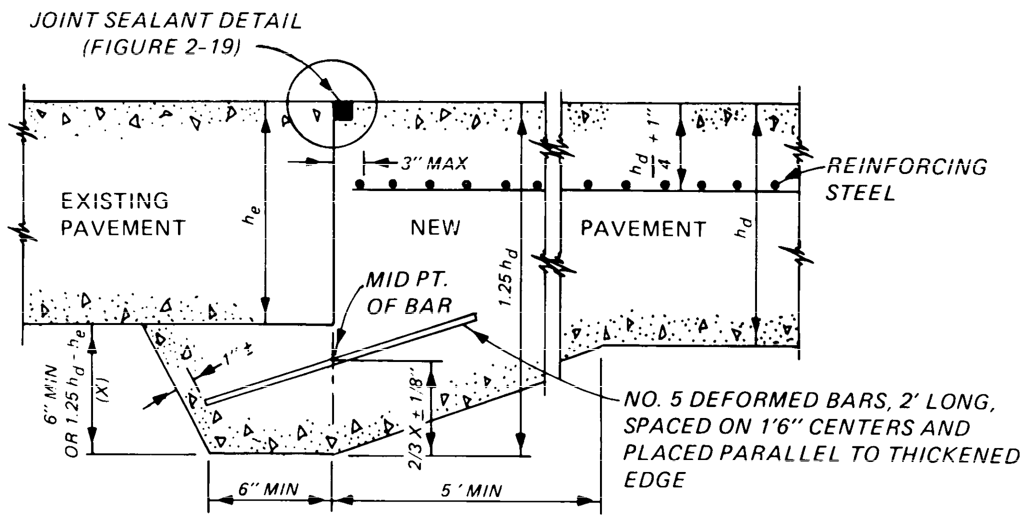
NOTE: A TOLERANCE OF ±1/16 INCH MAY BE ALLOWED
FOR KEY DIMENSIONS AND LOCATION

KEYED THICKENED EDGE LONGITUDINAL

Figure 3-5. Construction joints for reinforced concrete pavements. (Sheet 2 of 4)

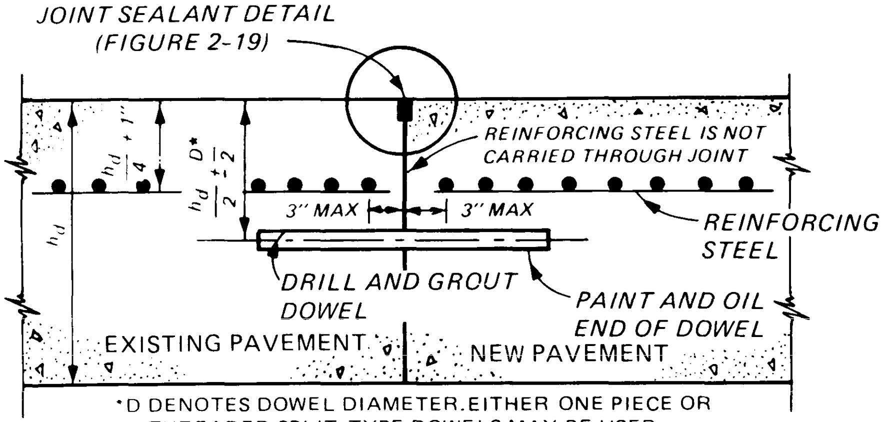


THICKENED EDGE LONGITUDINAL



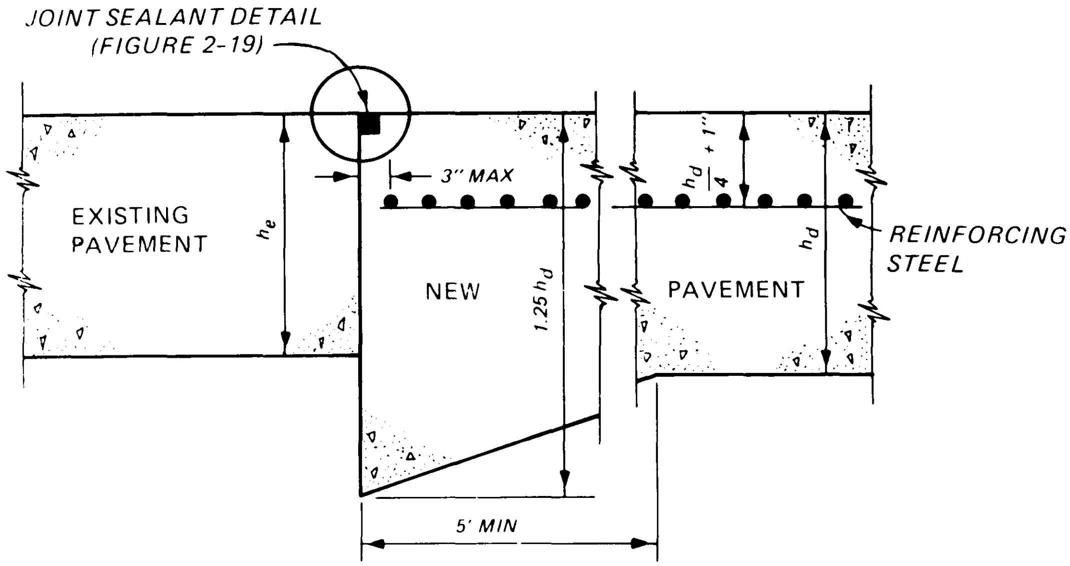
SPECIAL JOINT BETWEEN NEW
AND EXISTING PAVEMENTS

Figure 3-5. Construction joints for reinforced concrete pavements. (Sheet 3 of 4)



*D DENOTES DOWEL DIAMETER. EITHER ONE PIECE OR THREADED SPLIT-TYPE DOWELS MAY BE USED.

DOWELED JOINT BETWEEN NEW AND EXISTING PAVEMENT



NOTE: THIS TYPE JOINT SHOULD BE USED ONLY WHEN EXISTING PAVEMENT IS TO BE REPLACED IN A SHORT PERIOD OF TIME, SINCE WITHOUT LOAD TRANSFER, IT WILL DETERIORATE QUICKLY.

THICKENED EDGE JOINT BETWEEN NEW AND EXISTING PAVEMENTS

Figure 3-5. Construction joints for reinforced concrete pavements. (Sheet 4 of 4)

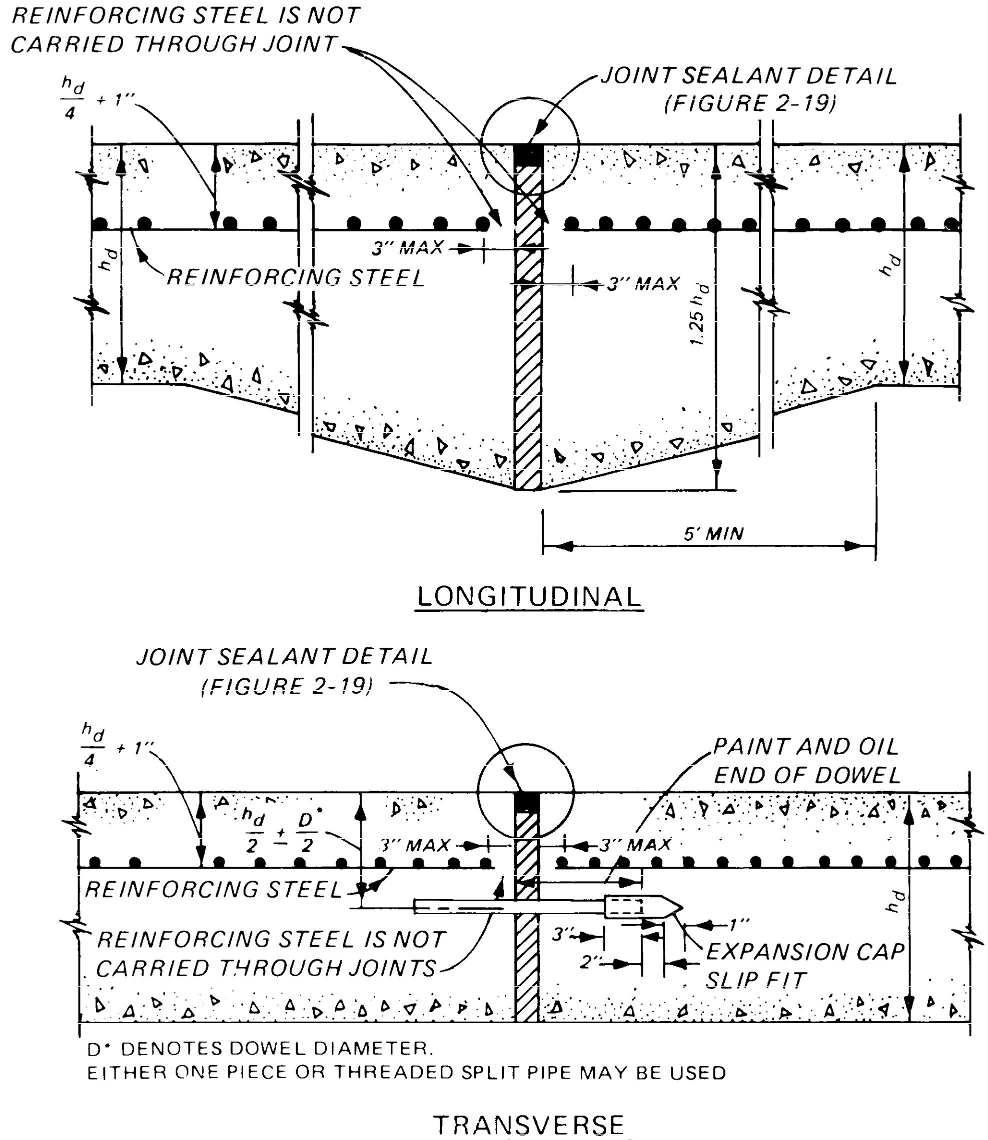


Figure 3-6. Expansion joints for reinforced concrete pavements.

Traffic area (1)	Thickness of plain concrete inches (2)	Initial thickness of reinforced concrete, in. (3)	Design thickness of reinforced concrete, in. (4)	Percent steel (5)	Length or width of slab, ft (6)	Percent steel (7)	Length or width of slab, ft (8)
	Design example preselecting percent steel					Design example preselecting thickness of reinforced concrete	
A	22.4	18.0	18.0	0.195	100*	0.297	100*
B	22.2	17.8	18.0	0.180	100*	0.270	100*
C	18.0	14.5	14.5	0.192	97	0.068	51
D	13.6	10.9	11.0	0.188	87	0.365	100*

*Maximum length or width allowed.

Table 3-1. Reinforced concrete pavement design example

Traffic area (1)	Thickness of plain concrete, inches (2)	Plain concrete overlay thickness, in. (3)	Initial reinforced concrete overlay thickness, in. (4)	Design thickness of reinforced concrete, in. (5)	Percent steel (6)	Length or width of slab, ft (7)	Percent steel (8)	Length or width of slab, ft (9)
	Design example preselecting percent steel						Design example preselecting thickness of reinforced concrete	
A	22.4	20.5	16.5	16.5	0.195	100*	0.390	100*
B	22.2	20.3	16.3	16.5	0.180	97	0.354	100*
C	18.0	16.0	12.9	13.0	0.187	92	0.068	49
D	13.6	11.3	9.1	9.0	0.190	83	0.101	56

*Maximum length or width allowed.

Table 3-2. Reinforced concrete pavement design example on a lean concrete base course

CHAPTER 4
FIBROUS CONCRETE PAVEMENT DESIGN

4-1. Basis of design

The design of fibrous concrete pavement is based upon limiting the ratio of the concrete flexural strength and the maximum tensile stress at the joint, with the load either parallel or normal to the edge of the slab, to a value found to give satisfactory performance in full-scale accelerated test tracks. Because of the fibrous concrete's increased flexural strength and the bridging of fibers across cracks that develop in the fibrous concrete, the thickness can be significantly reduced; however, this results in a more flexible structure, which causes an increase in vertical deflections and potential for densification and/or shear failures in the foundation, pumping of the subgrade material, and joint deterioration. To protect against these latter factors, a limiting vertical deflection criterion has been applied to the thickness developed from the tensile stress criteria.

4-2. Uses

Although several types of fiber have been studied for concrete reinforcement, most of the experience has been with steel fibers, and the design criteria presented herein are limited to steel fibrous concrete. Fibrous concrete is a relatively new material for pavement construction and lacks a long-time performance history. Because of this, its use will require approval of the Commander, U.S. Army Corps of Engineers (DAEN-ECE-G), Washington, DC 20314-1000, or HQ Air Force Engineering and Services Center (AFESC/DEMP), Tyndall AFB, FL 32403-6001. The major uses to date have been for thin resurfacing or strengthening overlays where grade problems restrict the thickness of overlay that can be used. The use of fibrous concrete pavement should be based upon the economics involved.

4-3. Mix proportioning considerations

a. The design mix proportioning of fibrous concrete will be determined by a laboratory study. Typical mix proportions are shown on table 4-1. The following are offered as guides and to establish limits where necessary for the use of the design criteria included herein. Additional details may be found in TM 5-822-7/AFM 88-6, Chap. 8.

b. The criteria contained herein are based upon fibrous concrete containing 1 to 2 percent by volume (100 to 250 pounds) of steel fibers per cubic yard of concrete, and fiber contents within this range are recommended.

c. Most experience to date has been with fibers 1 to 1½ inches long, and for use of the criteria contained herein, fiber lengths within this range are recommended.

d. For proper mixing, the maximum aspect ratio (length to diameter or equivalent diameter) of the fibers should be about 100.

e. The large surface-area-to-volume ratio of the steel fibers requires an increase in the paste necessary to ensure that the fibers and aggregates are coated. To ac-

	3/8-in. Maximum Sized Aggregate	3/4-in. Maximum Sized Aggregate
Cement (lb/yd^3)	600-1,000	500-900
Water-cement ratio	0.35-0.45	0.40-0.50
Percent of fine to coarse aggregate	45-60	45-55
Entrained air content (percent)	4-7	4-6
Fiber content (volume percent)		
Deformed steel fiber	0.4-0.9	0.3-0.8
Smooth steel fiber	0.9-1.8	0.8-1.6

From ACI 544.1R-82, "State of the Art Report on Fibrous Reinforced Concrete," used with permission of the American Concrete Institute.

Table 4-1. Range of proportions for normal-weight fibrous concrete

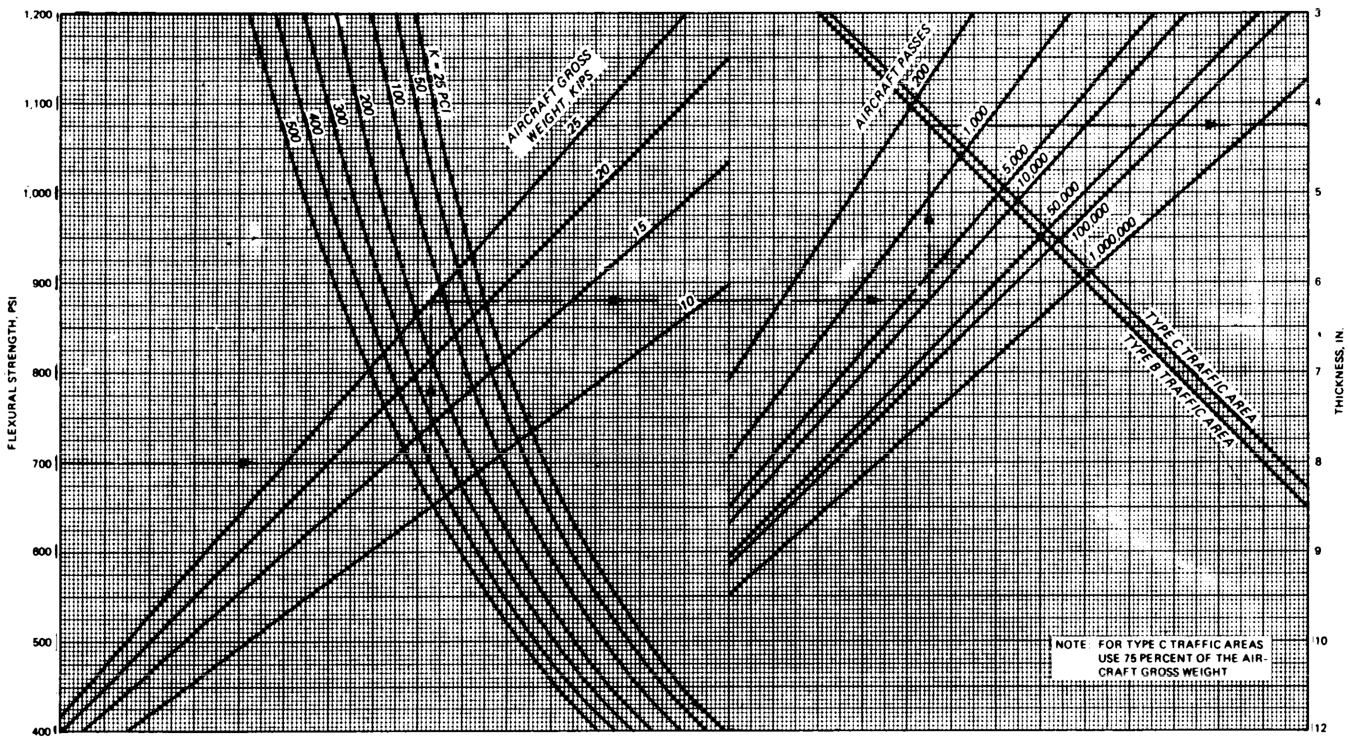


Figure 4-1. Fibrous concrete pavement design curves for Army Class I pavements.

complish this, cement contents of 750 to 900 pounds per cubic yard of concrete are common. The cement content may be all portland cement or a combination of portland cement and up to 25 percent by volume of fly ash or other pozzolans.

f. Maximum size coarse aggregates should fall between $\frac{3}{8}$ and $\frac{3}{4}$ inches. The percent of fine to coarse aggregate has been between 45 and 60 percent on typical projects using fibrous concrete.

4-4. Thickness determination

The required thickness of fibrous concrete will be a function of the design concrete flexural strength, the modulus of soil reaction, the thickness and flexural modulus of elasticity of stabilized material if used, the aircraft gross weight, the volume of traffic, the type of traffic area, and the allowable vertical deflection. When stabilized material is not used, the required thickness of fibrous concrete is determined directly from the appropriate chart (figures 4-1 through 4-9). If the base or subgrade is stabilized and meets the minimum strength requirements of TM 5-822-4/AFM 88-7, Chap. 4, the stabilized layer will be treated as a low-strength base and the design will be made using the overlay equation given in chapter 2 of this manual. The resulting thickness will be rounded up to the nearest half or full inch. The rounded thickness will then be checked for allowable deflection in accordance with paragraph 4-5. The minimum thickness for fibrous concrete pavements will be 4 inches.

4-5. Allowable deflection for fibrous concrete pavement

The elastic deflection that fibrous concrete pavements experience must be limited to prevent overstressing of the foundation material and thus premature failure of the pavement. Curves are provided (figures 4-10 through 4-18) for the determination of the vertical elastic deflection that a pavement will experience when loaded and must be checked for all design aircraft. Use of the curves requires three different inputs: slab thickness, subgrade modulus, and gross weight of the design aircraft. The modulus value to use for stabilized layers is determined from figure 1-2. The slab thickness is that which is determined from paragraph 4-4 above. The computed vertical elastic deflection is then compared with appropriate allowable deflections determined from figures 4-19 or 4-20 or, in the case of shoulder design, with an allowable deflection value of 0.06 inch. If the computed deflection is less than the allowable deflection, the thickness meets allowable deflection criteria and is acceptable. If the computed deflection is larger than the allowable deflection, the thickness must be increased or a new design initiated with a modified value for either concrete flexural strength or subgrade modulus. The process must be repeated until a thickness based upon the limiting stress criterion will also have a computed deflection equal to or less than the allowable value. Should the vertical deflection criteria indicate the need for a thickness increase greater than that required by the limiting stress criteria, the thickness increase should be limited to that thickness required for plain concrete with a flexural strength of 900 psi.

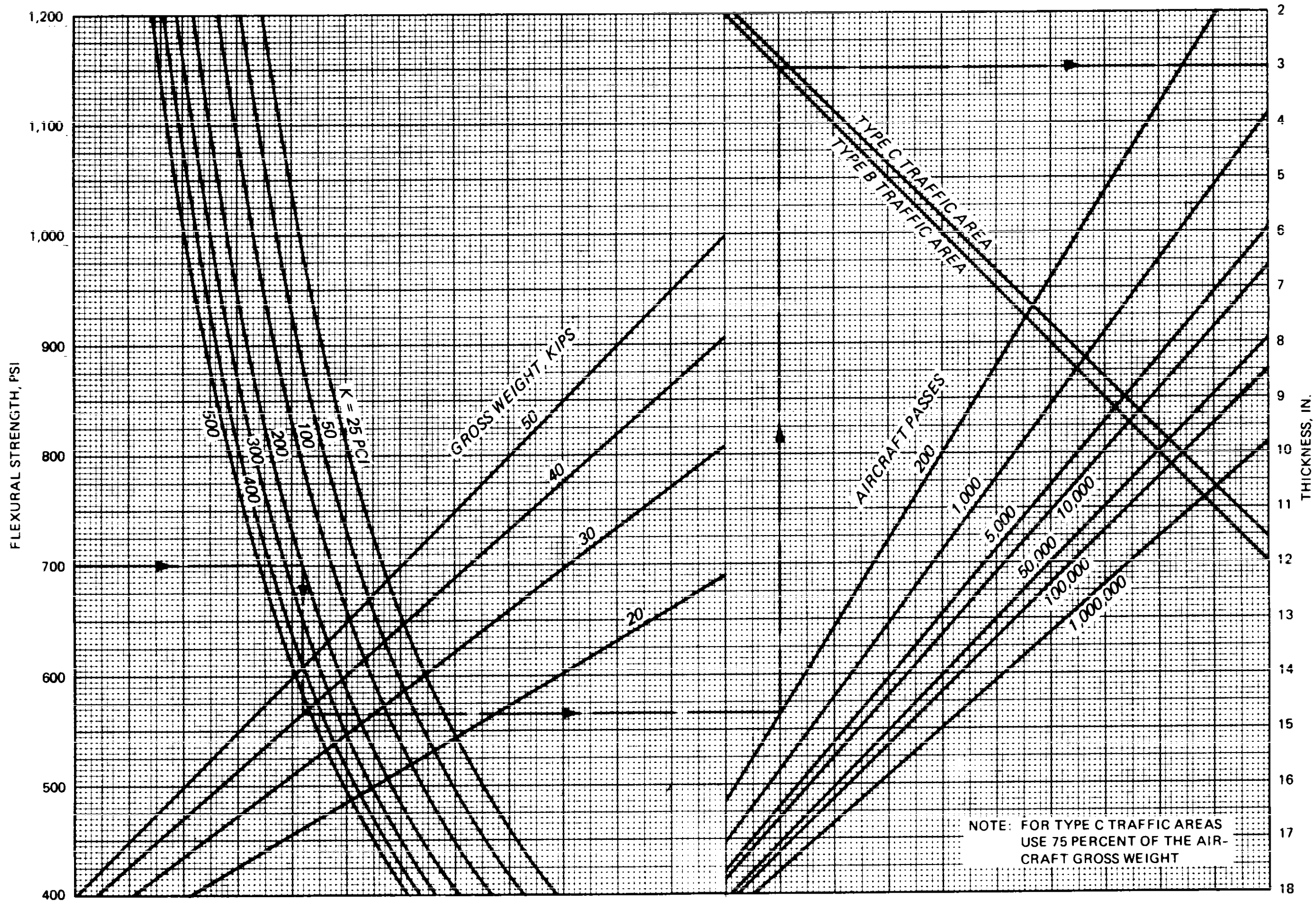


Figure 4-2. Fibrous concrete pavement design curves for Army Class II pavements.

4-6. Jointing

The jointing types and designs discussed in paragraph 2-4 generally apply to fibrous concrete pavement. For the mix proportionings discussed in paragraph 4-3, the maximum spacing of contraction joints will be the same as for plain concrete, except that for thicknesses of 4 to 6 inches, the maximum spacing will be 12½ feet. Joints in pavements 6 inches or greater in thickness will be cut ⅓ of the depth of the pavement and joints less than 6 inches will be cut ½ the depth of the pavement. Longitudinal construction joints may be either doweled, keyed, keyed and tied, or thickened-edge with a key, in which case the key dimensions will be based upon the thickened-edge thickness. The keyed and tied construction joint will be limited to a width of 100 feet. For widths greater than 100 feet, combinations of keyed and tied, doweled, or thickened-edge-type joints may be used. Sealing of joints in fibrous concrete will follow the criteria presented in paragraph 2-4g.

4-7. Example of fibrous concrete pavement design

a. General. A medium-load airfield is to be designed using fibrous concrete. Type A and B traffic areas are designed for the following conditions.

Traffic Area	*Aircraft*	*Gross Weight lb*	*Passes*
A and B	F-15	81,000	25,000
	C-141	345,000	100,000
	B-52	400,000	100
C	F-15	60,750	25,000
	C-141	258,750	100,000
	B-52	300,000	1
D	F-15	60,750	250
	C-141	258,750	1,000
	B-52	300,000	1

On-site and laboratory investigations have yielded the following data required for design: (a) subgrade material is a silty sand; (b) modulus of subgrade reaction is 200 pci; (c) an available source of crushed gravel meets the base course requirements; (d) frost does not enter subgrade; and (e) 90-day flexural strength is 1,000 psi with 0.15 percent steel fibers.

b. Example design—slab on grade. Figure 4-2 is entered with the subgrade k, concrete flexural strength, and the pavement thickness determined for the various traffic areas as follows:

Traffic Area	*Thickness inches*	*Computed Deflection inch*	*Allowable Deflection inch*
A	10.5	0.050	0.050
B	10.5	0.050	0.053
C	8.5	0.045	0.053
D	6.0	0.062	0.114

By entering 4–13, 4–14, and 4–15 with these thicknesses, the computed deflections for all aircraft may be determined and the controlling value is shown left. It should be noted that a comparison of the computed deflections with the allowable deflections from figure 4–20 reveals that the thicknesses determined by the allowable stress criterion are satisfactory since the allowable deflections are equal to or greater than the computed deflections for all traffic areas.

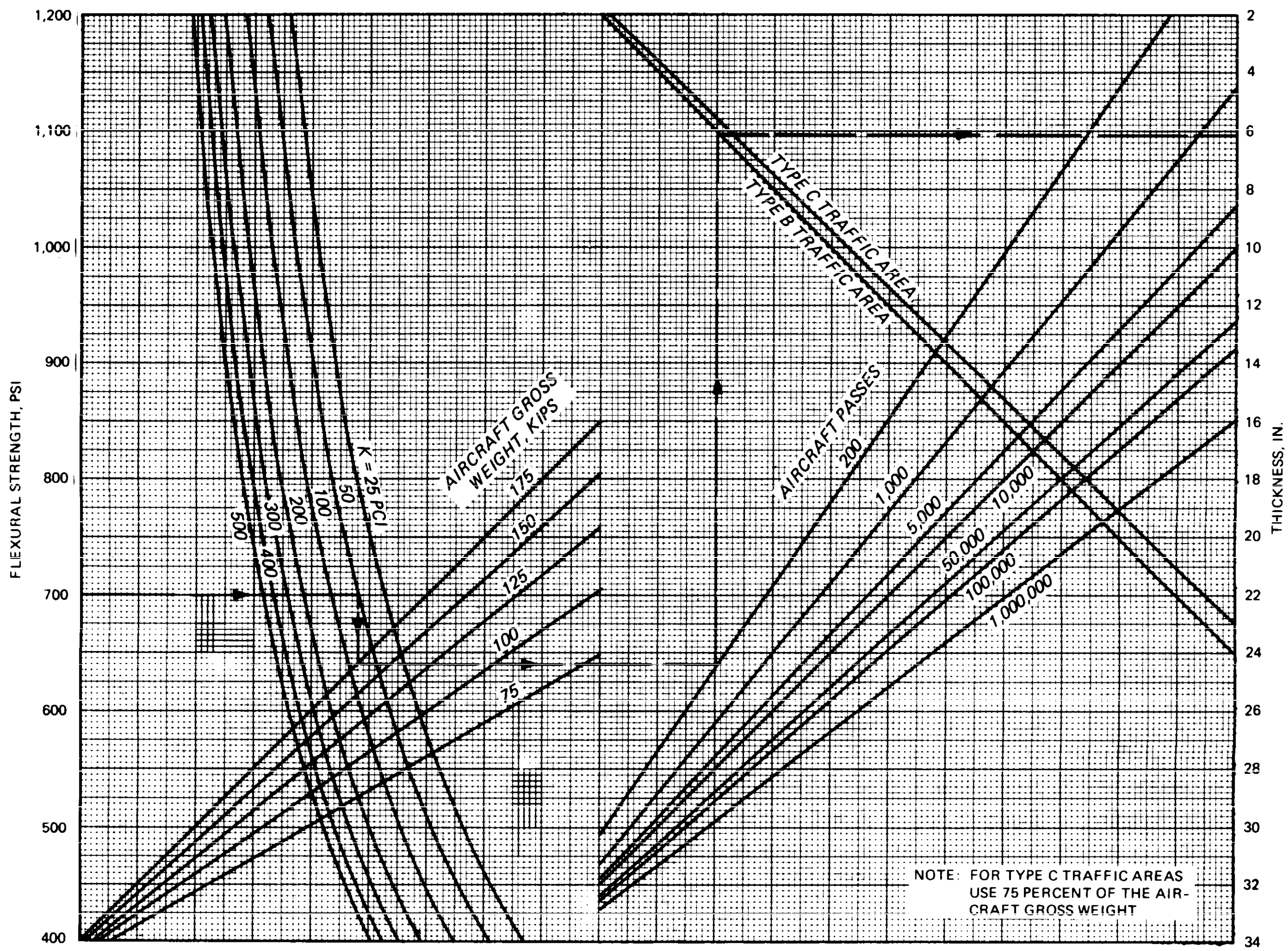


Figure 4-3. Fibrous concrete pavement design curves for Army Class III pavements.

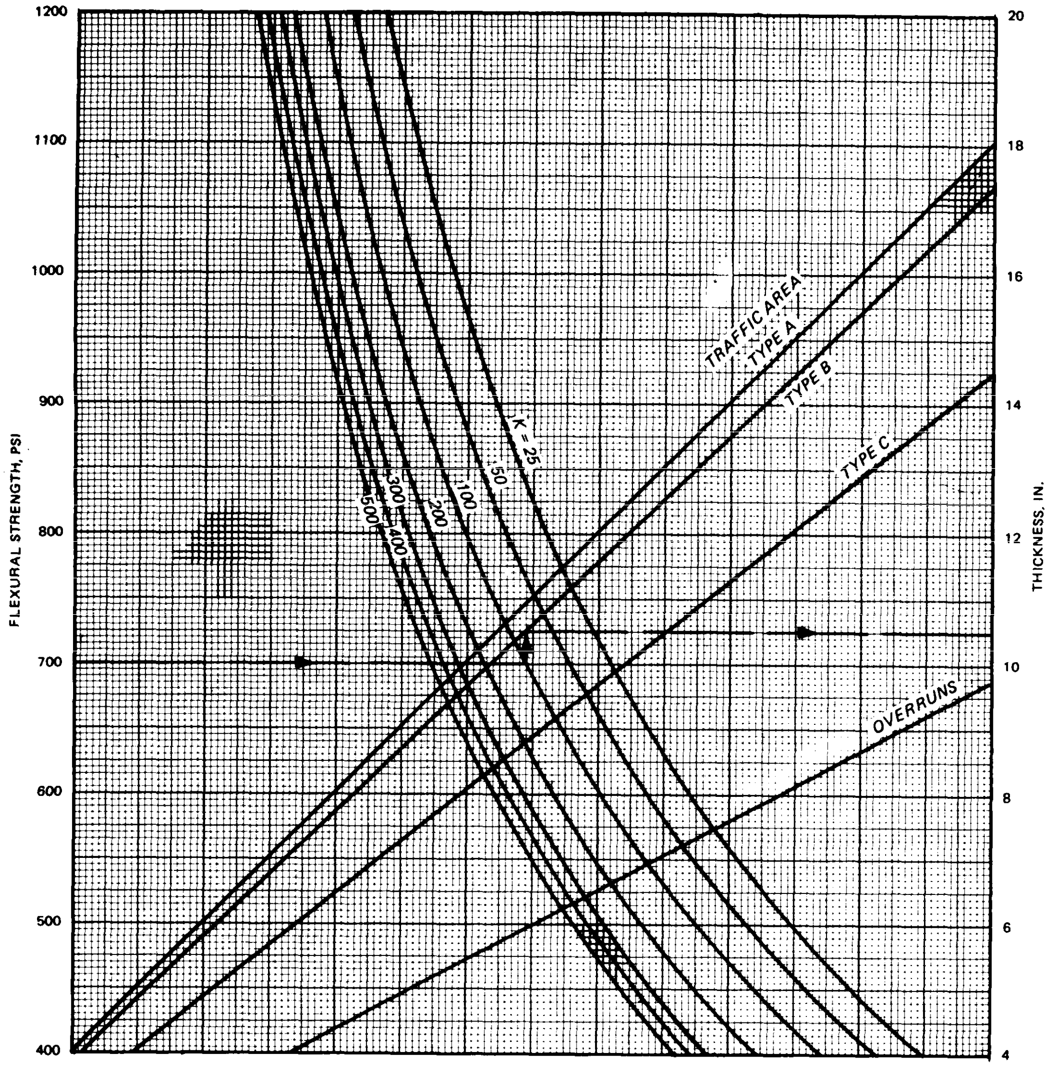


Figure 4-4. Fibrous concrete pavement design curves for light-load pavements.

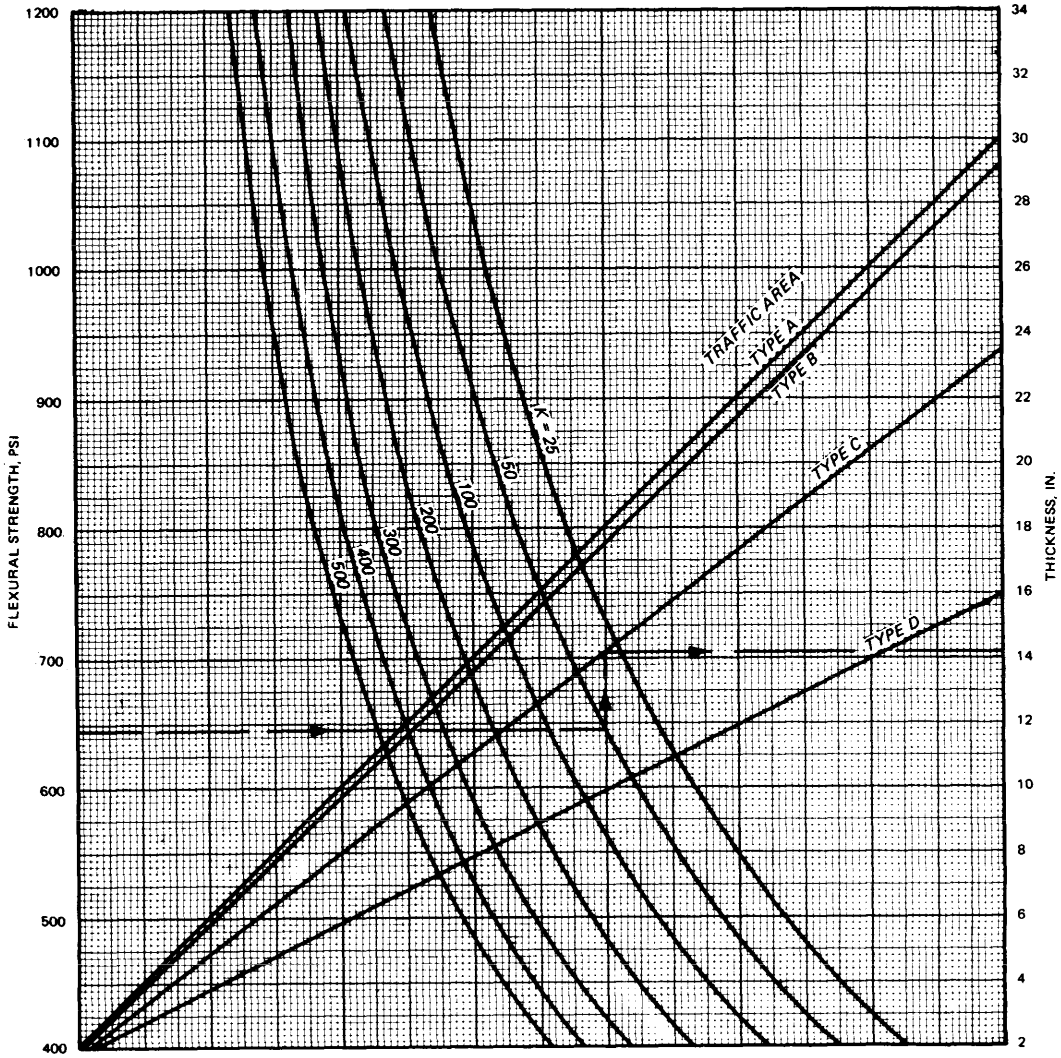


Figure 4-5. Fibrous concrete pavement design curves for medium-load pavements.

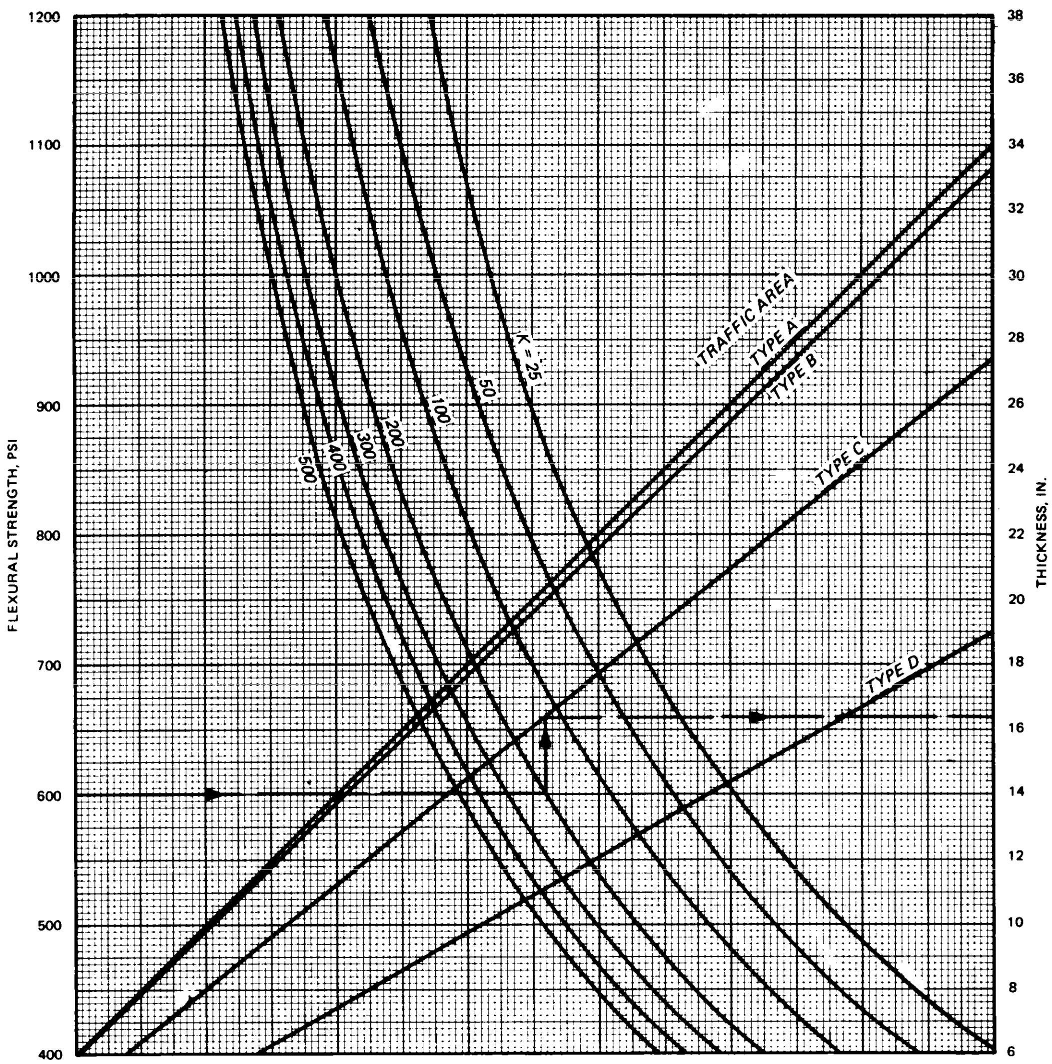


Figure 4-6. Fibrous concrete pavement design curves for heavy–load pavements.

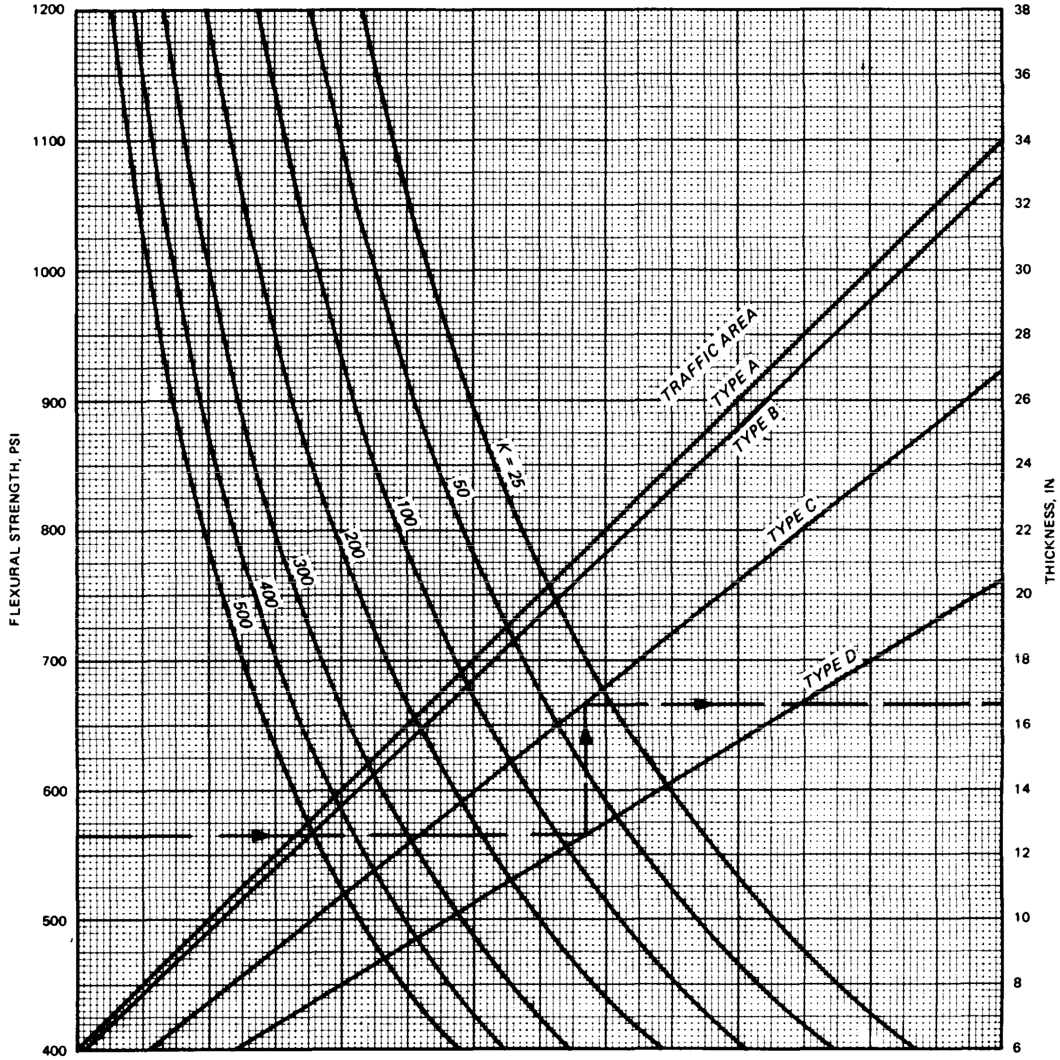


Figure 4-7. Fibrous concrete pavement design curves for modified heavy-load pavements.

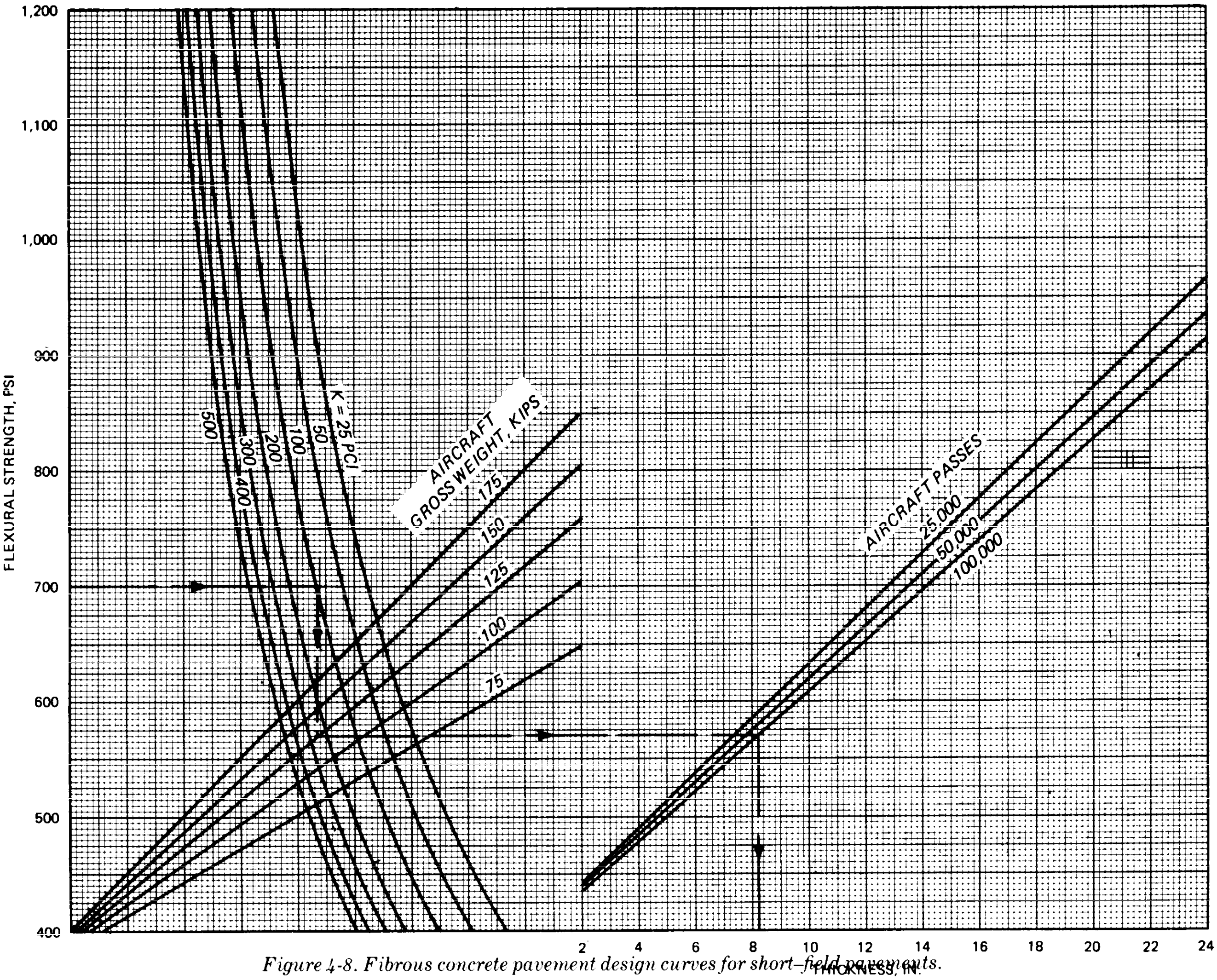


Figure 4-8. Fibrous concrete pavement design curves for short-field pavements.

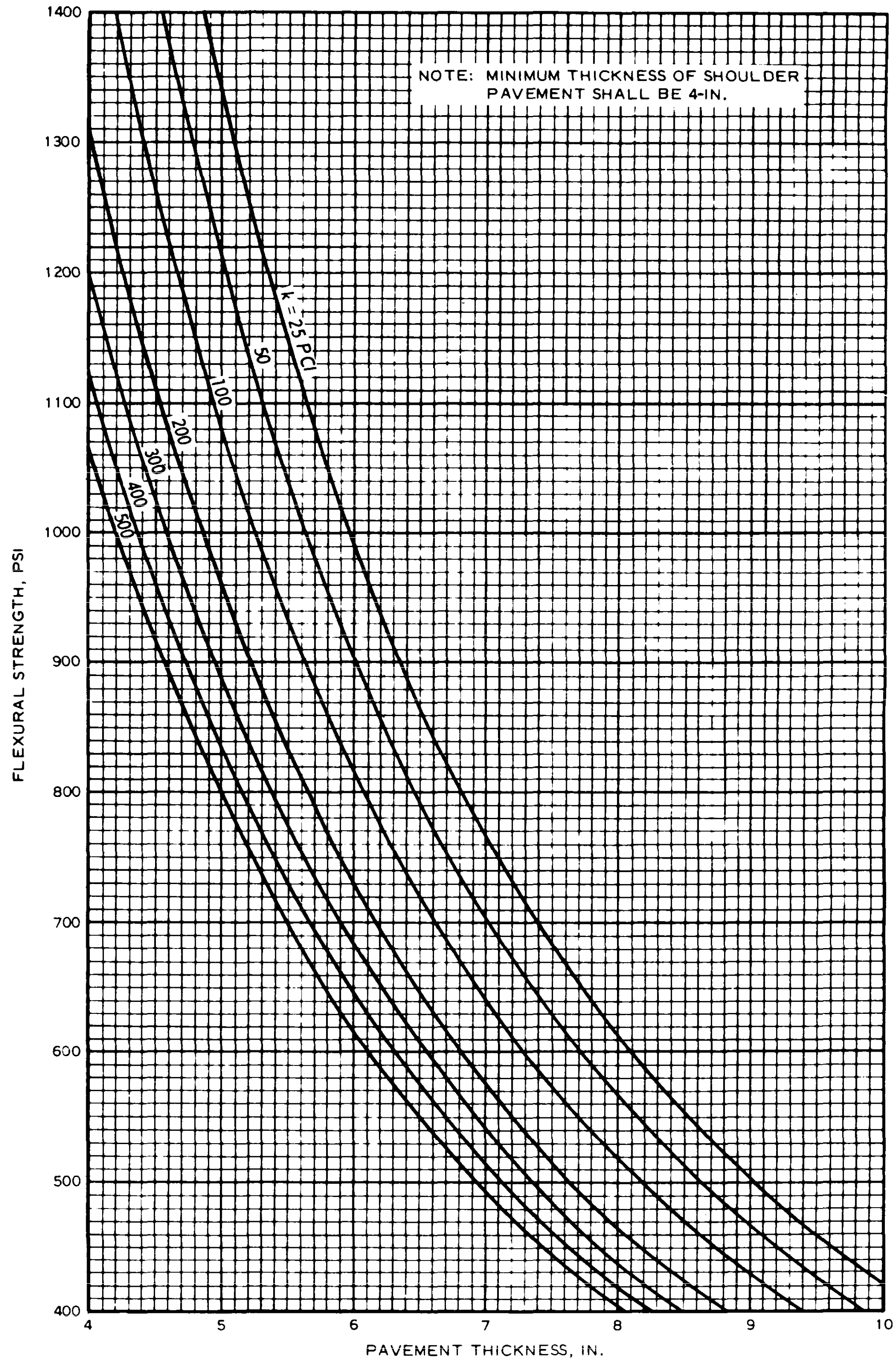


Figure 4-9. Fibrous concrete pavement design curves for shoulders.

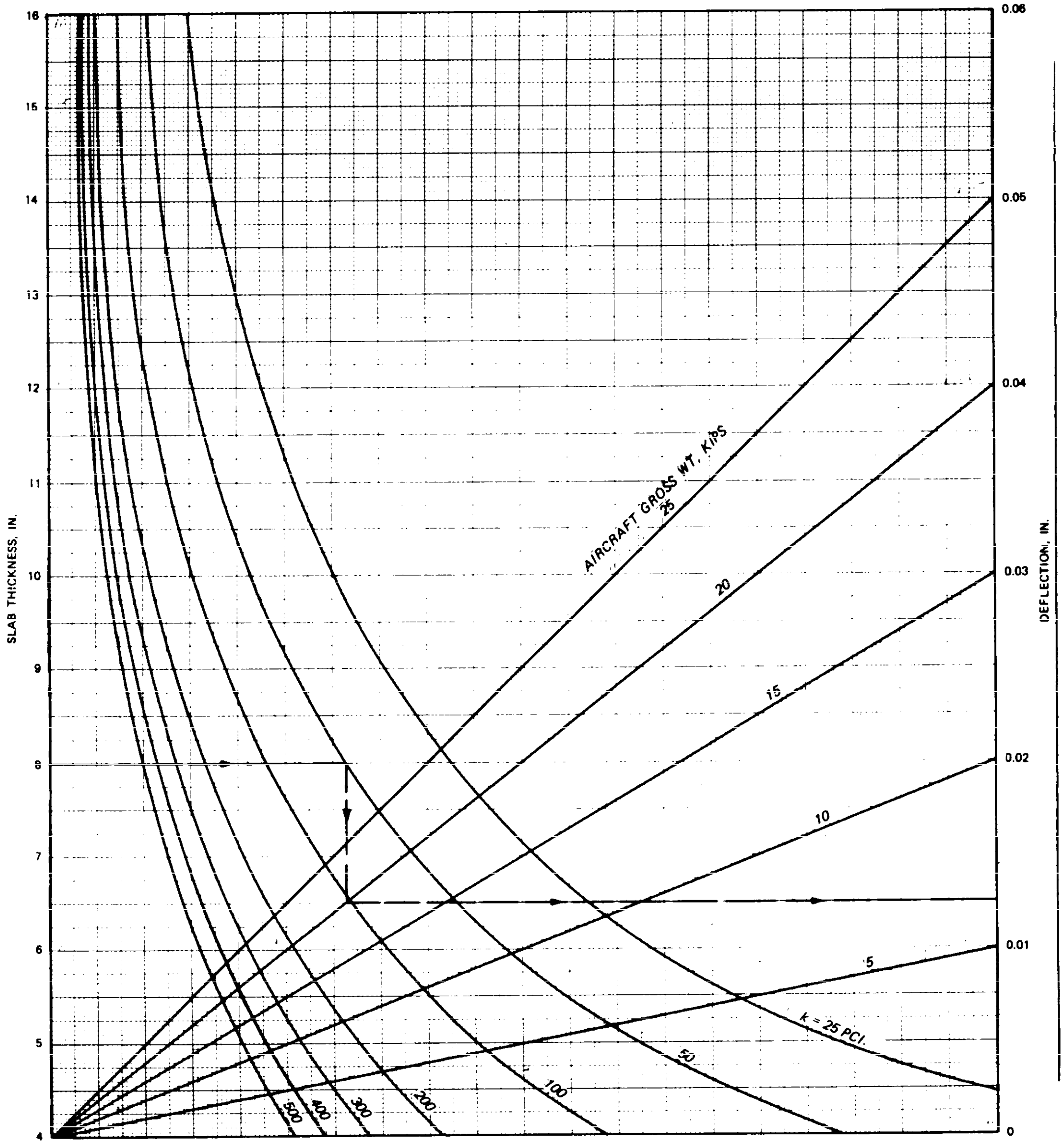


Figure 4-10. Deflection curves for Army Class I pavements.

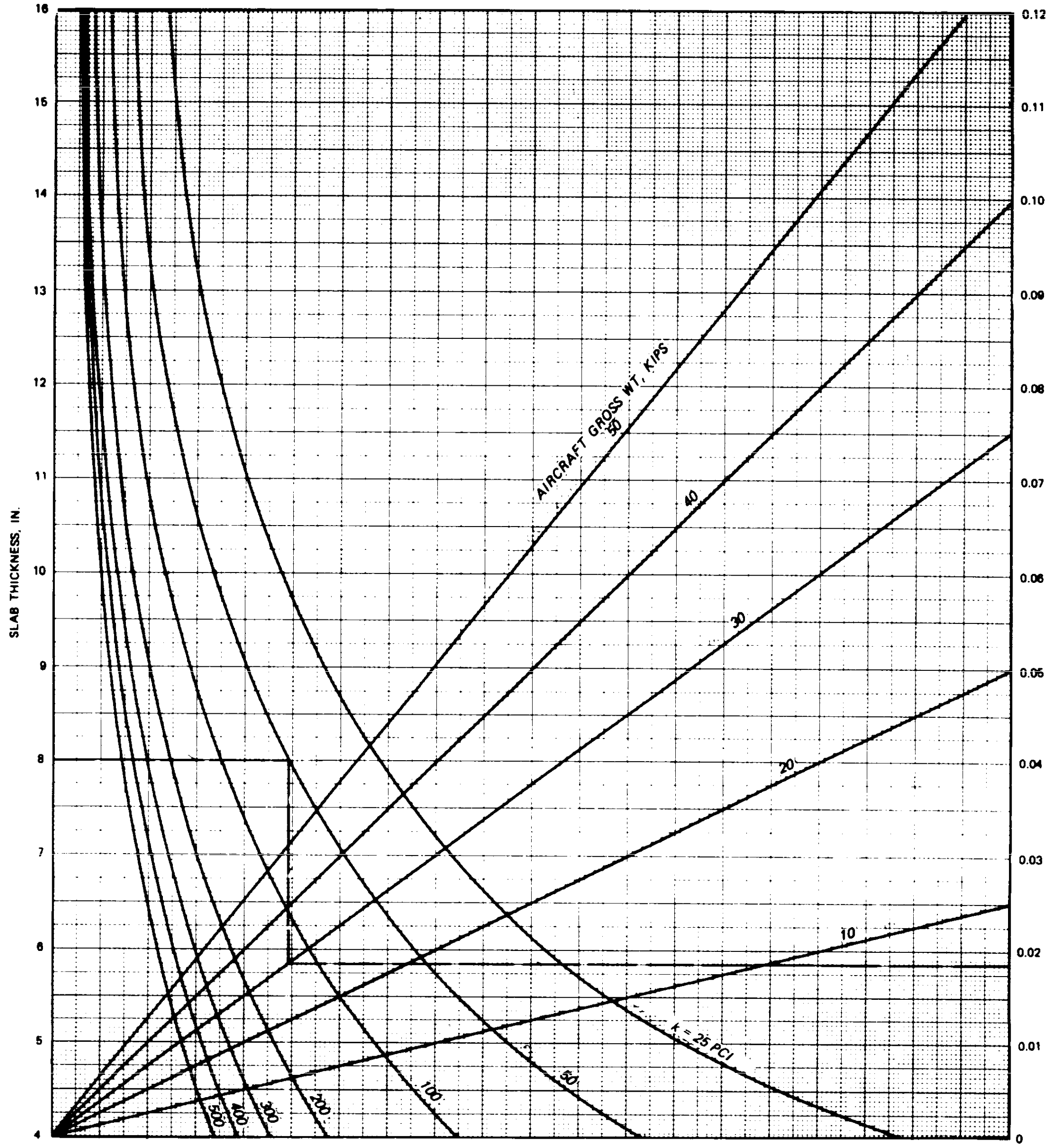


Figure 4-11. Deflection curves for Army Class II pavements.

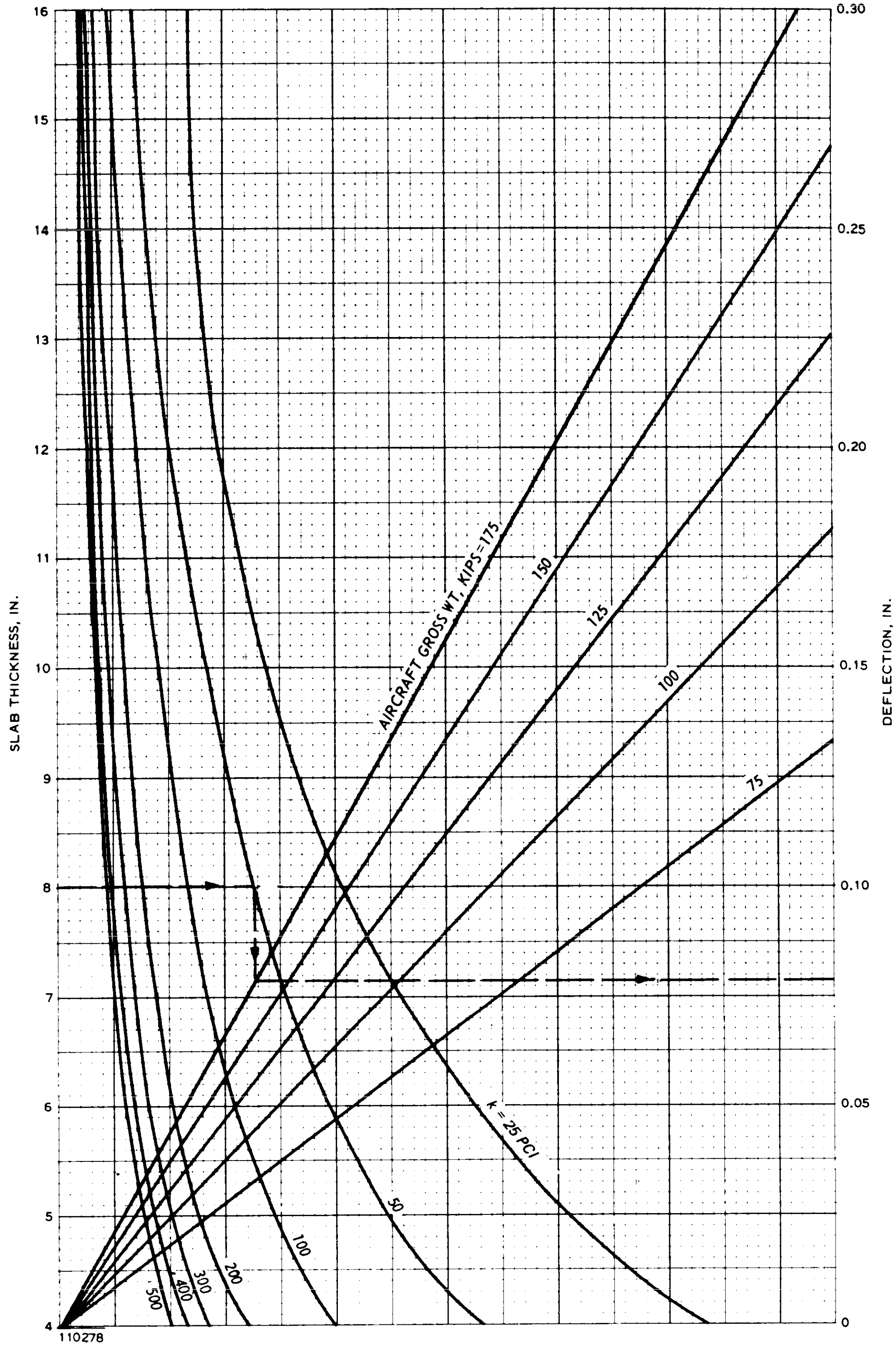


Figure 4-12. Deflection curves for Army Class III pavements.

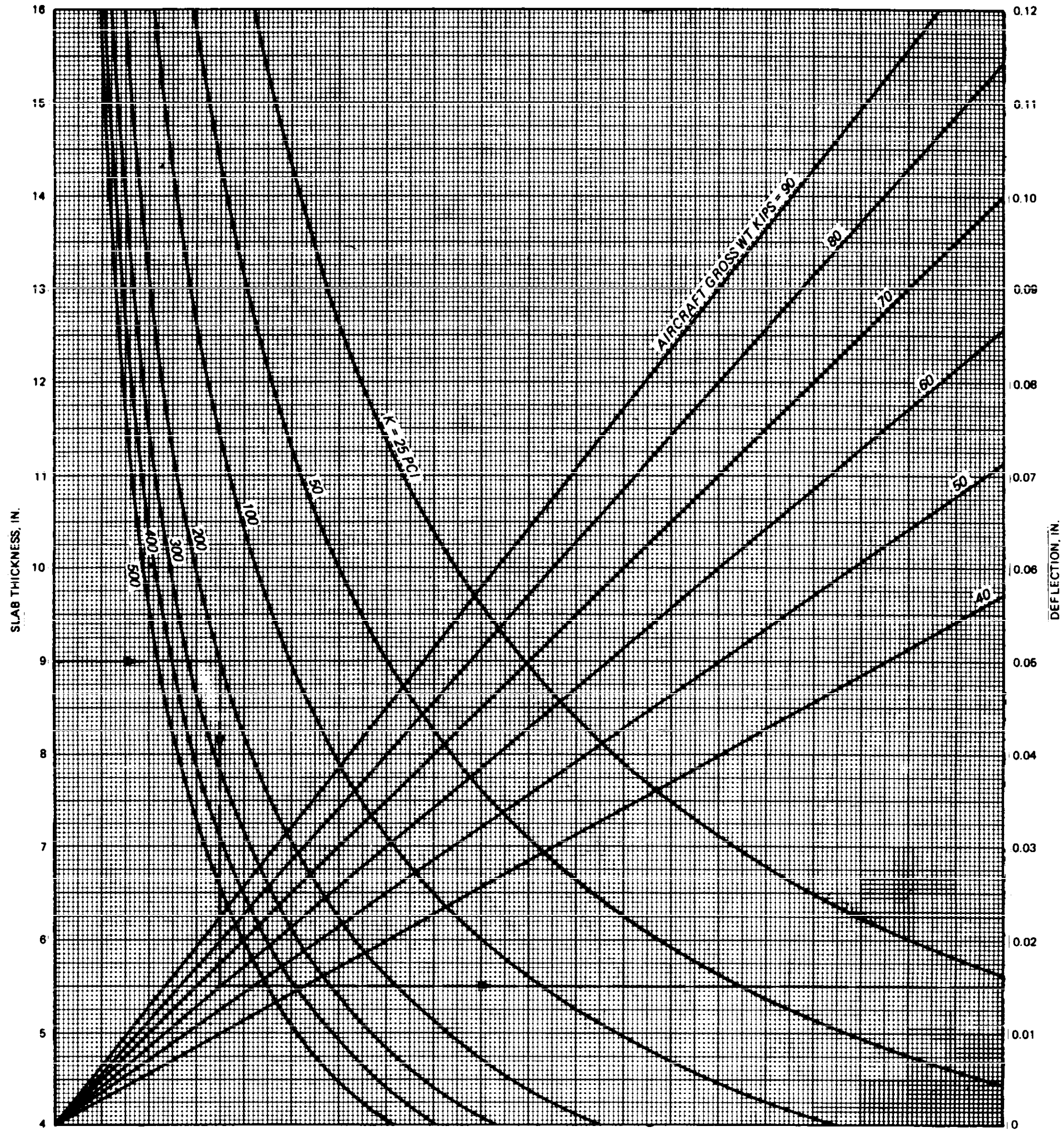


Figure 4-13. Deflection curves for light-load pavements.

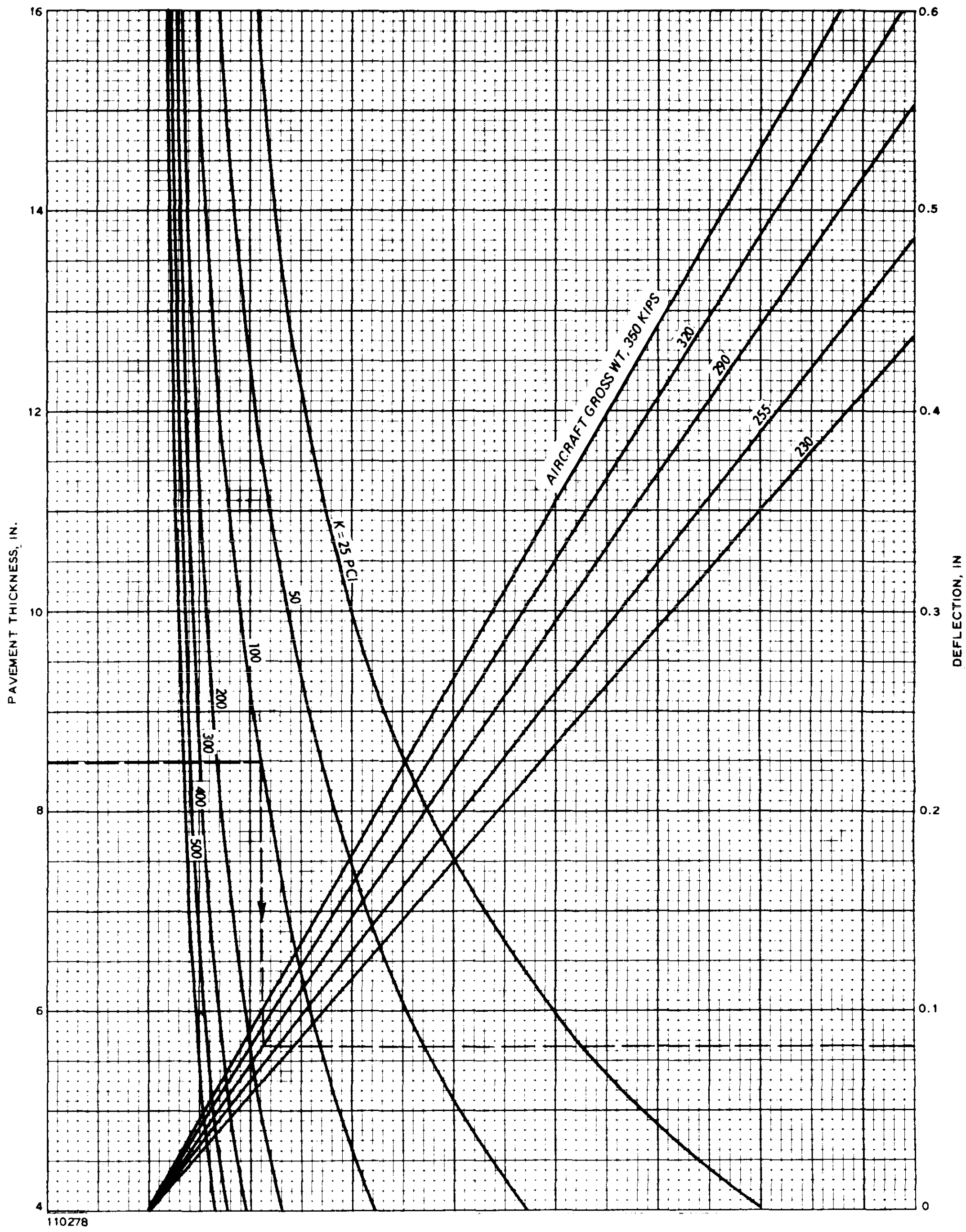


Figure 4-14. Deflection curves for medium-load pavements.

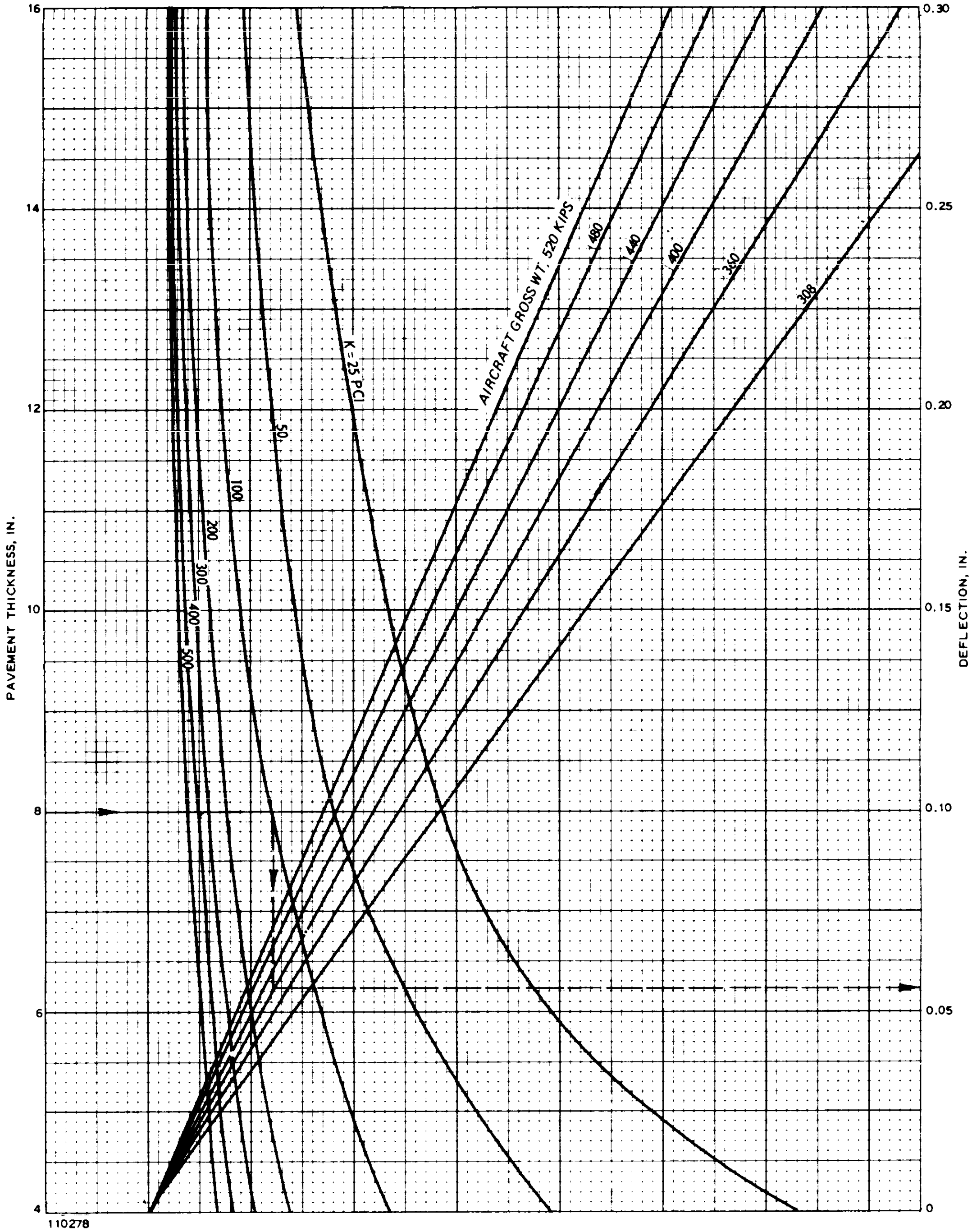


Figure 4-15. Deflection curves for heavy-load pavements.

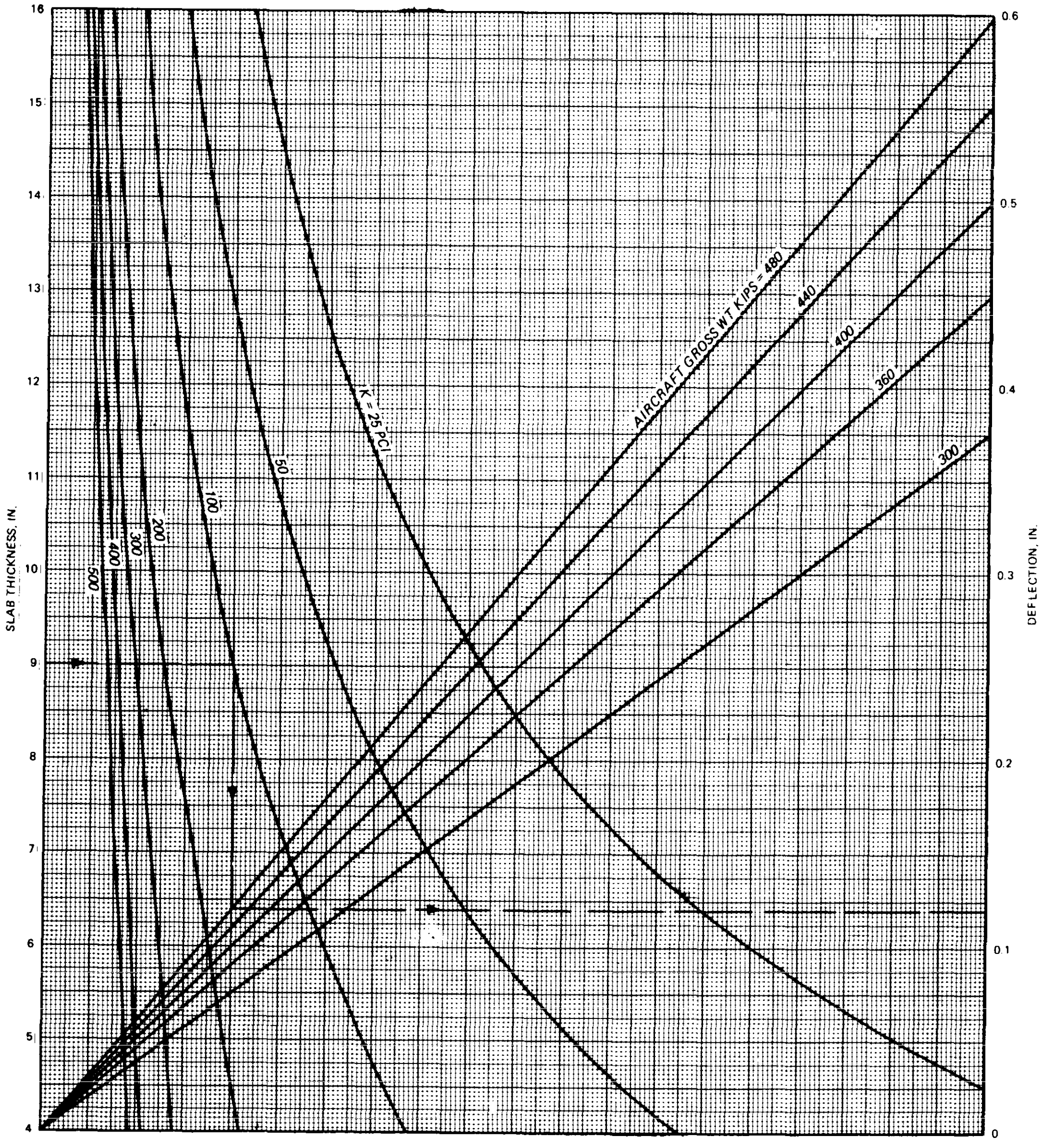


Figure 4-16. Deflection curves for modified heavy-load pavements.

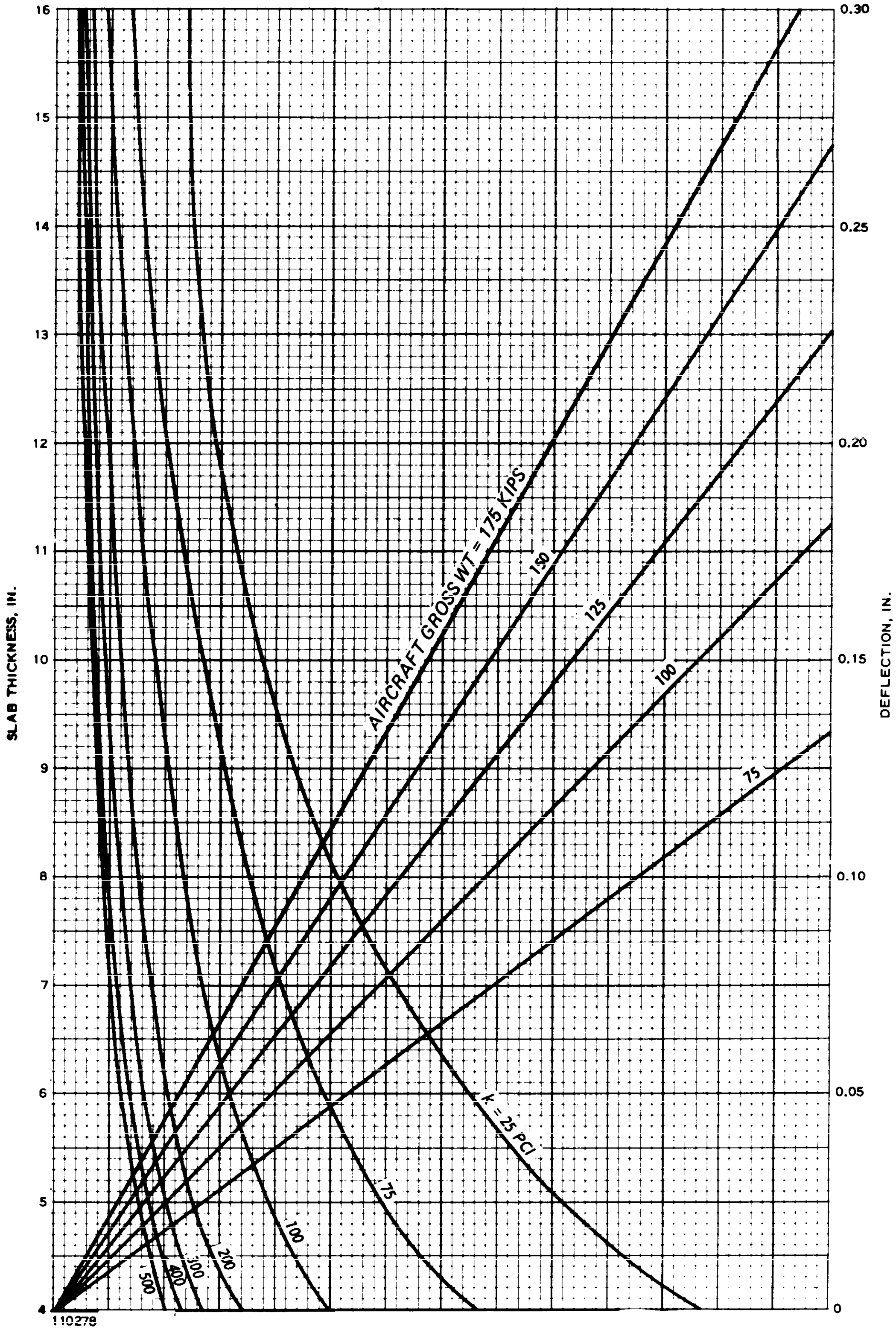


Figure 4-17. Deflection curves for shortfield pavements.

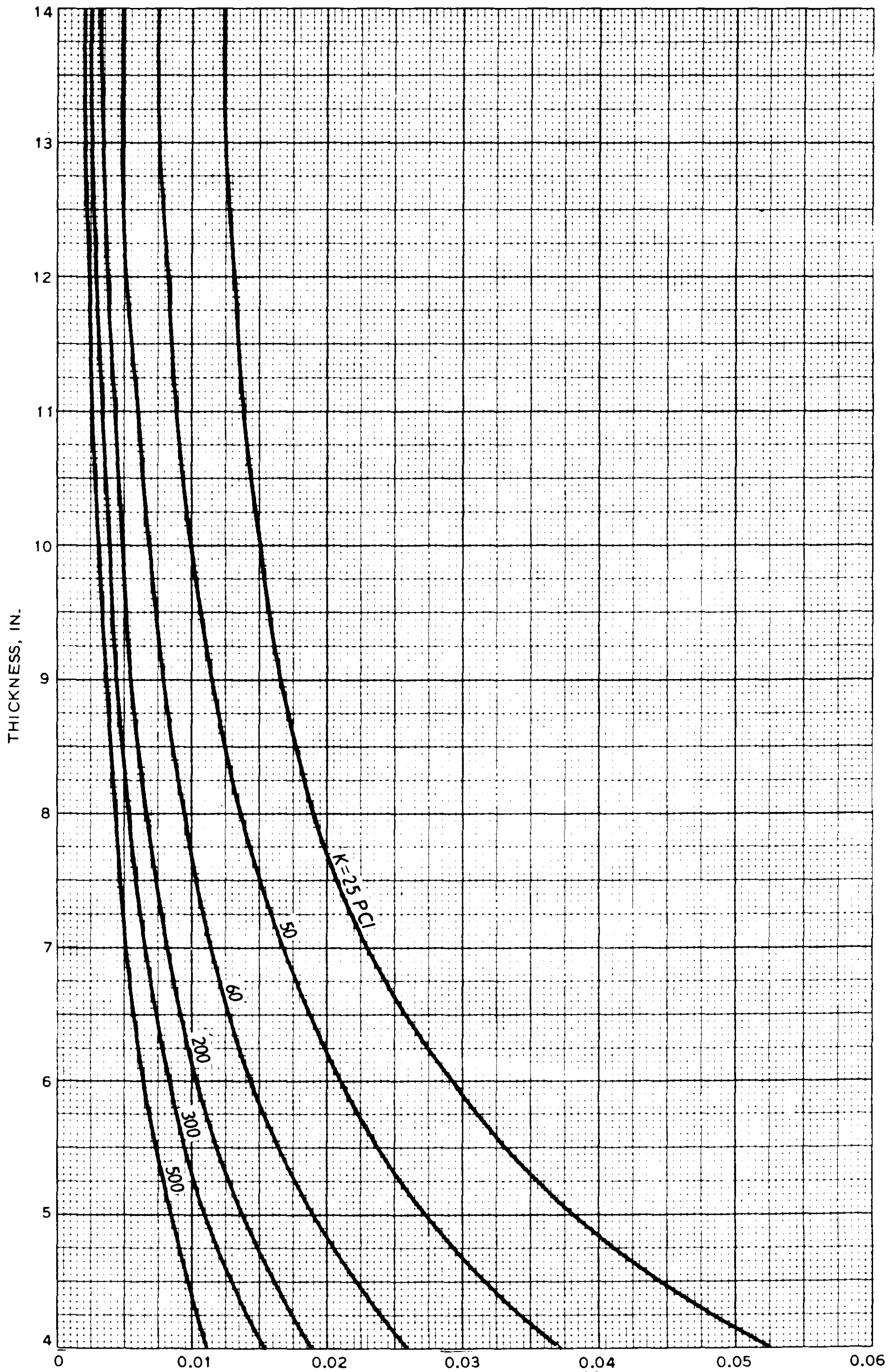


Figure 4-18. Deflection curves for shoulders.

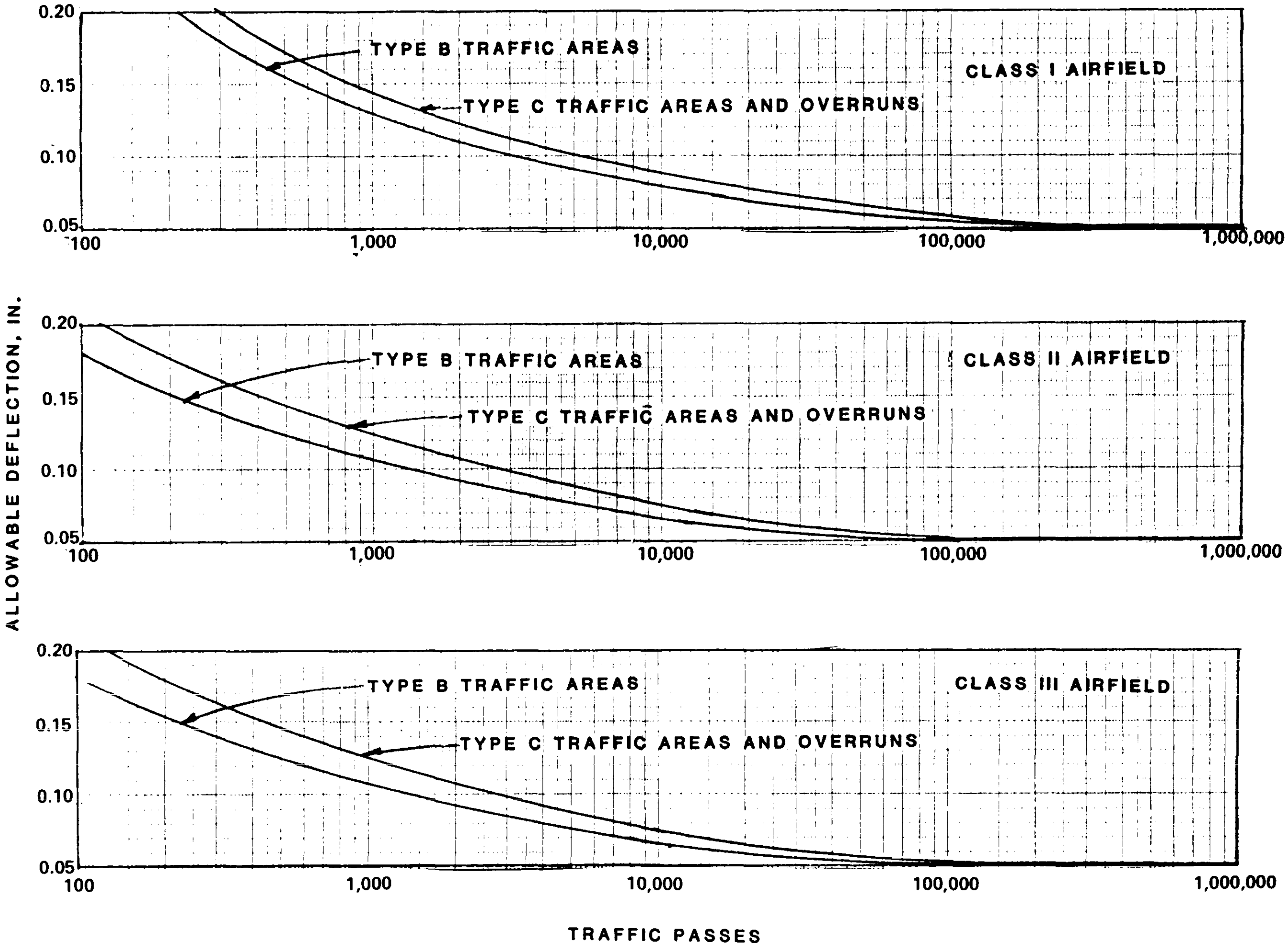


Figure 4-19. Allowable deflection curves for fibrous concrete pavements (Army).

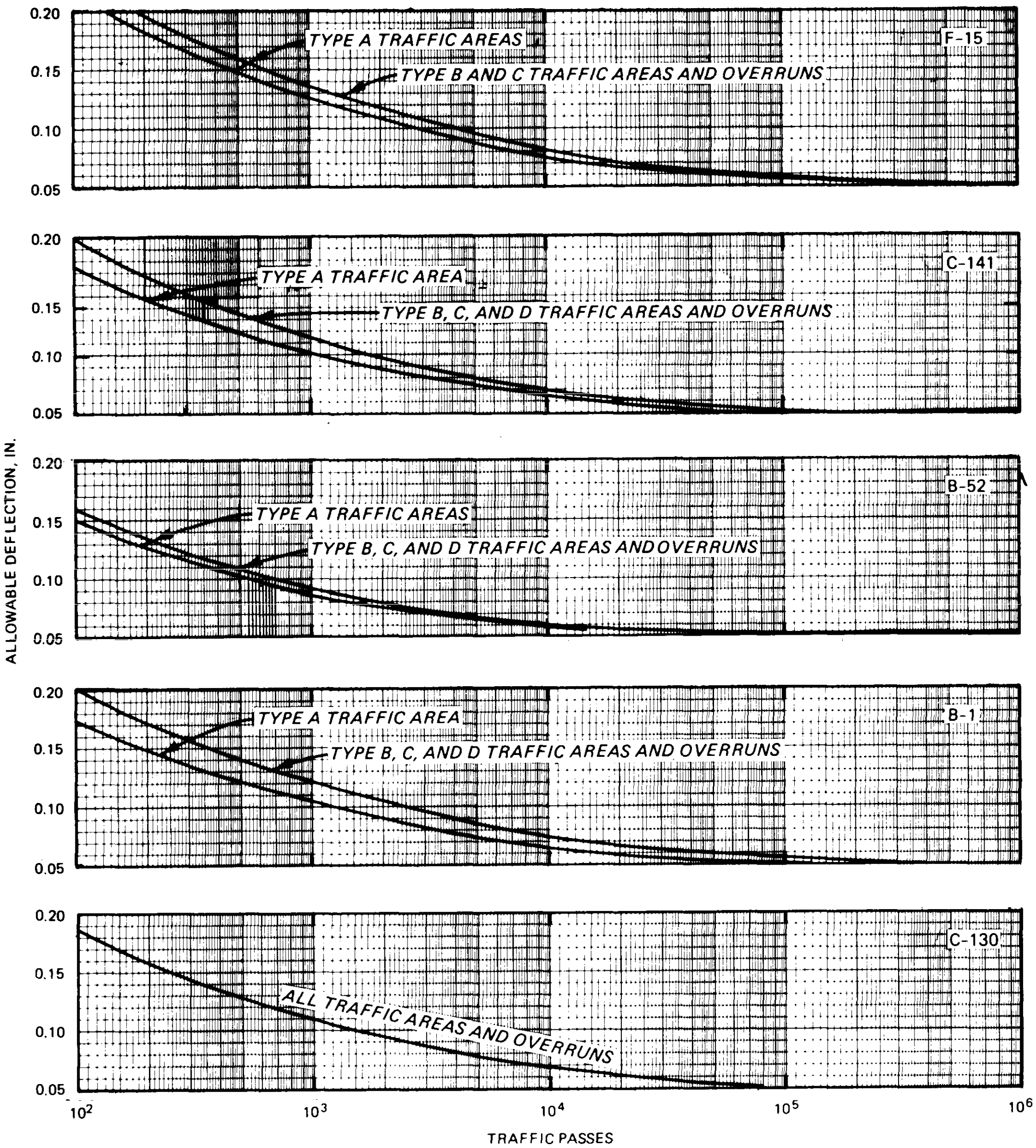


Figure 4-20. Allowable deflection curves for fibrous concrete pavements (Air Force).

CHAPTER 5
CONTINUOUSLY REINFORCED CONCRETE PAVEMENT DESIGN

5-1. Basis of design

A continuously reinforced concrete pavement is one in which the reinforcing steel is carried continuously, in both the longitudinal (direction of paving) and transverse (normal to direction of paving) directions, between terminal points. The terminal points may be either the longitudinal construction joints or ends of the pavement, junctures with other pavements or structures, etc. No joints are required between the terminal points; instead, the pavement is permitted to crack. The crack spacing will vary and be dependent upon the percent of reinforcing steel used, interface conditions between the pavement and foundation, and environmental conditions during the early life of the pavement. A transverse crack spacing ranging from 5 to 8 feet is desirable; however, experience has shown that even for the most carefully designed system, the crack spacing will vary from as little as 2 feet to as much as 10 to 12 feet. The reinforcing steel provides continuity across the nonload-induced cracks, holding them tightly closed and providing good transfer of load. Considerable trouble has been encountered from underdesigned continuously reinforced concrete highway pavements. Consequently, the current trend and the approach adopted here is to make continuously reinforced concrete pavements the same thickness as plain concrete. The steel is assumed to only handle nonload–related stresses and any structural contribution to resisting loads is ignored. When properly designed and constructed, continuously reinforced concrete pavements provide very smooth, low–maintenance pavements. Experience has shown that continuously reinforced concrete pavements perform satisfactorily until the level of cracking reaches the point where punchout of the concrete between the reinforcing steel bars is imminent. The design procedure has been developed primarily from the results of continously reinforced concrete pavement performance on highways since there has been only limited experience with airfield pavements.

5-2. Uses

Continuously reinforced concrete pavements are applicable for any airfield pavement, but they have received very limited usage for airfield pavement construction. Therefore, long–time performance history is minimal. Because of this, its use will require approval of the Commander, U.S. Army Corps of Engineers (DAEN-ECE-G), Washington, DC 20314-1000, or HQ Air Force Engineering and Services Center (AFESC/DEMP), Tyndall AFB, FL 32403-6001. The use of continuously reinforced concrete pavement should be based upon the economics involved.

5-3. Foundation requirements and evaluation

Subgrade compaction and evaluation for a continuously reinforced concrete pavement shall be as described for plain concrete pavements. If economically feasible, the subgrade and/or base course may be modified or stabilized. Stabilized materials must achieve the strength and durability requirements specified in TM 5-822-4/AFM 88-7, Chap. 4.

5-4. Thickness design

The required thickness of a continuously reinforced concrete pavement is determined using the same procedures as for plain concrete pavement and will be the same thickness as plain concrete pavement. Although continuously reinforced concrete pavement contains steel in addition to being the same thickness as plain concrete pavement, the advantage of using it is that contraction joints are eliminated.

5-5. Reinforcing steel design

a. Longitudinal direction. The percent of reinforcing steel required in the longitudinal direction for continuously reinforced concrete pavements will be the maximum calculated by the following three equations with the minimum percent steel being 0.5 percent.

$$P_s = (1.3 - 0.2F)\frac{f_t}{f_s} \times 100 \qquad \text{(eq 5-1)}$$

$$P_s = \frac{100 f_t}{2(f_s - \Delta T \epsilon_c E_s)} \qquad \text{(eq 5-2)}$$

$$P_s = \frac{f_t}{f_s} \times 100 \qquad \text{(eq 5-3)}$$

where

P_s = percent of reinforcing steel required in the longitudinal direction

F = friction factor; suggested values are 1.0 for unbound fine-grained soils, 1.5 for unbound coarse-grained soils, and 1.8 for stabilized soils

f_t = 7-day tensile strength of the concrete in psi determined using the splitting tensile test (Figure 5-1 may be used to convert 7-day flexural strength into tensile strength.)

f_s = working stress in the steel, psi (75% of yield tensile strength of steel). This produces a safety factor of 1.33.

ΔT = Seasonal temperature differential in degrees F

ϵ_c = thermal coefficient of expansion of concrete in inches per inch per degree F

E_s = modulus of elasticity of the reinforcing steel in tension, psi

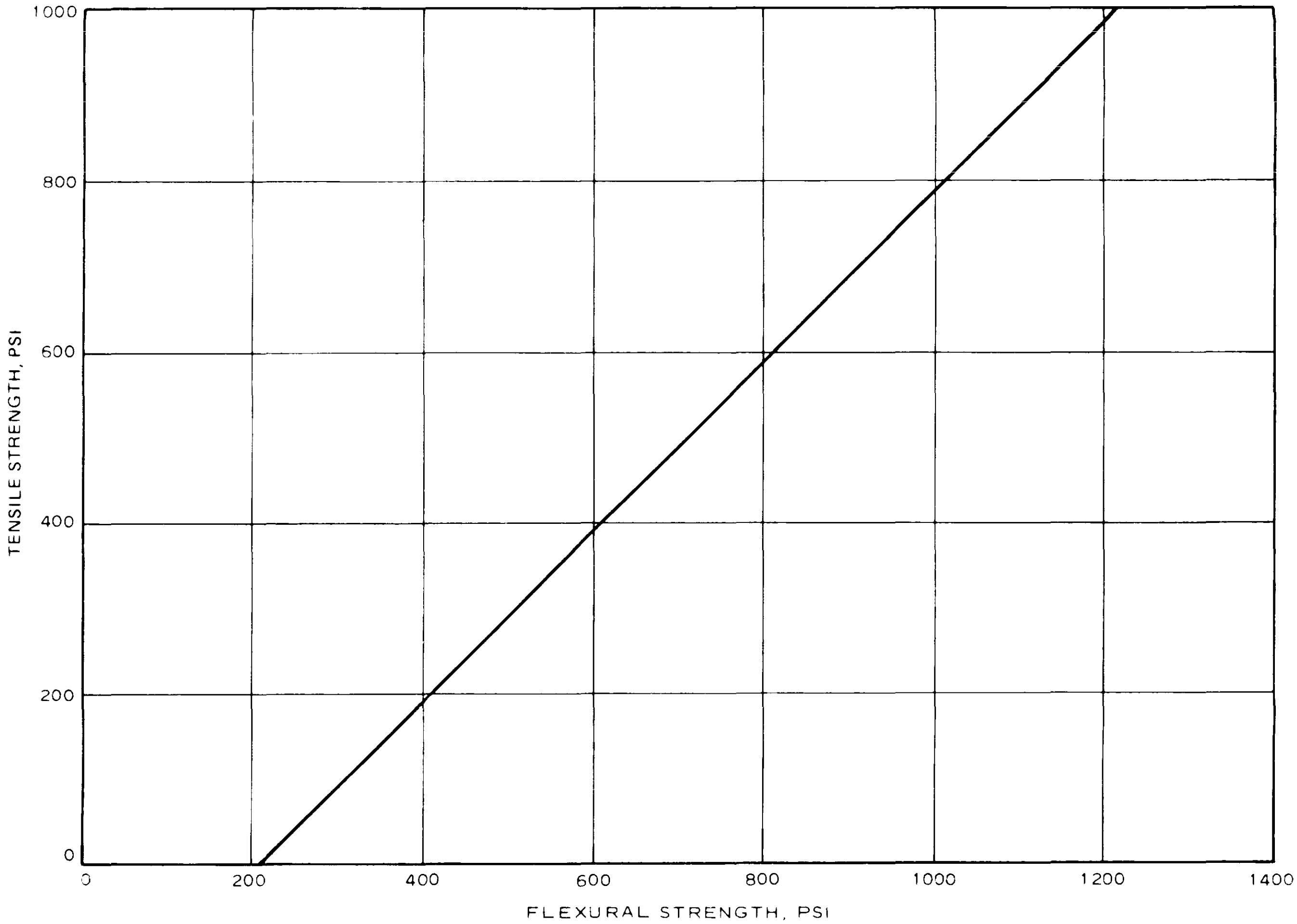


Figure 5-1. Relationship between flexural strength and tensile strength.

b. Transverse direction. Transverse reinforcement is required for all continuously reinforced concrete airfield pavements to control any longitudinal cracking that may develop from load repetitions. The percent steel required in the transverse direction will be determined as follows:

$$P_s = \frac{W_s F}{2f_s} \times 100 \qquad \text{(eq 5-4)}$$

where

W_s = width of slab, feet

c. Type of reinforcing steel. The reinforcing steel may be either deformed bars conforming to ASTM A 615 or welded deformed steel wire fabric conforming to ASTM A 497. Generally, longitudinal reinforcement is provided by deformed billet bars with 60,000-psi minimum yield strength; however, other grades may be used. A grade 40 deformed bar should be used for the transverse reinforcement or for tie bars if bending is anticipated during construction.

d. Placement of reinforcing steel. When the slab thicknesses is 8 inches or less, the longitudinal reinforcement should be placed at the middepth of the slab. For thickness in excess of 8 inches, the longitudinal steel should be placed slightly above the middepth, but a minimum cover of 3 inches of concrete shall be maintained in all cases. Transverse reinforcement is normally placed below and used to support the longitudinal steel; however, it may be placed on top of the longitudinal steel if the minimum of 3 inches of concrete cover is maintained. Proper lapping of the longitudinal reinforcement is important from the standpoint of load development and is essential for true continuity in the steel. The deformed bars or welded deformed wire fabric shall be lapped in accordance with paragraphs 3-6a and b. It is particularly important to stagger the laps in the reinforcing steel. Generally, not more than one-third to one-half of the longitudinal steel should be spliced in a single transverse plane across a paving lane. The width of this plane should be 2 feet if the one-third figure is used, and 4 feet if the one-half requirement is used. The latter case shall be interpreted to read that not more than one-half of the longitudinal reinforcing members may be spliced in any 4-foot length of pavement. The stagger of laps with deformed bars may be on a continuous basis rather than the one-third or one-half detail described above.

5-6. Terminal design

When appreciable lengths of continuously reinforced concrete pavement are used, the ends experience large movements if unrestrained and will exert large forces if restrained. To protect abutting pavements or structures from damage, the ends of continuously reinforced concrete pavements must be either isolated or restrained. Experience has shown that it is practically impossible to completely restrain or completely isolate the pavement ends, and a combination of these schemes (that is, partial restraint and limited available expansion space) has proven practical. End anchorage and/or expansion joints must be provided when continuously reinforced concrete pavement is not continuous through intersections or when it abuts a structure. Although numerous terminal treatment systems have been attempted, especially on highway pavements, the most successful system appears to be the wide-flange beam joint. Typical drawings of this terminal system are shown in figure 5-2. For runways, the continuously reinforced concrete pavement should extend to the runway end, where the wide flange beam joint would be placed as a part of the overrun area.

5-7. Jointing

Continuously reinforced concrete pavements will normally use the same type of joints as used for plain concrete pavements except that contraction joints are not normally required. Longitudinal construction joints will be required with the spacing dictated by the paving equipment. The longitudinal construction joints will be butt joints as shown in figure 2-15. Transverse construction joints, which are required for construction expediency, will be designed to provide slab continuity by continuing the normal longitudinal steel through the joint. The normal reinforcement will be supplemented by additional steel bars, 5 feet long (2.5 feet on each side of the joint) and the same diameter as the longitudinal reinforcement. The additional steel will be placed between the normal reinforcement and at the same depth in the slab. Thickened-edge slip joints will be used at intersections of pavements where slippage will occur. Otherwise, doweled expansion joints will be used. Expansion joint design will be in accordance with paragraph 2-4d. It will be necessary to provide for expansion at all barriers located in or adjacent to continuously reinforced concrete pavement.

5-8. Joint sealing

The only joints requiring sealing in continuously reinforced concrete pavements will be longitudinal construction joints and expansion joints. Transverse construction joints need not be sealed since they will behave as conventional volume-change cracks that are present elsewhere in the pavement. Joint sealing membranes will be as specified for plain concrete pavements.

5-9. Example of continuously reinforced concrete pavement design

It is required that a pavement be designed as a medium-load airfield. According to TM 5-824-1/AFM 88-6, Chap. 1, Type A and B traffic areas are designed for the F-15 at 81,000 pounds, the C-141 at 345,000 pounds, and the B-52 at 400,000 pounds. Type C and D traffic areas and overruns are designed for the F-15 at 60,750 pounds, the C-141 at 258,750 pounds, and the B-52 at 300,000 pounds. Type A, B, and C traffic areas are designed for 25,000 passes of the F-15, 100,000 passes of the C-141, and 100 passes of the B-52. Type D traffic areas and overruns are designed for 250 passes of the F-15, 1,000 passes of the C-141, and 1 pass of the B-52. On-site and laboratory investigations have yielded the following data required for design:

- Subgrade = silty sand (SM)
- Modulus of subgrade reaction = 200 pci
- Flexural strength = 700 psi

The thickness of the continuously reinforced concrete pavement will be the same as required for plain concrete according to the procedures set forth in chapter 2. The required thicknesses are therefore as follows:

Traffic Area	*Thickness, inches*
A	15.5
B	15.0
C	12.0
D and Overruns	9.0

Additional data required for determining the percent longitudinal steel are as follows;

- Tensile strength of concrete = 500 psi
- Yield strength of steel = 60,000 psi
- Coefficient of thermal expansion of concrete $= 4 \times 10^{-6}$ inch per inch per degree F
- Modulus of elasticity of steel $= 30 \times 10^{6}$ psi

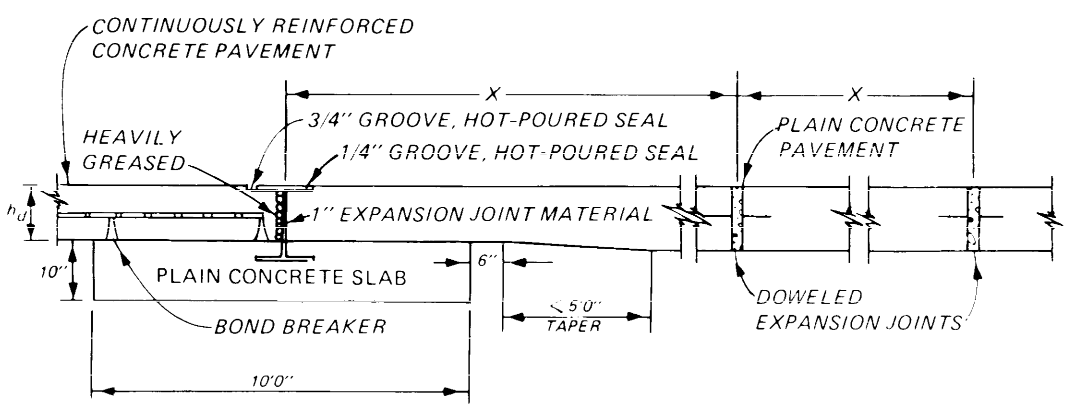


Figure 5-2. Details of a wide-flange beam joint.

— Seasonal temperature differential of pavement = 130 degrees F.
— Friction factor for fine-grained soils = 1.0

The required percentage of longitudinal reinforcement steel is determined from the maximum of the following three equations:

$$P_s = (1.3 - 0.2F)\frac{f_t}{f_s} \times 100$$
$$= [1.3 - 0.2(1.0)]\frac{500}{45,000} \times 100 = 1.222 \quad \text{(eq 5-5)}$$

$$P_s = \frac{100f_t}{2(f_s - \Delta T\epsilon_c E_s)}$$
$$= \frac{100(500)}{2[45,000 - 130(4 \times 10^{-6})(30 \times 10^6)]}$$
$$= 0.850 \quad \text{(eq 5-6)}$$

$$P_s = \frac{f_t}{f_s} \times 100 \times \frac{500}{45,000} \times 100 = 1.111 \quad \text{(eq 5-7)}$$

The design percent of longitudinal steel is therefore 1.222. The cross-sectional area of steel, A_s, required per foot of pavement for the Type A traffic area is:

$$A_s = \frac{P_s \times A_p}{100} = \frac{1.222 \times 15.5 \times 12}{100}$$
$$= 2.273 \text{ square inches}$$

where

A_p = the cross-sectional area of 1 foot of pavement, square inches

In determining the percent of steel required in the transverse direction, it is assumed that 20-foot paving lanes will be used along the with following equation:

$$P_s = \frac{W_s F}{2f_s} \times 100 = \frac{20 \times 1.0}{2(45,000)} \times 100 = 0.022 \quad \text{(eq 5-9)}$$

The design percent steel in the transverse direction is therefore 0.022. The cross-sectional area of steel required per foot of pavement for the 15.5-inch pavement is therefore

$$A_s = \frac{P_s \times A_p}{100} = \frac{0.022 \times 15.5 \times 12}{100}$$
$$= 0.0409 \text{ square inches} \quad \text{(eq 5-10)}$$

The percent steel for other traffic areas would be computed in the same manner.

CHAPTER 6
PRESTRESSED CONCRETE PAVEMENT DESIGN

6-1. Basis of design

A prestressed concrete pavement is one in which a significant compressive stress has been induced in both the longitudinal and transverse directions prior to the application of a live load. The induced compressive stress offsets the damaging effects of tensile stresses resulting from applied live loads and permits the formation of momentary, or partial, plastic hinges under passage of wheel loads that change the failure mode from tensile cracking at the bottom of the pavement due to negative moments in the upper surface of the pavement. These two factors permit the prestressed concrete pavement to carry substantially greater loadings than equal thicknesses of plain concrete or reinforced concrete pavement and still provide a functionally adequate pavement.

6-2. Uses

Although prestressed concrete pavements have been used in Europe, a long-time performance history of prestressed concrete pavements in the United States is not extensive. Therefore, its use will require the approval of the Commander, U.S. Army Corps of Engineers (DAEN-ECE-G), Washington, DC 20314-1000, or HQ Air Force Engineering and Services Center (AFESC/DEMP), Tyndall AFB, FL 32403-6001. Several test or demonstration sections in the United States have shown good performance, but problems have been experienced with joints between long prestressed sections where large movements are experienced. For this reason, complex joints and extreme care are required during construction. The selection of prestressed concrete pavements should be based upon the economics involved.

6-3. Foundation requirements

a. Subgrade and base. In general, the subgrade for a prestressed concrete pavement will be treated and evaluated in the same manner as for other types of rigid pavements. The reduced thickness of prestressed concrete pavement will result in a more flexible system and higher vertical stresses in the foundation than for plain concrete pavements. For this reason, the quality and strength of the foundation becomes more important. The foundation should be strengthened through the use of a high-quality (stabilized or nonstabilized) base course and/or stabilized or modified subgrade to provide a minimum modulus of soil reaction or composite modulus of soil reaction of 200 psi. In addition, because the amount of design prestress is a function of the foundation restraint, the surface of the foundation should be finished as smooth and as free of undulations, holes, etc., as possible.

b. Friction-reduction layer. A friction-reducing layer shall be used between the prestressed concrete pavement and the foundation. A satisfactory friction-reducing layer may consist of two polyethylene sheets over a thin (¼- to ½-inch) uniform size sand layer. The sand layer is used primarily to smooth out the surface irregularities of the foundation. Other types of friction-reducing material may be considered.

6-4. Method of prestressing

Pavements may be prestressed using pretensioning or posttensioning, the method most commonly used for pavements is posttensioning, in which tendons are installed before concrete placement and stressed after concrete placement. The tendons either are placed in conduits or are plastic-encased to prevent bonding with the concrete. The tendons are threaded through bearing plates cast into the face of the concrete at the ends or sides of the concrete slabs. After the concrete has gained sufficient strength, the tendons are stressed, using the bearing plates and concrete slab as a reaction, to the required total stress level and locked. The total stress level in the tendons is the sum of the stress needed to provide the design prestress level in the concrete plus the stress necessary to offset the various losses that will occur. To help reduce cracking in the concrete during the cure period, a preliminary level of prestress is normally applied at a very early age, and the final level of prestress applied after several days of curing. Both longitudinal and lateral prestressing is needed to obtain the desired structural capacity in the pavement.

6-5. Design procedure

a. General. In the design of prestressed pavements, both thickness and level of prestress will be unknowns; therefore, their determination, in both the longitudinal and transverse directions, becomes an iterative process (that is, one is selected and the other computed). A normal practice is to compute the thickness requirements for a range of prestress levels, after which the final selection is made based upon an economic analysis. A maximum value of design prestress of 400 psi is recommended; and based upon experience, a design prestress level falling between 100 and 400 psi has been found to be most economical. The minimum thickness of prestressed concrete pavement will be 6 inches.

b. Design equation. The design prestress for a given thickness of pavement will be determined as follows:

$$d_s = \frac{6PNB}{wh_p^2} - R + r_s + t_s \qquad \text{(eq 6-1)}$$

Where

d_s = design prestress required in concrete, psi
P = aircraft gear load, pounds
N = load-repetition factor

B = load-moment factor
w = ratio of multiple-wheel gear load to single-wheel gear load
h_p = design thickness of prestressed concrete pavement, inches
R = design flexural strength of concrete, psi
r_s = foundation restraint stress, psi
t_s = temperature warping stress, psi

Since both d_s and h_p will be unknown, it is necessary to select values of h_p and compute d_s. For guidance, experience has shown that d_s levels between 100 and 400 psi are generally economical, and at these levels h_p will be about one-third of the required thickness of plain concrete pavement. The design gear load, P, will depend upon the aircraft for which the pavement is being designed (TM 5-824-1/AFM 88-6, Chap. 1 and TM 5-803-4). The load-repetition factor, N, is a function of the type of design aircraft and the traffic area type as determined from TM 5-824-1/AFM 88-6, Chap. 1 and/or TM 5-803-4. The design aircraft pass level is divided by the aircraft repetition level (table 2-3) to determine the design number of stress repetitions, which are in turn used in figure 6-1 to obtain N. The load-moment factor, B, and ratio of multiple-wheel load to single-wheel load, w, are determined from figures 6-2 and 6-3, respectively, by entering with a value of with a value of A/ℓ^2 (note that for the light-load and Class I airfields, w is 1.0 for all values of A/ℓ^2). A is the contact area in square inches of a tire in the main gear of the design aircraft, and ℓ is computed by

$$\ell = \left[\frac{Eh_p^3}{12(1-\mu^2)k}\right]^{1/4} \qquad \text{(eq 6-2)}$$

where
E = the modulus of elasticity of concrete (a value of 4,000,000 psi is normally used)
h_p = design thickness of prestressed concrete pavement, inches
μ = Poisson's ratio
k = modulus of subgrade reaction, pci

c. Foundation restraint stress. The subgrade restraint stress, r_s, is a function of the coefficient of sliding friction between the pavement and underlying foundation and the length or width of the prestressed concrete slab and is determined by

$$r_s = \frac{C_f L \gamma}{2(144)} \quad \text{or} \quad r_s = \frac{C_f W \gamma}{2(144)} \qquad \text{(eq 6-3)}$$

where
r_s = foundation restraint stress, psi
C_f = coefficient of sliding friction
L = length of prestressed concrete slab, feet
W = width of prestressed concrete slab, feet
γ = density of concrete, pcf

Experience has shown that for a prestressed concrete pavement constructed with sand and polyethylene sheet bond-breaking medium on the surface of the prepared foundation, a value of C_f of 0.60 is representative. This value can be reduced, with a subsequent reduction in the design prestress level, through the selection of materials with lower coefficients of friction and through careful preparation of the foundation layer.

d. Temperature warping stress. The temperature warping stress results from the development of a temperature gradient through the prestressed concrete pavement thickness and can be determined by

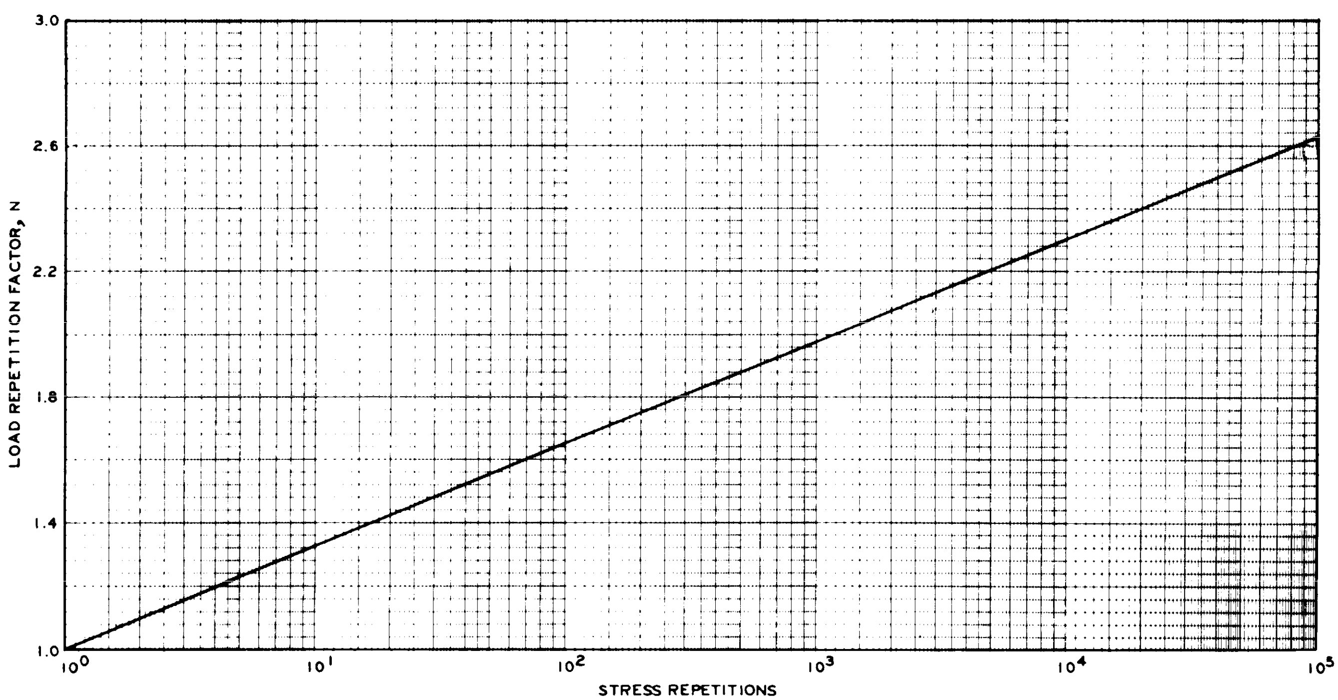


Figure 6-1. Stress repetitions versus load-repetition factor.

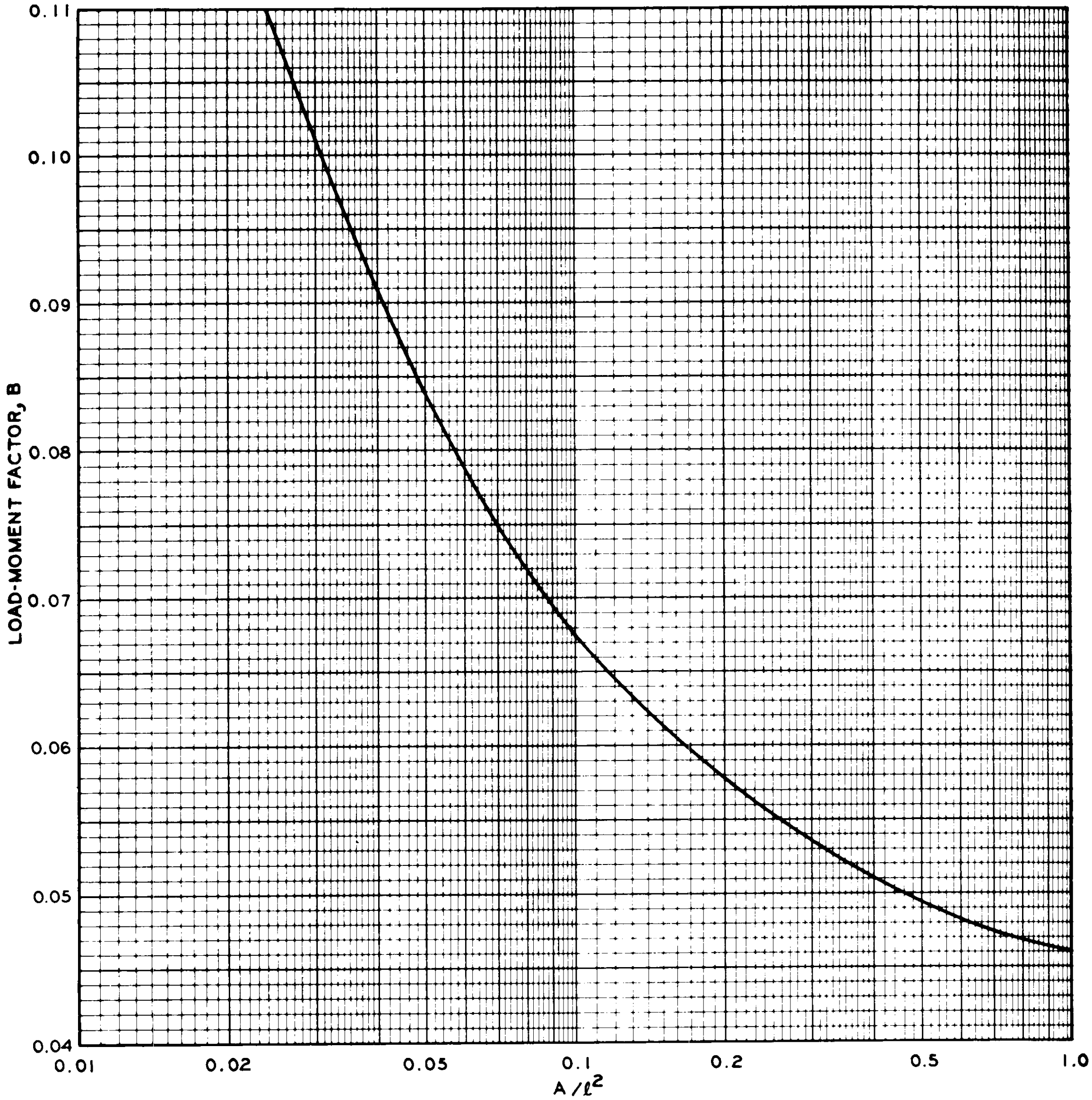


Figure 6-2. Aℓ² versus load-moment factor.

$$t_s = \frac{ET\epsilon_c}{2(1 - \mu)} \qquad \text{(eq 6-4)}$$

where

t_s = temperature warping stress, psi

T = difference in temperature in degrees F between the top and bottom of the prestressed concrete pavement

ϵ_c = coefficient of thermal expansion, inches/inch

Values of T should be determined by test on a pavement in the vicinity of the proposed prestressed concrete pavement; however, without other data, a value of 1 to 3 degrees per inch of pavement has been found to be fairly representative of the maximum temperature gradient.

6-6. Prestressing tendon design

a. General. The size and spacing of prestressing tendons required will be a function of the required prestress level and the various losses that will occur in the steel tendons during and following construction.

b. Size and spacing on tendons. The tendon stress losses occur as a result of elastic shortening and creep of the concrete, concrete shrinkage, tendon relaxation, and slippage in the anchorage system. The determination of these tendon losses is complex because of the many variables, some of which are unknown without extensive field testing. From the experience gained in the few test and demonstration sections and actual pavement sections, the tendon losses can be approximated as 20 percent of the tendon stress needed to achieve the design prestress level in the concrete. With this approximation, the total area of tendon steel required to accomplish the prestress level in the concrete after allowance for tendon losses can be determined by

$$A_s = \frac{1.2 d_s A_c}{0.7 f_\mu} \qquad \text{(eq 6-5)}$$

where

A_c = cross-sectional area of concrete being prestressed, square inches

f_μ = ultimate strength of the tendon steel, psi

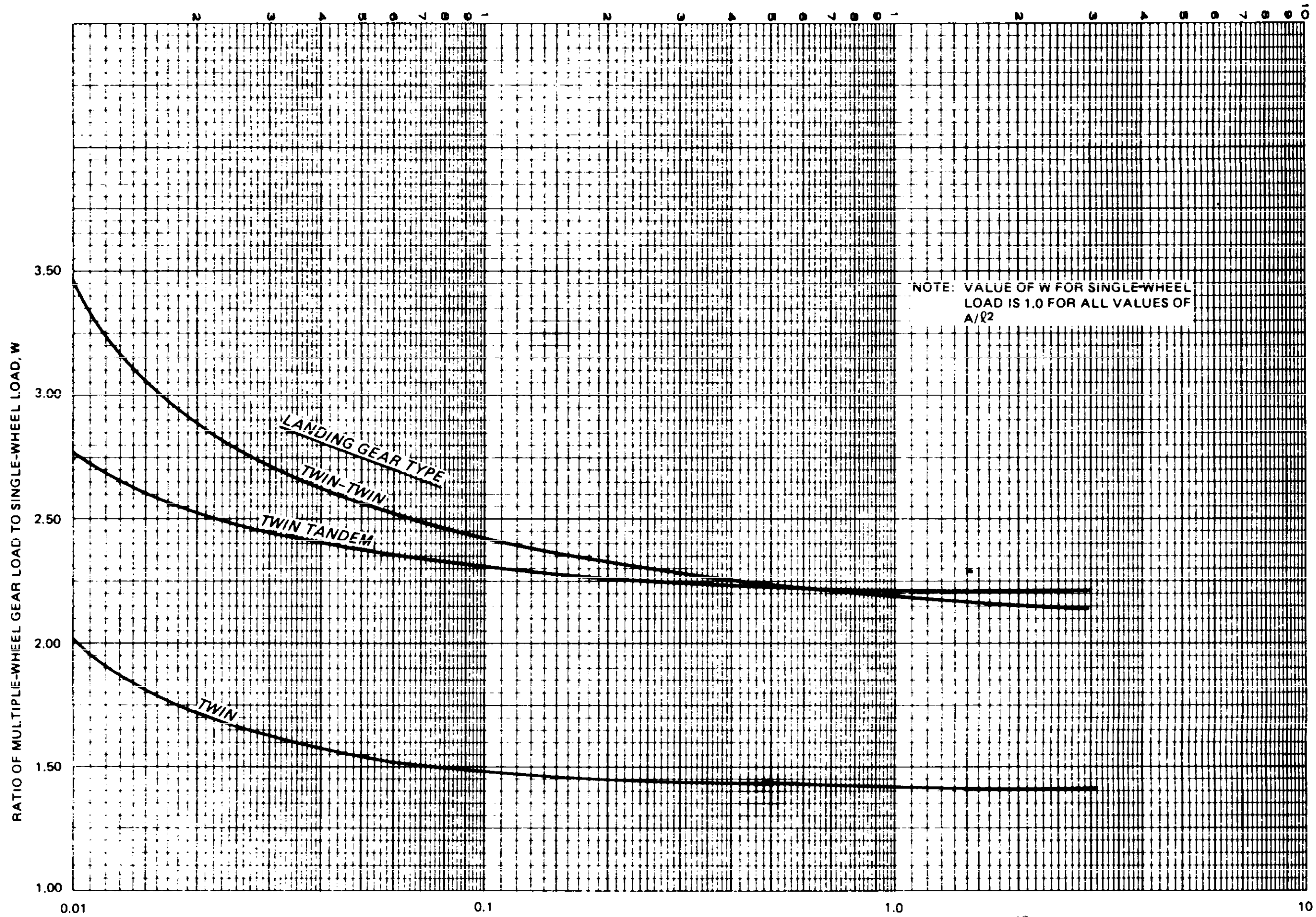


Figure 6-3. Ratio of multiple-wheel gear load to single-wheel gear load versus A/ℓ^2.

The equation above is applicable to the determination of A_s based upon a recommended maximum anchorage stress equal to seven-tenths of the ultimate strength of the tendon steel. If the steel is anchored at a stress other than seven-tenths of the ultimate strength, the equation above must be modified accordingly. With the total required A_s determined, the number and size of prestressing tendons can be selected. Spacings of two to four times the prestressed concrete pavement thickness are recommended for the longitudinal tendons, and spacings of three to six times the prestressed concrete pavement thickness are recommended for the transverse tendons.

c. Prestressing steel tendons. The tendons used for prestressed concrete pavement will consist of either high-strength wires, strands, or bars.

(1) Wires will conform to the requirements of ASTM A 421.

(2) Seven-wire strands will conform to the requirements of ASTM A 416.

(3) High-strength bars will conform to the requirements of section 405(f) of ACI 318.

d. Prestressing conduits. Conduits used for enclosing the steel tendons should be either rigid or flexible metal tubing. However, the tendons may be plastic-encased.

(1) Metal conduits must be strong enough to resist damage in transit or during handling. The metal may be bright or galvanized.

(2) When tendons are plastic-encased, the tendons should be permanently protected from rust or corrosion.

e. Placement of tendons and conduits. The transverse conduits will be placed on metal chairs at the desired depth and used to support the longitudinal conduits or tendons. Conduits and tendons will be tied firmly in place to maintain proper alinement during placement of the concrete. A preliminary stress applied to the tendons may help maintain the alinement. The inside diameter of metal conduits will be at least 0.25 inch larger than the diameter of the stressing tendons. The minimum cover of the conduits will be 3 inches at the pavement surface and 2 inches at the bottom of the pavement.

f. Tendon stressing. The prestressed tendons must be stressed to provide a stress in the concrete equal to 1.2 times the design prestress, d_s, plus sufficient stress to overcome the frictional resistance between the tendon and conduit. After concrete placement and prior to beginning the prestressing operation, any preliminary tension in the tendons must be released. If the tendons are conduit-encased, they should be pulled back and forth several times to reduce and to measure the tendon stress due to friction. This need not be done for plastic-encased tendons. The measured tendon-friction stress

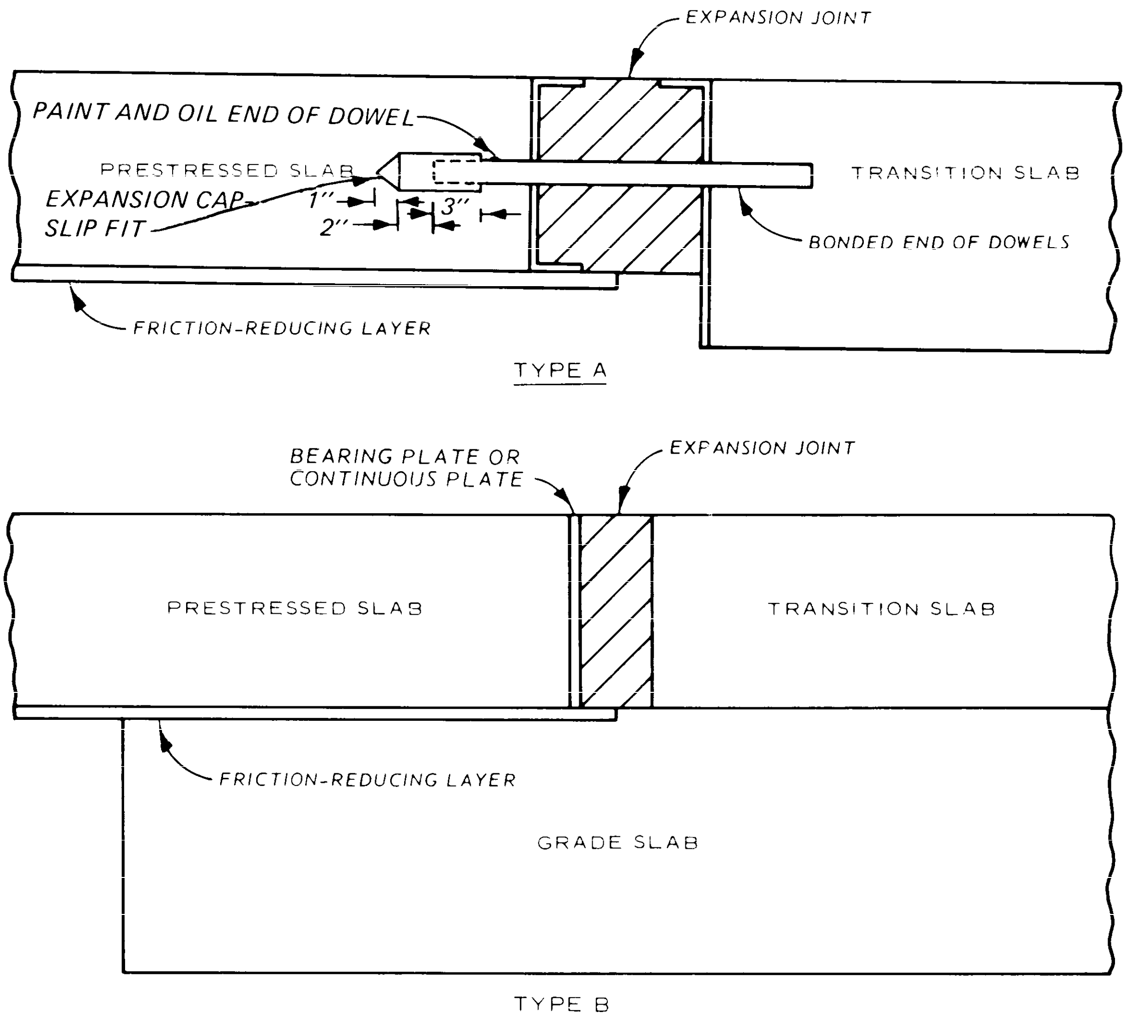


Figure 6-4. Typical sections of transverse joints.

must be added to the tendon stress required to produce $1.2d_s$ in the concrete. If the tendons were sized as described in b above, the required tendon stress will be the selected anchorage stress ($0.7f_{\mu}$ or other value if used to size the tendon), plus the stress required to overcome friction. After the maximum tendon stress is reached, it will be held for several minutes and then released to the selected anchorage stress. The longitudinal tendon stressing will be applied in three stages with the amount of prestress at each successive stage being 25, 50, and 100 percent of the anchorage stress. The prestressing will be applied as soon as possible to prevent or minimize the occurrence of contraction cracking in the concrete.

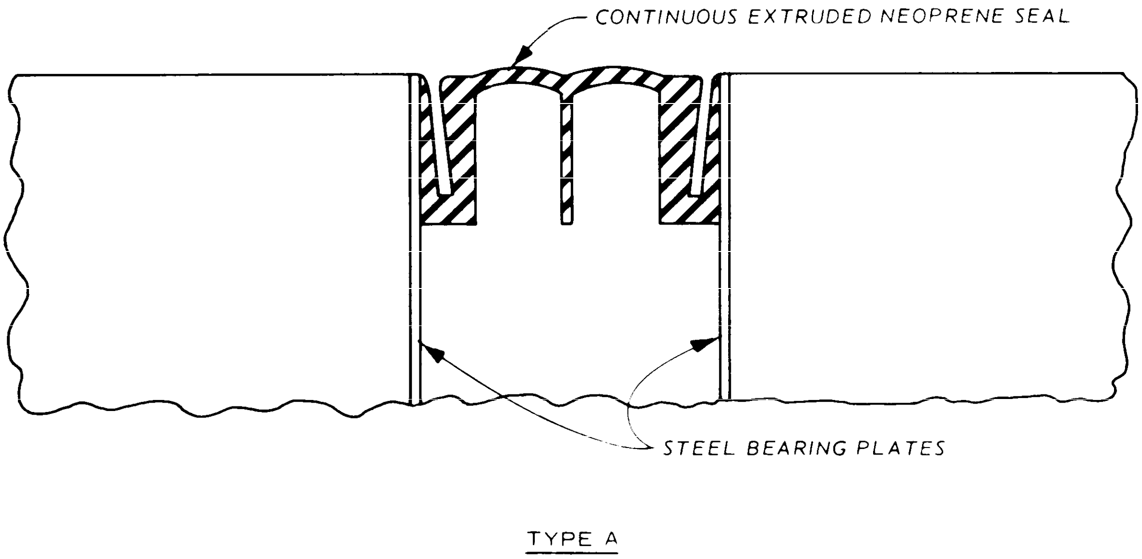
g. Grouting. When the stressing tendons are placed in conduits, the space between the tendons and conduits will be grouted after the final prestressing load is reached. The grout will be made from either cement and water or cement, fine sand, and water. Admixtures to obtain high early strength or to increase workability may be used if they will have no injurious effects on the stressing tendons or conduits. Grouting vents will be provided at each end of the conduits and along the conduits at intervals not to exceed 150 feet. A grouting pump will be used to inject the grout. The grouting will commence at an end vent and continue until grout is forced out of the first interior vent along the conduit. The end vent will then be sealed, and grout will be injected through the first interior vent until it is extruded from the second interior vent. This procedure will be continued until the entire length of conduit has been grouted.

6-7. Jointing

a. Joint spacing. Experience has shown that from a practical standpoint, the maximum length of prestressed concrete slabs should be 500 feet, although lengths of 600 and 700 feet have been constructed. The width of the slab will vary depending upon the capability of the construction equipment but will generally be a minimum of 25 feet.

b. Joint types.

(1) Longitudinal joint. Runway and taxiway pavements will be prestressed for their full width, and the longitudinal joints will be the butt type with the prestressed tendons carried through the joint. The transverse prestressing operation will be carried out after all paving lanes have been completed. For areas wider than 500 feet (such as aprons), the pavement must be constructed in widths not to exceed 500 feet; therefore, lon-



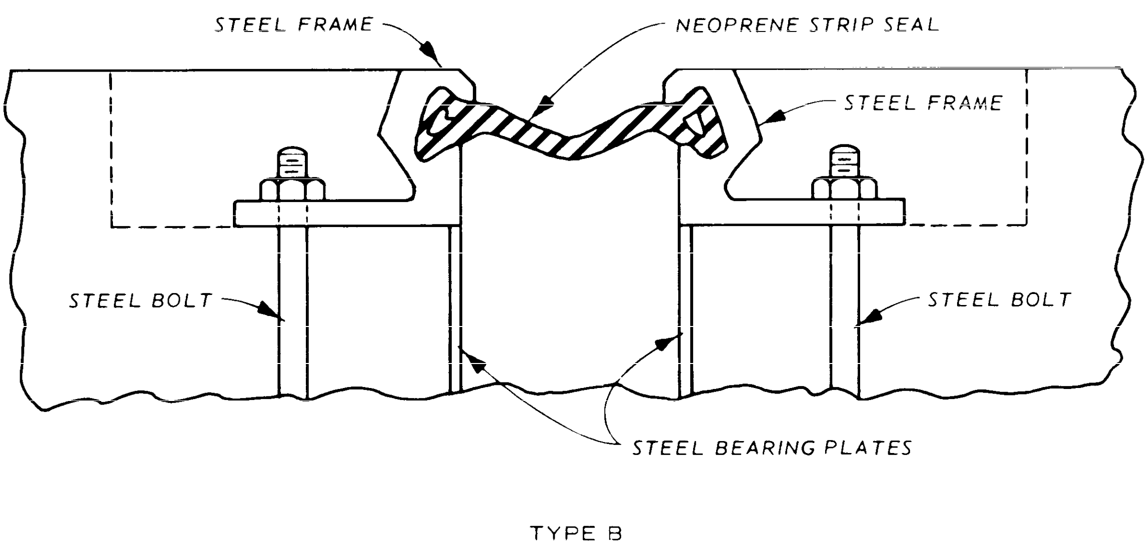


Figure 6-5. Typical transverse joint seals. (Sheet 1 of 3)

gitudinal fill-in lanes will be required to permit access for applying the transverse prestressing.

(2) Transverse joint. Because of the length of prestressed slabs and the low subgrade restraint, large movements will occur at the transverse joints. The transverse joint must be designed to accommodate these movements that are a function of the temperature change, slab length, and moisture conditions. The anticipated movements can be determined by

$$\Delta_{LT} = 12L\epsilon_c\Delta T \quad \text{(eq 6-6)}$$

and

$$\Delta_{LM} = 12L\epsilon_M \quad \text{(eq 6-7)}$$

where

Δ_{LT} = change in length of slab due to temperature change ΔT, inches

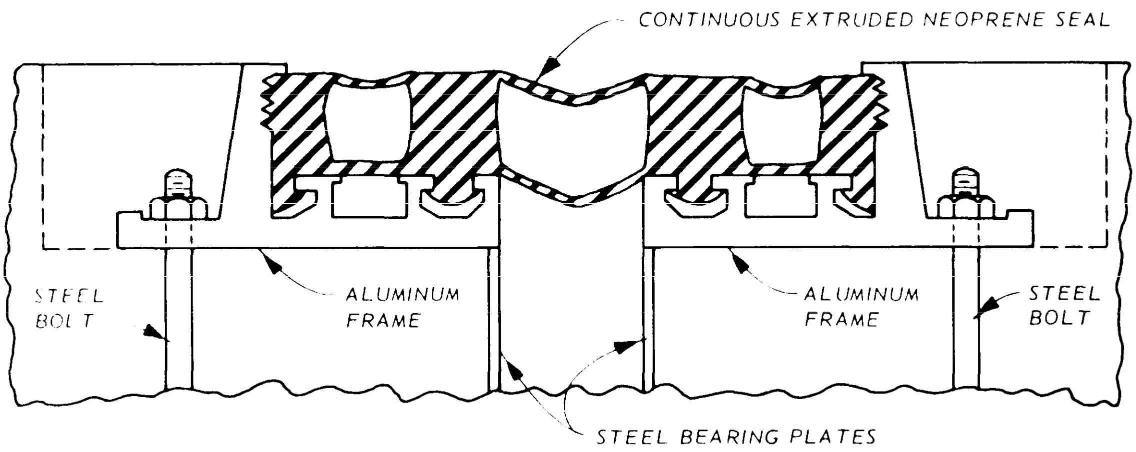
L = slab length, feet

Δ_T = change in temperature in degrees (either daily or seasonally)

Δ_{LM} = maximum change in length of slab due to seasonable moisture change

ϵ_M = coefficient of moisture expansion of concrete (assumed to be 1×10^{-4} inch per inch seasonally)

The transverse joint must be capable of withstanding the sum of the temperature and moisture change in



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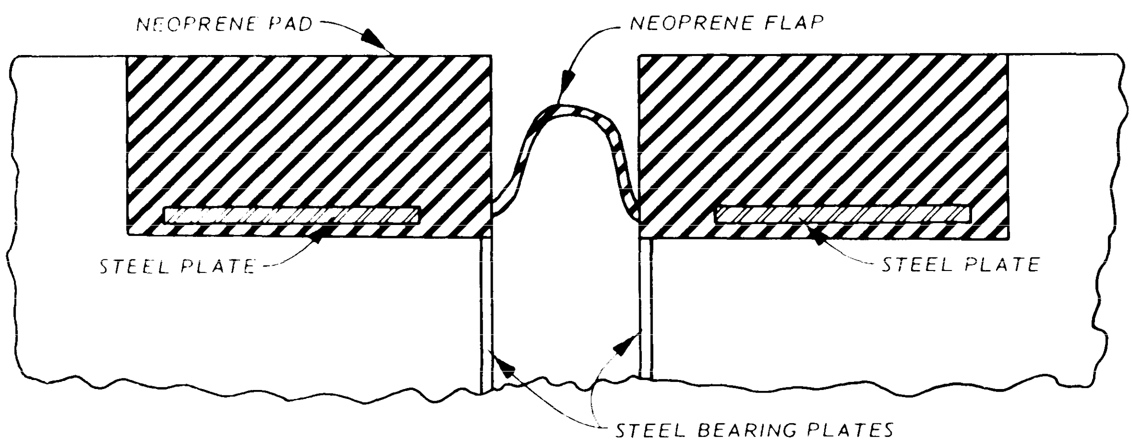
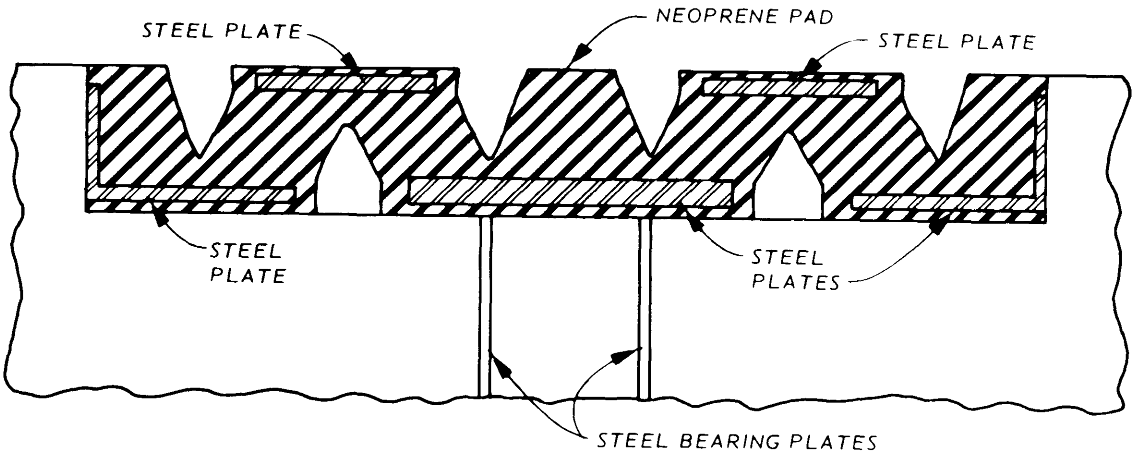


TYPE D

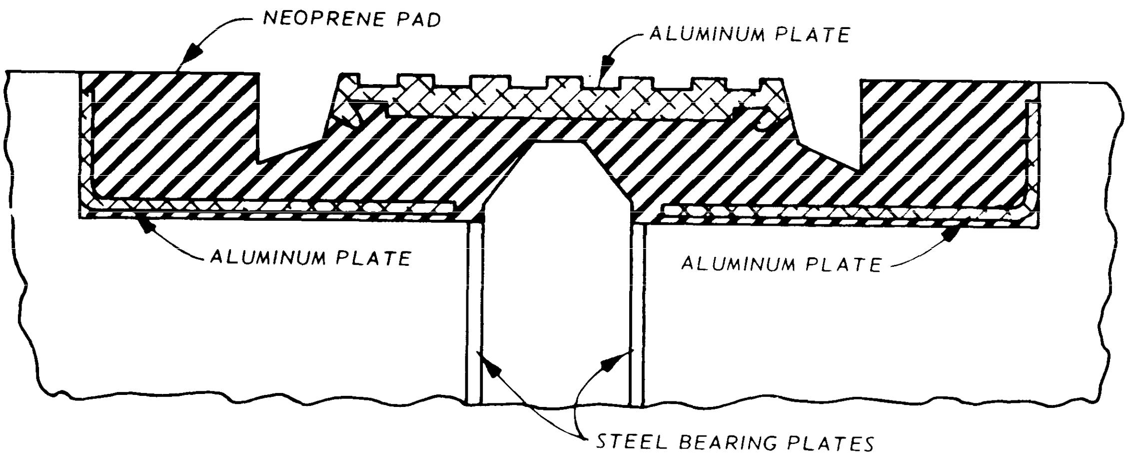
Figure 6-5. Typical transverse joint seals. (Sheet 2 of 3)

length. Figure 6–4 shows typical sections of two general methods of construction of the transverse joints. Type A consists of having the transition slab rest directly on the subbase. The transition slab will be constructed to the thickness requirements of either plain or reinforced concrete pavements and connected to the prestressed slabs with dowel bars to provide load transfer through the joint. The size and spacing of the dowel bars will be determined from chapter 2 based upon the plain or reinforced concrete thickness requirements. Type B consists of a grade slab underlying the ends of the prestressed concrete pavement and transition slab. The transition slab will be reinforced concrete of the same thickness as the prestressed concrete pavement. The grade slab will also be reinforced concrete. The thickness of the grade slab and the percent of reinforcing steel in both the transition slab and grade slab will be determined in accordance with overlay design procedures if the transition slab is a reinforced concrete overlay of the reinforced grade slab.

c. Joint seals. Longitudinal joints in prestressed concrete pavements, except where longitudinal transition lanes will be required to permit prestressing operations of wide paved areas, need not be sealed since they will be held tightly closed by the prestressing. However, if these joints are sealed, materials meeting the requirements



TYPE E



TYPE F

Figure 6-5. Typical transverse joint seals. (Sheet 3 of 3)

for plain concrete pavements should be used. When longitudinal transition lanes are required, the longitudinal joint should be treated in the same manner as a transverse joint. Several types of sealants have been used for the transverse joints, but no standardized seals have been established. Poured–in–place materials have not been satisfactory to accommodate the large movements that occur. Preformed and mechanical seals, such as shown in figure 6–5, are recommended. The final selection of a sealant will be a matter of engineering judgment that must be approved by the Commander, U.S. Army Corps of Engineers, (DAEN–ECE–G), Washington, DC 20314–1000, or the appropriate MACOM.

6-8. Examples of prestressed concrete pavement design

a. General. A 75–foot–wide by 10,000–foot–long taxiway pavement is to be designed for 100,000 passes of the C–141 aircraft at 320,000 pounds gross weight using prestressed concrete. Laboratory and field test programs have yielded the following pertinent physical property data for the foundation and concrete: modulus of soil reaction, k = 200 pci; 90–day flexural strength of concrete, R = 700 psi; density of concrete = 150 pcf; modulus of elasticity in flexure of concrete, $E = 4 \times 10^6$ psi; Poisson's ratio of concrete, $\mu = 0.15$; and coefficient

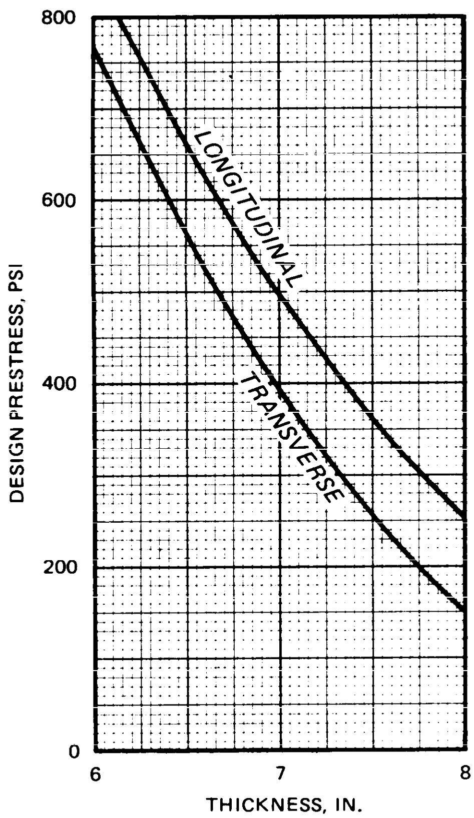


Figure 6-6. Thickness versus design prestress.

of thermal expansion of concrete, $\epsilon_c = 4 \times 10^{-6}$ inch per inch per degree F.

b. Determination of design prestress level. Prestress loads will be determined for preselected thicknesses, h_p, of 6, 7, and 8 inches. Following the procedures described in paragraph 6-5, the load-repetition factor, N, is 2.46 (fig 6-1) and the load-moment factor, B, is 0.0523, 0.0544, and 0.0565 for thicknesses of 6, 7, and 8 inches, respectively. The ratio of multiple-wheel gear load to single-wheel gear load, w is 2.22, 2.23, and 2.335 for thicknesses of 6, 7, and 8 inches, respectively. A polyethylene sheet bond-breaking medium will be used between the foundation and prestressed slab, and the coefficient of sliding friction, C_f, will be 0.60. A slab length, L, of 400 feet will be used; therefore, the subgrade restraint stress in the longitudinal direction will be

$$r_s = \frac{C_f L \gamma}{2(144)} = \frac{0.60 \times 400 \times 150}{2(144)} = 125 \text{ psi} \qquad \text{(eq 6-8)}$$

In the transverse direction, the subgrade restraint stress will be

$$r_s = \frac{C_f W \gamma}{2(144)} = \frac{0.60 \times 75 \times 150}{2(144)} = 23.4 \text{ psi} \qquad \text{(eq 6-9)}$$

The maximum difference in temperature between the top and bottom of the prestressed concrete pavement is estimated to be about 6, 7, and 8 degrees for the 6-, 7-, and 8-inch pavements, respectively, with resulting temperature warping stresses of 46, 65, and 75 psi, respectively. The design prestressing required in the concrete is then determined by the following equation:

$$d_s = \frac{6PNB}{wh_p^2} - R + r_s + t_s \qquad \text{(eq 6-10)}$$

For h_p values of 6, 7, and 8 inches, the design prestress, d_s, in the longitudinal direction will be 853, 492, and 253 psi, respectively, and in the transverse direction the values of d_s will be 761, 391, and 151 psi, respectively. Plotting these values, as shown in figure 6-6, permits the selection of various thicknesses and prestressing levels that will support the design loading condition. Experience has shown that d_s levels between 100 and 400 psi are most practicable; therefore, from figure 6-6, a 7.5-inch pavement with longitudinal prestress of 360 psi and transverse prestress of 250 psi would provide a satisfactory pavement. With a slab length of 400 feet, 25 slabs and thus 24 joints will be required for the 10,000-foot-long taxiway. In actual design, several combinations of k, h_p, slab length, etc., should be considered, and the final selection should be based on an economic study considering all aspects of material and construction costs.

c. Prestressed tendon design. Plastic-encased stranded wire having an ultimate strength, f_μ, of 240,000 psi is selected for the prestressed tendons. The stranded wire tendon will be finally anchored at a stress not to exceed $0.7f_\mu$ or 168,000 psi. The required area of steel in the longitudinal and transverse directions to achieve the design prestressing level in the concrete and allowing for the various tendon stress losses will be

Longitudinal Direction

$$A_s = \frac{1.2 \times 360 \times 7.5 \times 75 \times 12}{0.7 \times 240{,}000} = 17.4 \text{ square inches} \qquad \text{(eq 6-11)}$$

Transverse Direction

$$A_s = \frac{1.2 \times 250 \times 7.5 \times 400 \times 12}{0.7 \times 240{,}000} = 64.3 \text{ square inches} \qquad \text{(eq 6-12)}$$

Several combinations of wire diameter and spacing will yield the required cross-sectional area of steel for the stressing tendons. For example, if in the longitudinal direction, a spacing of four times the prestressed concrete pavement thickness (30 inches) is selected, then 30 tendons will be required, each having a cross-sectional area of 0.58 square inch and diameter of 0.86 inch. Therefore, a 7/8-inch-diameter tendon could be selected. Selection of a tendon that is greater or less than that required may require the final anchor stress to be revised. If, in the transverse direction, a spacing of five times the prestressed concrete pavement thickness (37.5 inches) is selected, then 128 tendons would be needed and the required cross-sectional area of the tendons would be 0.50 square inch. Therefore, a 13/16-inch-diameter tendon would provide the required prestressing.

CHAPTER 7
OVERLAY PAVEMENT DESIGN

7-1. General

Overlay pavements are designed to increase the load-carrying capacity (strength) of the existing pavement. The basis for design is to provide a layer or layers of material on the existing pavement that will result in a layered system which will yield the predicted performance of a new rigid pavement if constructed on the same foundation as the existing pavement. Two general types of overlay pavement are considered: rigid and nonrigid. The procedures described will use the rigid overlays to strengthen existing rigid or flexible pavements and nonrigid overlays to strengthen existing rigid pavements. The strengthening of existing flexible pavements with additional flexible material will be accomplished in accordance with TM 5-825-2/NAVFAC DM 21.3/AFM 88-6, Chap. 2. Procedures are presented for the design of plain concrete, reinforced concrete, continuously reinforced concrete, fibrous concrete, prestressed concrete, and nonrigid overlays. Nonrigid overlays include both flexible (nonstabilized base and bituminous concrete wearing course) and all-bituminuous concrete for strengthening existing plain concrete or reinforced concrete pavements. Continuously reinforced, fibrous, and prestressed concrete overlays will not be permitted unless it is technically and economically justified and approved by the Commander, U.S. Army Corps of Engineers (DAEN-ECE-G), Washington, DC 20314-1000, or HQ, Air Force Engineering and Services Center (AFESC/DEMP), Tyndall AFB, FL 32403-6001. Flexible overlays will be used only when the nonstabilized aggregate base course can be positively drained. The use of flexible overlays and the design of the drainage system must be approved by the Commander, U.S. Army Corps of Engineers (DAEN-ECE-G), Washington, DC 20314-1000, or HQ, Air Force Engineering and Services Center (AFESC/DEMP), Tyndall AFB, FL 32403-6001. Guidance for the use of rigid and nonrigid overlays to strengthen other types of existing rigid pavements (such as continuously reinforced, fibrous, or prestressed) may be obtained from the Commander, U.S. Army Corps of Engineers (DAEN-ECE-G), Washington, DC 20314-1000, or the appropriate MACOM.

7-2. Site investigations

Explorations and tests of the existing pavement will be made to determine the structural condition of the existing pavement prior to overlay, assess the required physical properties of the existing pavement and foundation materials, and locate and analyze all existing areas of defective pavement and subgrade that will require special treatment. The determination of the structural condition and required physical properties of the existing pavement will depend upon the type of overlay used as described in subsequent paragraphs. An investigation will be conducted to determine whether there are any voids under the existing rigid pavement. This investigation is especially important if there has been, or is, any evidence of pumping or bleeding of water at cracks, joints, or edges of the existing rigid pavement. Nondestructive pavement test equipment has application for this type of investigation, and its availability can be obtained from the Commander, U.S. Army Corps of Engineers (DAEN-ECE-G), Washington, DC 20314-1000, or HQ Air Force Engineering and Services Center (AFESC/DEMP), Tyndall AFB, FL 32403-6001. If voids are found under the existing rigid pavements, fill the voids with grout before the overlay is placed. The results of the investigation, especially the nondestructive tests, may show rather large variations in the strength of the existing pavement and may lead to a requirement for more extensive testing to determine the cause of the variation. It will then be necessary to determine the feasibility and economics of using a variable thickness overlay, basing the design on the lower strength pavement section, or removing and replacing the low-strength pavement areas.

7-3 Preparation of existing pavement

a. General. The preparation of the existing pavement prior to overlay will vary, depending upon whether the overlay is rigid or nonrigid.

b. Rigid overlay. Overlay thickness criteria are presented for three conditions of bond between the rigid overlay and existing rigid pavement: fully bonded, partially bonded, and nonbonded. The fully bonded condition is obtained when the concrete is cast directly on concrete and special efforts are made to obtain bond. The partially bonded condition is obtained when the concrete is cast directly on concrete with no special efforts to achieve or destroy bond. The nonbonded condition is obtained when the bond is prevented by an intervening layer of material. When a fully bonded or partially bonded rigid overlay is to be used, the existing rigid pavement will be cleaned of all foreign matter (such as oil and paint), spalled concrete, extruded joint seal, bituminous patches, or anything else that would act as a bond-breaker between the overlay and existing rigid pavement. In addition, for the fully bonded overlay, the surface of the existing pavement must be prepared using acid etching and thorough flushing with water. A sand-cement grout or an epoxy grout is applied to the cleaned surface just prior to placement of the concrete overlay. When a nonbonded rigid overlay is being used, the existing rigid pavement will be cleaned of all loose particles and covered with a leveling or bond-breaking course of bituminous concrete, sand-asphalt, heavy building paper, polyethylene, or other similar stable material. The bond-breaking medium generally should not exceed a thickness of about 1 inch except in the case of leveling courses where greater thicknesses may be necessary. When a rigid overlay is being applied to an existing flexible pavement, the surface of the existing pavement will be cleaned of loose materials and any potholing or unevenness, exceeding about 1 inch, will be repaired by cold planing or localized patching or the application of a leveling course using bituminous concrete, sand–asphalt, or a similar material.

c. Nonrigid overlay. When a flexible overlay is used, no special treatment of the surface of the existing rigid pavement will be required, other than the removal of loose material. When an all–bituminous concrete overlay is used, the surface of the existing rigid pavement will be cleaned of all foreign matter, spalled concrete, fat spots in bituminous patches, and extruded soft or spongy joint seal material. Joints or cracks less than 1 inch wide in the existing rigid pavement will be filled with joint sealant. Joints or cracks that are 1 inch or greater in width will be cleaned and filled with an acceptable bituminous mixture (such as sand-asphalt) which is compatible with the overlay. Leveling courses of bituminous concrete will be used to bring the existing rigid pavement to the proper grade when required. Prior to placing the all–bituminous concrete overlay, a tack coat will be applied to the surface of the existing pavement.

7-4. Condition of existing concrete pavement

a. General. The support that the existing rigid pavement will provide to an overlay is a function of its structural condition just prior to the overlay. In the overlay design equations, the structural condition of the existing concrete pavement is assessed by a condition factor, C. The value of C should be selected based upon a condition survey (TM 5-827-3/AFM 88-24, Chap. 3) of the existing rigid pavement. Interpolation of C values between those shown below may be used if it is considered necessary to more accurately define the existing structural condition. As an alternative, figure 7-1 may be used to select the C value for plain concrete or nonrigid overlays. This figure relates a structural condition index (SCI) and C. The SCI is that part of the pavement condition index (PCI) related to structural distress types as deduct values. To determine SCI values, a condition survey is conducted according to AFR 93-5. However, rather than calculating the PCI, an SCI is calculated by subtracting the deduct values for corner breaks, longitudinal, transverse and diagonal cracking, shattered slabs, spalling along joints, and spalling corners from 100.

b. Plain concrete overlay. The following values of C are assigned for the following conditions of plain and reinforced concrete pavements.

(1) Condition of existing plain concrete pavement:

C = 1.00—pavements in the trafficked areas are in good condition with little or no structural cracking due to load

C = 0.75—pavements in the trafficked areas exhibit initial cracking due to load but no progressive cracking or faulting of joints or cracks

C = 0.35—pavements in the trafficked areas exhibit progressive cracking due to load accompanied by spalling, raveling, or faulting of cracks and joints

(2) Condition of existing reinforced concrete pavement.

C = 1.00—pavements in the trafficked areas are in good condition with little or no short–spaced transverse (1- to 2–foot) cracks, no longitudinal cracking, and little spalling or raveling along cracks

C = 0.75—pavements in the trafficked areas exhibit short–spaced transverse cracking but little or no interconnecting longitudinal cracking due to load and only moderate spalling or raveling along cracks

C = 0.35—pavements in the trafficked areas exhibit severe short-spaced transverse cracking and interconnecting longitudinal cracking due to load, severe spalling along cracks, and initial punchout –type failures

c. Nonrigid overlay. The following values of C are assigned for the following conditions of plain and reinforced concrete pavement.

(1) Condition of existing plain concrete pavements.

C = 1.00—pavements in the trafficked areas are in good condition with some cracking due to load but little or no progressive–type cracking

C = 0.75—pavements in the trafficked areas exhibit progressive cracking due to load and spalling, raveling, and minor faulting at joints and cracks

C = 0.50—pavements in the trafficked areas exhibit multiple cracking along with raveling, spalling, and faulting at joints and cracks

(2) Condition of existing reinforced concrete pavement.

C = 1.00—pavements in the trafficked areas are in good condition but exhibit some closely spaced load-induced transverse cracking, initial interconnecting longitudinal cracks, and moderate spalling or raveling of joints and cracks

C = 0.75—pavements in trafficked areas exhibit numerous closely spaced load-induced transverse and longitudinal cracks, rather severe

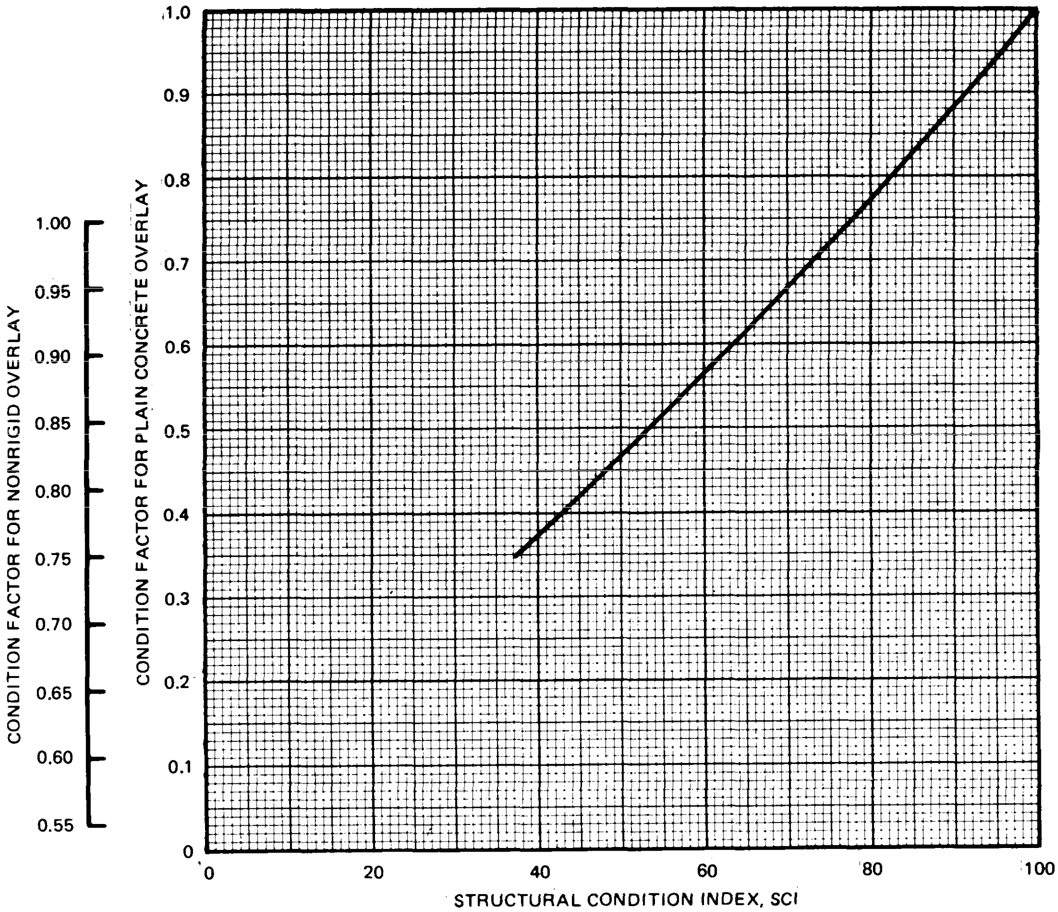


Figure 7-1. Structural condition index versus condition factor.

spalling or raveling, or initial evidence of punchout failures

7-5. Rigid overlay of existing rigid pavement

a. General. There are three basic equations for the design of rigid overlays which depend upon the degree of bond that develops between the overlay and existing pavement: fully bonded, partially bonded, and nonbonded. The fully bonded overlay equation is used when special care is taken to provide bond between the overlay and the existing pavement. The partially bonded equation will be used when the rigid overlay is to be placed directly on the existing pavement and no special care is taken to provide bond. A bond-breaking medium and the nonbonded equation will be used when (a) a plain concrete overlay is used to overlay an existing reinforced concrete pavement, (b) when a continuously reinforced or prestressed concrete overlay is used to overlay an existing plain concrete or reinforced concrete pavement, (c) when a plain concrete overlay is being used to overlay an existing plain concrete pavement that has a condition factor $C \leq 0.35$, and (d) when matching joints in a plain concrete overlay with those in the existing plain concrete pavement causes undue construction difficulties or results in odd-shaped slabs.

b. Plain concrete overlay.

(1) Thickness determination. The required thickness, h_o, of plain concrete overlay will be determined from the following applicable equations:

Fully bonded

$$h_o = h_d - h_E \qquad \text{(eq 7-1)}$$

Partially bonded

$$h_o = \sqrt[1.4]{h_d^{1.4} - C\left(\frac{h_d}{h_e} \times h_E\right)^{1.4}} \qquad \text{(eq 7-2)}$$

Nonbonded

$$h_o = \sqrt{h_d^2 - C\left(\frac{h_d}{h_e} \times h_E\right)^2} \qquad \text{(eq 7-3)}$$

where h_d and h_e are design thicknesses of plain concrete pavement determined using the design flexural strength of the overlay and measured flexural strength of the existing rigid pavement, respectively; the modulus of soil reaction, k, of the existing rigid pavement foundation; and the design loading, traffic area, and pass level needed for overlay design. Use of the fully bonded overlay is limited to existing pavements having a condition index of 1.0, and to overlay thickness of 2.0 to 5.0 inches. The fully bonded overlay is used primarily to correct a surface problem such as scaling rather than as a structural upgrade. The factor h_E represents the thickness of the existing plain concrete pavement or the equivalent thickness of plain concrete pavement having the same load-carrying capacity as the existing pavement. If the existing pavement is reinforced concrete, h_E is determined from figure 3-1 using the percent reinforcing steel, S, and design thickness, h_e. The minimum thickness of plain concrete overlay will be 2 inches for a fully bonded overlay, and 6 inches for a partially bonded or nonbonded overlay. The required thickness of overlay must be rounded to the nearest full or half-inch increment. When the indicated thickness falls midway between a full and half-inch, the thickness will be rounded upward.

(2) Jointing. For all partially bonded and fully bonded plain concrete overlays, joints will be provided in the overlay to coincide with all joints in the existing rigid pavement. It is not necessary for joints in the overlay to be of the same type as joints in the existing pavement. When it is impractical to match the joints in the overlay to joints in the existing rigid pavement, either a bond-breaking medium will be used and the overlay designed as a nonbonded overlay, or the overlay will be reinforced over the mismatched joints. Should the mismatch of joints become severe, a reinforced concrete overlay design should be considered as an economic alternative to the use of nonbonded plain concrete overlay. For nonbonded plain concrete overlays, the design and spacing of transverse contraction joints will be in accordance with requirements for plain concrete pavements on grade. For both partially bonded and nonbonded plain concrete overlays, the longitudinal construction joints will be doweled using the dowel size and spacing given in table 2-2. Any contraction joint in the overlay that coincides with an expansion joint in the existing rigid pavement within the prescribed limits of a type A traffic area will be doweled. Dowels and load-transfer devices will not be used in fully bonded overlays. Joint sealing for plain concrete overlays will conform to the requirements for plain concrete pavements on grade.

(3) Example of plain concrete overlay design. An existing plain concrete pavement will be strengthened to serve as a type A traffic area for a medium-load pavement (TM 5-824-1/AFM 88-6, Chap. 1) using a plain concrete overlay. The pertinent physical properties of the existing rigid pavement are: $h_E = 8$ inches, $R = 700$ psi, and $k = 100$ pci. The design (90-day) flexural strength of the concrete for the overlay is 750 psi.

(a) The existing pavement is showing some initial cracking due to load so that the condition factor, C, is 0.75. The condition of the existing pavement is such that there is no reason to use a leveling course or other bond-breaking medium. The required thickness h_o, of the plain concrete overlay is then determined using the partially bonded overlay equation:

$$h_o = \sqrt[1.4]{h_d^{1.4} - C\left(\frac{h_d}{h_e} \times h_E\right)^{1.4}}$$

The design thickness, h_d, of plain concrete pavement, using the design flexural strength of the overlay concrete (750 psi) and k value of the existing foundation (100 pci) from figure 2-5 (medium-load design curve) and type A traffic area, is 16.7 inches. The design thickness, h_e, of plain concrete pavement using the flexural strength of the existing pavement (700 psi) and k value of 100 pci from figure 2-3 is 17.6 inches. Since the existing rigid pavement is plain concrete, $h_E = 8$ inches. Substituting these values in the equation above,

$$h_o = \sqrt[1.4]{16.7^{1.4} - 0.75\left(\frac{16.7}{17.6} \times 8\right)^{1.4}}$$

$$= 13.6 \text{ inches (use 13.5 inches)}$$

(b) The existing rigid pavement is 8 inches of reinforced concrete with 0.15 percent of reinforcing steel, S, and a condition factor, C, of 0.75. All properties of the existing pavement and proposed plain concrete overlay are the same as above. Since the existing pavement is reinforced concrete, it will be necessary to use a bond-breaking medium and determine the required thickness of plain concrete overlay using the nonbonded overlay equation:

$$h_o = \sqrt{h_d^2 - C\left(\frac{h_d}{h_e} \times h_E\right)^2} \qquad \text{(eq 7-3)}$$

The design thickness, h_d, of plain concrete is 16.7 inches, and the design thickness, h_e, is 17.6 inches. The value of h_E, the thickness of plain concrete pavement equivalent to the existing thickness of reinforced concrete pavement, determined from figure 3-1 using the existing thickness of reinforced concrete pavement of 8 inches and $S = 0.15$ percent, is 9.5 inches. Substituting these values in the equation above,

$$h_o = \sqrt{16.7^2 - 0.75\left(\frac{16.7}{17.6} \times 9.5\right)^2}$$

$$= 14.7 \text{ inches (use 14.5 inches)}$$

c. *Reinforced concrete overlay.* A reinforced concrete overlay may be used to strengthen either an existing plain concrete or reinforced concrete pavement. Generally, the overlay will be designed as a partially bonded overlay. The nonbonded overlay design will be used only when a leveling course is required over the existing pavement. The reinforcement steel for reinforced concrete overlays will be designed and placed in accordance with reinforced concrete slabs on grade.

(1) Thickness determination. The required thickness of reinforced concrete overlay will be determined using figure 3-1 after the thickness of plain concrete overlay has been determined using the appropriate overlay equation. Then, using the value for the thickness of plain concrete overlay, either the thickness of reinforced concrete overlay can be selected and the required percent steel determined, or the percent steel can be selected and the thickness of reinforced concrete overlay determined from figure 3-1. The minimum thickness of reinforced concrete overlay will be 6 inches.

(2) Jointing. Whenever possible, the longitudinal construction joints in the overlay should match the lon-

gitudinal joints in the existing pavement. All longitudinal joints will be of the butt-doweled type with dowel size and spacing designated in accordance with paragraph 2-4using the thickness of reinforced concrete overlay. It is not necessary for transverse joints in the overlay to match joints in the existing pavement; however, when practical, the joints should be matched. The maximum spacing of transverse contraction joints will be determined in accordance with figure 3-1 or paragraph 2-4b, but it will not exceed 100 feet regardless of the thickness of the pavement or the percent steel used. Joint sealing for reinforced concrete pavements will conform to the requirements for plain concrete pavements.

(3) Example of reinforced concrete overlay design. An existing rigid pavement will be strengthened to serve as a type B traffic area for a heavy-load pavement (TM 5-824-1/AFM 88-6, Chap. 1) using a reinforced concrete overlay. The pertinent physical properties of the existing rigid pavement are: $h_E = 10$ inches, $R = 650$ psi, and $k = 200$ pci. The design (90-day) flexural strength of the overlay is 750 psi.

(a) The existing rigid pavement is plain concrete ($h_E = 10$ inches) with a structural condition, C, of 0.35; however, there is no significant faulting of the slabs and a leveling course is not needed. The required thickness of plain concrete overlay is determined using the partially bonded overlay equation:

$$h_o = \sqrt[1.4]{h_d^{1.4} - C\left(\frac{h_d}{h_e} \times h_E\right)^{1.4}}$$

The required thickness, h_d, of plain concrete pavement for the design flexural strength of the overlay concrete (750 psi) and the k value of the foundation under the existing pavement (200 pci) determined from figure 2-6 (heavy-load design curve) type B traffic area is 19.3 inches. The design thickness, h_e, of plain concrete pavement for the flexural strength of the existing pavement (650 psi) and the k value of 200 pci from figure 2-6 is 21.4 inches. Since the existing pavement is plain concrete, the equivalent thickness, h_E, is equal to the thickness of the existing slab (10 inches). Substituting these values in the equation above,

$$h_o = \sqrt[1.4]{19.3^{1.4} - 0.35\left(\frac{19.3}{21.4} \times 10\right)^{1.4}}$$

$$= 17.6 \text{ inches}$$

This is the thickness of the plain concrete overlay required to strengthen the existing plain concrete pavement for the design loading condition. The thickness of reinforced concrete overlay is then dependent upon the percent of reinforcing steel, S, that will be used. Let it be assumed that because of grade problems, the overlay thickness must be limited to 15 inches. Then, the value of S required, determined from figure 3-1 using the plain concrete overlay thickness of 17.6 inches and the reinforced concrete overlay thickness of 15 inches, is 0.13 percent. It is also noted from figure 3-1 that a maximum joint spacing of 75 feet may be used with a reinforcing steel having a yield strength, y_s, of 60,000 psi.

(b) The existing pavement in the example above consists of 10 inches of reinforced concrete with 0.10 percent of reinforcing steel and all other properties and design requirements remain the same. The thickness of plain concrete pavement, h_E, equivalent to the 10 inches of existing reinforced concrete pavement, determined from figure 3-1 using the existing thickness of 10 inches and $S = 0.10$, is 11.3 inches. Substituting these values in the partially bonded overlay equation yields a required overlay thickness, h_o, of plain concrete equal to:

$$h_o = \sqrt[1.4]{19.3^{1.4} - 0.35\left(\frac{19.3}{21.4} \times 11.3\right)^{1.4}}$$

$$= 17.3 \text{ inches}$$

From figure 3-1, the thickness of reinforced concrete overlay using the thickness of plain concrete of 17.3 inches and a percent steel of 0.13 is 14.7 inches.

d. Continuously reinforced concrete overlay. A continuously reinforced concrete overlay may be used to strengthen either an existing plain concrete or reinforced concrete pavement. For both conditions, a bond-breaking medium is required between the overlay and the existing pavement. The required thickness of a continuously reinforced concrete pavement is determined in the same manner and will be equal in thickness to a plain concrete overlay. Jointing and sealing of joints in a continuously reinforced concrete pavement will be the same as for continuously reinforced concrete pavements on grade.

e. Fibrous concrete overlay. A fibrous concrete overlay may be used to strengthen either an existing plain or reinforced concrete pavement. The mix proportioning of the fibrous concrete overlay will follow the considerations presented for fibrous concrete pavements on grade.

(1) Thickness determination. The required thickness of fibrous concrete overlay will be determined using the partially bonded or nonbonded overlay equations. Normally, the partially bonded equation will be used, but in cases of extremely faulted or uneven existing pavement surfaces, a leveling course may be required and the design of the overlay will be made using the nonbonded overlay equation. If the existing rigid pavement is plain concrete, then the equivalent thickness is equal to the existing slab thickness. If the existing rigid pavement is reinforced concrete, however, then the equivalent thickness must be determined from figure 3-1 using the thickness of the existing slab and the percent of reinforcing steel. The minimum thickness of fibrous concrete overlay will be 4 inches.

(2) Jointing. In general, the joint types, spacing, and designs discussed for plain concrete pavements apply to fibrous concrete overlays, except that for thicknesses from 4 inches to 6 inches, the maximum spacing will be 12½ feet. Joints in the fibrous overlay should coincide with joints in the existing rigid pavement. Longitudinal construction joints will be the butt-doweled type, and dowels will be required in transverse contraction

joints exceeding 50-foot spacings. For pavement thickness less than 6 inches, it will be necessary to obtain guidance on joint construction from the Commander, U.S. Army Corps of Engineers (DAEN-ECE-G), Washington, DC 20314-1000, or HQ Air Force Engineering and Service Center (AFESC/DEMP), Tyndall AFB, FL 32403-6001. Sealing of joints in fibrous overlays will be in accordance with sealing of joints in fibrous concrete pavements on grade.

(3) Example of fibrous concrete overlay design. An existing rigid pavement will be strengthened to serve as a type B traffic area for a light-load pavement (TM 5-824-1/AFM 88-6, Chap. 1 for design aircraft gross loading and pass level) using a fibrous concrete overlay. The pertinent physical properties of the existing rigid pavement are: existing thickness is 6 inches, R = 700 psi, and k = 100 pci. The design (90-day) flexural strength of the fibrous concrete overlay is 900 psi. The existing rigid pavement is plain concrete with a structural condition, C, of 1.0. A leveling course will not be required; therefore, the required thickness of fibrous concrete overlay will be determined using the partially bonded overlay equation. Use of this equation requires that h_d be the thickness of fibrous concrete from the appropriate fibrous concrete design curve. The design thickness of fibrous concrete pavement, using the design flexural strength of the fibrous concrete overlay (900 psi) and k value (100 pci) for the existing rigid pavement foundation from figure 4-4 is 8.99 inches. The design thickness of plain concrete, using the flexural strength of the existing pavement (700 psi) and k of 100 pci for the existing foundation strength, is 12.2 inches. Since the existing rigid pavement is plain concrete, h_E = 6 inches; substituting these values in the partially bonded overlay equation yields a required thickness of fibrous concrete overlay of

$$h_o = \sqrt[1.4]{8.99^{1.4} - 1.0\left(\frac{8.99}{12.2} \times 6\right)^{1.4}}$$

$$= 6.5 \text{ inches}$$

7-6. Prestressed concrete overlay of rigid pavement

A prestressed concrete overlay may be used above any rigid pavement. The procedure for designing the prestressed concrete overlay is to consider the base pavement to have a k value of 500 pci and design the overlay as a prestressed concrete pavement on grade.

7-7 Rigid overlay of existing flexible or composite pavement

Any type of rigid overlay may be used to strengthen an existing flexible or composite pavement. The existing pavement is considered to be a composite pavement when it is composed of a rigid base pavement that has been strengthened with 4 inches or more of nonrigid (flexible or all-bituminous) overlay. If the nonrigid overlay is less than 4 inches, the rigid overlay is designed using the nonbonded overlay equation. The design of the rigid overlay will follow the procedures outlined in chapters 2 through 6 of this manual. The strength afforded by the existing pavement will be characterized by the modulus of soil reaction, k, determined using the plate-bearing test, or figure 1-1. The following modifications or limitations apply: (a) the plate-bearing test will be performed when the pavement temperature equals or exceeds the maximum ambient temperature for the hottest period of the year, and (b) in no case will a k value greater than 500 pci be used for design. When figure 1-1 is used to estimate the k value at the surface of the existing flexible pavement, the bituminous concrete portion will be assumed to be unbound base material since its performance will be similar to a base course.

7-8. Nonrigid overlay of existing rigid pavement

a. General. Two types of nonrigid overlay, all-bituminous concrete overlay, and flexible overlay, may be used with certain reservations to strengthen an existing rigid pavement.

b. All-bituminous overlay. The all-bituminous overlay will be composed of hot-mix bituminous concrete meeting the requirements of TM 5-822-8. A tack coat is required between the existing rigid pavement and the overlay. The all-bituminous overlay is the preferred nonrigid type overlay to lessen the danger of entrapped moisture in the overlay.

c. Flexible overlay. The flexible overlay will be composed of hot-mix bituminous concrete and high-quality (California bearing ratio (CBR) = 100) crushed aggregate base provided positive drainage of the base course is achieved. The bituminous concrete will meet the requirements of TM 5-822 and the minimum thickness requirements of TM 5-825-2/NAVFAC DM 21.3/AFM 88-6. If the design thickness of nonrigid overlay is less than that required by the minimum thickness of bituminous concrete and base course, the overlay will be designed as an all-bituminous overlay.

d. Thickness determination. Regardless of the type of nonrigid overlay, the required thickness, t_o, will be determined by

$$t_o = 3.0\,(Fh_d - Ch_E) \quad \text{(eq 7-4)}$$

where h_d is the design thickness of plain concrete pavement using the flexural strength, R, of the concrete in the existing rigid pavement and the modulus of soil reaction, k, of the existing pavement. The factor h_E represents the thickness of plain concrete pavement equivalent in load-carrying ability to the thickness of existing rigid pavement. If the existing rigid pavement is plain concrete, then the equivalent thickness equals the existing thickness; however, if the existing rigid pavement is reinforced concrete, the equivalent thickness must be determined from figure 3-1. F is a factor, determined from figure 7-2 that projects the cracking expected to occur in the base pavement during the design life of the overlay. Use of figure 7-2 requires converting

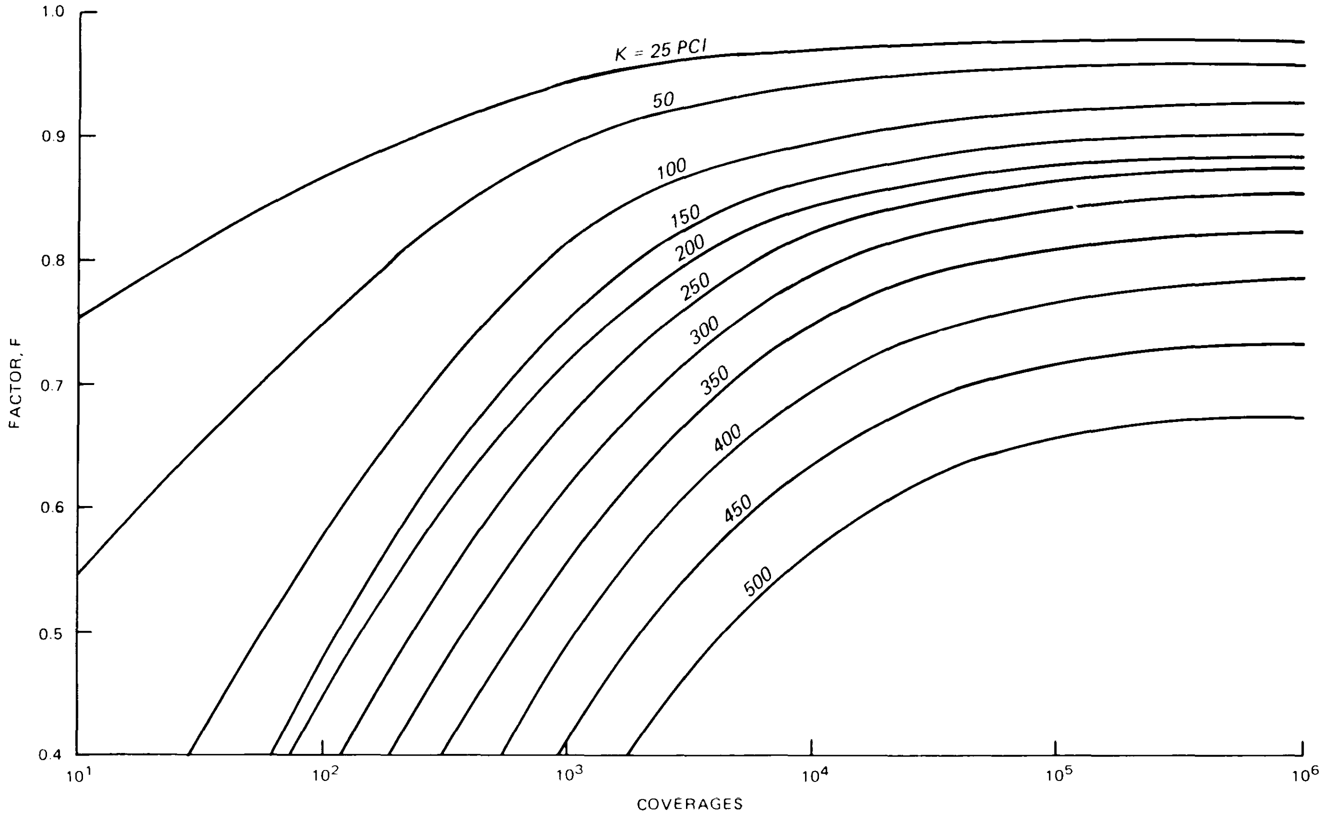


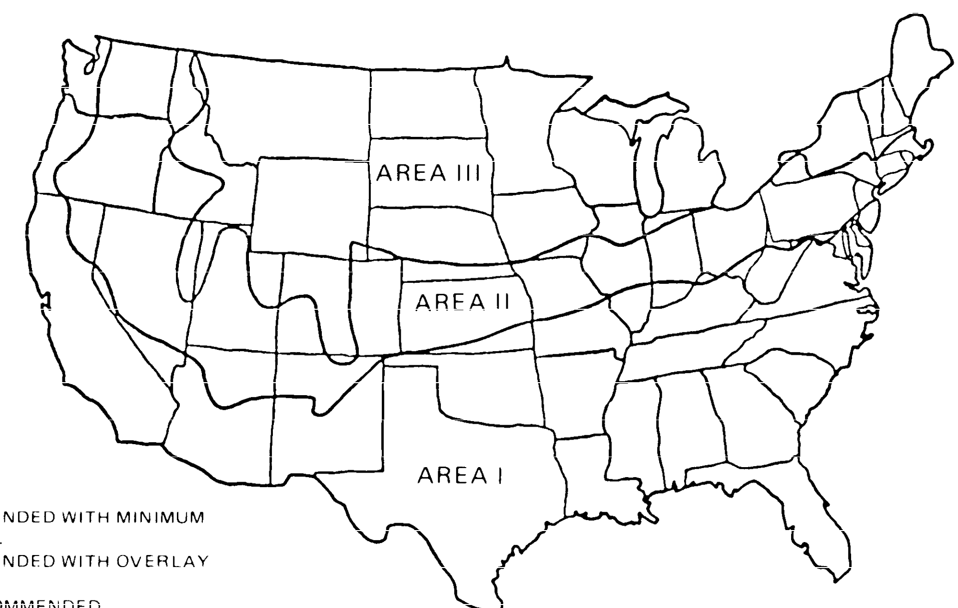
Figure 7-2. Factor for projecting cracking in a flexible overlay.

Aircraft type	Pass-to-coverage ratios for traffic areas A	B	C	D	Overruns
OV-1	N/A	10.24	15.77	N/A	15.77
CH-54	N/A	4.31	8.51	N/A	8.51
C-130 (Army)	N/A	4.18	8.10	N/A	8.10
F-15	9.36	14.78	14.78	14.78	14.78
C-141	3.44	6.34	6.34	6.34	6.34
B-52	1.63	2.00	2.00	2.00	2.00
B-1	3.50	6.16	6.16	6.16	6.16
C-130 (Air Force)	4.18	8.10	8.10	N/A	8.10

Table 7-1. Pass per coverage ratios

passes to coverages using values shown in table 7-1. C is a coefficient from paragraph 7-4 based upon the structural condition of the existing rigid pavement. The computed thickness of overlay will be rounded to the nearest half-inch. The minimum thickness of overlay used for strengthening purposes will be 2 inches for all type D traffic areas and overruns, 3 inches for types B and C traffic areas in light-load pavements and Army airfield pavements, and 4 inches for all others. In certain instances, the nonrigid overlay design equation will indicate thickness requirements less (sometimes negative values) than the minimum values. In such cases the minimum thickness requirement will be used. When strengthening existing rigid pavements that exhibit low flexural strength (less than 500 psi) or that are constructed on high-strength foundations (k exceeding 200 pci), it may be found that the flexible pavement design procedure in TM 5-825-2/NAVFAC DM 21.3/AFM 88-6 may indicate a lesser required overlay thickness than the overlay design formula. For these conditions, the overlay thickness will be determined by both methods, and the lesser thickness used for design. For the flexible pavement design procedure, the existing rigid pavement will be considered to be either an equivalent thickness of high–quality crushed aggregate base (CBR = 100) or an equivalent thickness of all-bituminous concrete (equivalency factor or 1.15 for base and 2.3 for subbase), and the total pavement thickness determined based upon the subgrade CBR. Any existing base or subbase layers will be considered as corresponding layers in the flexible pavement. The thickness of required overlay will then be the difference between the required flexible pavement thickness and the combined thicknesses of existing rigid pavement and any base or subbase layers above the subgrade.

e. Jointing. Normally, joints, other than those required for construction of a bituminous concrete pavement, will not be required in nonrigid overlays of existing rigid pavements. It is good practice to attempt to lay out paving lanes in the bituminous concrete to prevent joints in the overlay from coinciding with joints in the rigid base pavement. Movements of the existing rigid pavement, both from contraction and expansion and deflections due to applied loads, cause high concentrated stresses in the nonrigid overlay directly over joints and cracks in the existing rigid pavements. These stresses may result in cracking, often referred to as reflection cracks, in the overlay. The severity of this type will, in part, depends upon the type of rigid pavement. For example, a plain concrete pavement normally will have closely spaced joints and may result in reflection cracks over the joints, but the cracks will be fairly tight and less likely to ravel. On the other hand, reinforced concrete pavements will normally have joints spaced farther apart, which will, in turn, experience larger movements. The reflection cracks over these joints are more likely to ravel and spall. Likewise, either existing plain concrete or reinforced concrete pavements may have expansion joints that experience rather large movements, and consideration may be given to providing an expansion joint in the nonrigid overlay to coincide with the expansion joint in the existing pavement. No practical method has been developed to absolutely prevent reflection cracking in nonrigid overlays; however, experience has shown that the degree of cracking is related to the thickness of the overlay, with the thinner overlays exhibiting the greater tendency to crack. In addition, geotextiles have been effective in retarding reflective cracking in some areas of the United States as shown on figure 7-3. When geotextiles are used under an asphalt concrete pavement, the existing pavement should be relatively smooth with all cracks larger than ¼ inch sealed. A leveling course is also recommended before application of the fabric to ensure a suitable surface. A tack coat is also required prior to placement of the geotextile. The minimum overlay thickness is 2 inches. When using geotextiles under a nonrigid pavement overlay, the geotextiles can be used as a membrane strip or a full-width application. The existing pavement should be stable with negligible movement under loads and all joints and cracks larger than ¼ inch sealed. The strip method is applied directly on the concrete joints and cracks and then overlaid. The full-width application can be applied directly to the existing pavement or placed on a leveling course. The minimum overlay thickness is 4 inches. It has also been experienced that in nonrigid overlays, the lower viscosity (or higher penetration grade) asphalts are less likely to experience reflection cracking. Therefore, the lowest viscosity grade asphalt that will provide sufficient stability during high temperatures should be used.



AREA I - GEOTEXTILES ARE RECOMMENDED WITH MINIMUM OVERLAY THICKNESS OF 2 IN.
AREA II - GEOTEXTILES ARE RECOMMENDED WITH OVERLAY THICKNESS OF 3-4 IN.
AREA III - GEOTEXTILES ARE NOT RECOMMENDED

Figure 7-3. Location guide for the use of geotextiles in retarding reflective cracking.

f. Example of nonrigid overlay design. The existing rigid pavements at an airfield will be strengthened to the Army Class III type B traffic area (TM 5-824-1/AFM 88-6, Chap. 1) using a nonrigid overlay. The existing rigid pavement is 9 inches of plain concrete on a 6–inch crushed aggregate base and has the following pertinent properties: R = 700 psi, k of subgrade = 150 pci, and C = 0.75. The k value on top of the base course is determined from figure 1–1 using the subgrade k of 150 pci and 6 inches of base course. The required thickness of nonrigid overlay is determined by

$$t_o = 3.0\,(Fh_d - Ch_E) \qquad \text{(eq 7-5)}$$

To determine F, convert passes of the C-130 (Army Class III design aircraft) into coverages using the pass per coverages ratio of 4.18 from table 7–1. The 10,000 passes convert to 2,392 coverages. Therefore, for a k of 200 and 2,392 coverages, the F factor from figure 7–2 is 0.77. Values of h_d, determined from figure 2–3 with the design gross aircraft weight of 175 kips, flexural strength of 700 psi, and k value of 200 pci is 10.1 inches. Since the existing pavement is concrete, then the equivalent thickness, h_E, is equal to the existing thickness of 9.0 inches. Therefore, the required overlay thickness, t_o, is 3 inches ($(0.77 \times 10.1 - 0.75 \times 9) = 3.06$ inches).

7-9. Overlays in frost regions

Whenever the subgrade is subject to frost action, the design will meet the requirements for frost action stated in TM 5-818-2/AFM 88-6, Chap. 4. The design will conform to frost requirements for rigid pavements. If subgrade conditions will produce detrimental nonuniform frost heaving, overlay pavement design will not be considered unless the combined thickness of overlay and existing pavement is sufficient to prevent substantial freezing of the subgrade.

CHAPTER 8
RIGID PAVEMENT INLAY DESIGN

8-1. General

Many existing airfield pavement facilities have developed severe distress because the design life or the load-carrying capacity of the facilities has been exceeded. The distress normally occurs first in the center lanes of the runways and taxiways because of the concentration of traffic. A method commonly used to rehabilitate these distressed facilities is to construct an adequately designed rigid pavement inlay section in the center of the facility. These inlays are generally 50 feet wide for taxiways and 75 feet wide for runways; however, the widths will be influenced by the lateral traffic distribution and, in existing rigid pavements, by the joint configuration. The inlay pavement may consist of any type of rigid pavement discussed in chapters 2 through 6, but the use of any pavement other than plain concrete or reinforced concrete will require the approval of the Commander, U.S. Army Corps of Engineers (DAEN-ECE-G), Washington, DC 20314-1000, or HQ Air Force Engineering and Services Center (AFESC/DEMP), Tyndall AFB, FL 32403-6001. The thickness design of the rigid inlay will be the same as outlined in chapters 2 through 6 except for the special requirements presented herein. Because of the possible emergency nature of this type of rehabilitation program, some design requirements may be waived.

8-2. Rigid inlays in existing flexible pavement

a. Figure 8-1 shows a section of a typical rigid pavement inlay in an existing flexible pavement.

b. Removal of the existing flexible pavement will be held to the absolute minimum. The depth of the excavation will not exceed the design thickness of rigid inlay pavement. The width of excavation of the existing pavement will not exceed the required width of the inlay section plus the minimum necessary, approximately 3 feet, for forming or slipforming the edges of the concrete pavement (figure 8-1).

c. Subdrains will be considered only when they are essential to the construction of the inlay section or necessary for proper drainage. When required, the subdrains will be placed outside of the edge of the rigid inlay and at least 4 inches below the bottom of the inlay pavement to permit construction of the stabilized layer required in d below.

d. Unless the materials in the bottom of the excavation are granular and free-draining or the airfield is located in an arid climate, the bottom full width of the excavation will be scarified to a minimum depth of 4 inches, stabilized with chemicals or bitumens, and recompacted to the density requirements for the top 6 inches of base course or subgrade as specified previously. This type of overlay may trap water, and satisfactory drainage must be provided. Reference should be made to TM 5–822–4/AFM 88–7, Chap. 4 for selection of stabilizing agent and minimum strength requirements.

e. The modulus of soil reaction, k, used for the design of the rigid pavement inlay will be determined on the surface of the material at the bottom of the excavation prior to stabilization. If the strength of the stabilized material does not meet the requirements in TM 5–822–4/AFM 88–7, Chap. 4 for pavement thickness reduction, no structural credit will be given to the stabilized material in the design of the rigid pavement inlay. If the strength of the stabilized layer meets the minimum strength requirement for pavement thickness reduction in TM 5–822–4/AFM 88–7, Chap. 4, the rigid pavement inlay will be designed in accordance with applicable sections of chapters 2 through 6 pertaining to the use of stabilized soil layers.

f. If the existing pavement is not composed of non-frost–susceptible materials sufficient to eliminate substantial frost penetration into an underlying frost–susceptible material, an appropriate reduction in the k value will be made in accordance with TM 5–818–2/AFM 88–6, Chap. 4. In these cases, the inlay will be designed as a reinforced concrete pavement using a minimum of 0.15 percent steel. The pavement thickness may be reduced and longer slabs may be used as applicable to the design of reinforced concrete pavements.

g. After the construction of the rigid pavement inlay, the working areas used for forming or slipforming the sides of the concrete will be backfilled to within 4 inches of the pavement surface with either lean-mix concrete or normal paving concrete.

h. The existing bituminous concrete will be sawed parallel to and at a distance of 10 feet from each edge of the inlay. The bituminous concrete surface and binder courses and, if necessary, the base course will be removed to provide a depth of 4 inches. The exposed surface of the base course will be recompacted, and a 10–foot–wide paving lane of bituminous concrete, 4 inches thick, will be used to fill in the gap (figure 8-1). The bituminous concrete mix will be designed in accordance with TM 5–825–2/NAVFAC DM 21.3/AFM 88–6.

i. In cases where the 10–foot width of new bituminous concrete at either side of the inlay section does not permit a reasonably smooth transition from the inlay to the existing pavement, additional leveling work outside of the 10–foot lane will be accomplished by removal and replacement, planer operation, or both.

8-3. Rigid inlays in existing rigid pavement

a. Figure 8-2 shows a section of a typical rigid pavement inlay in an existing rigid pavement.

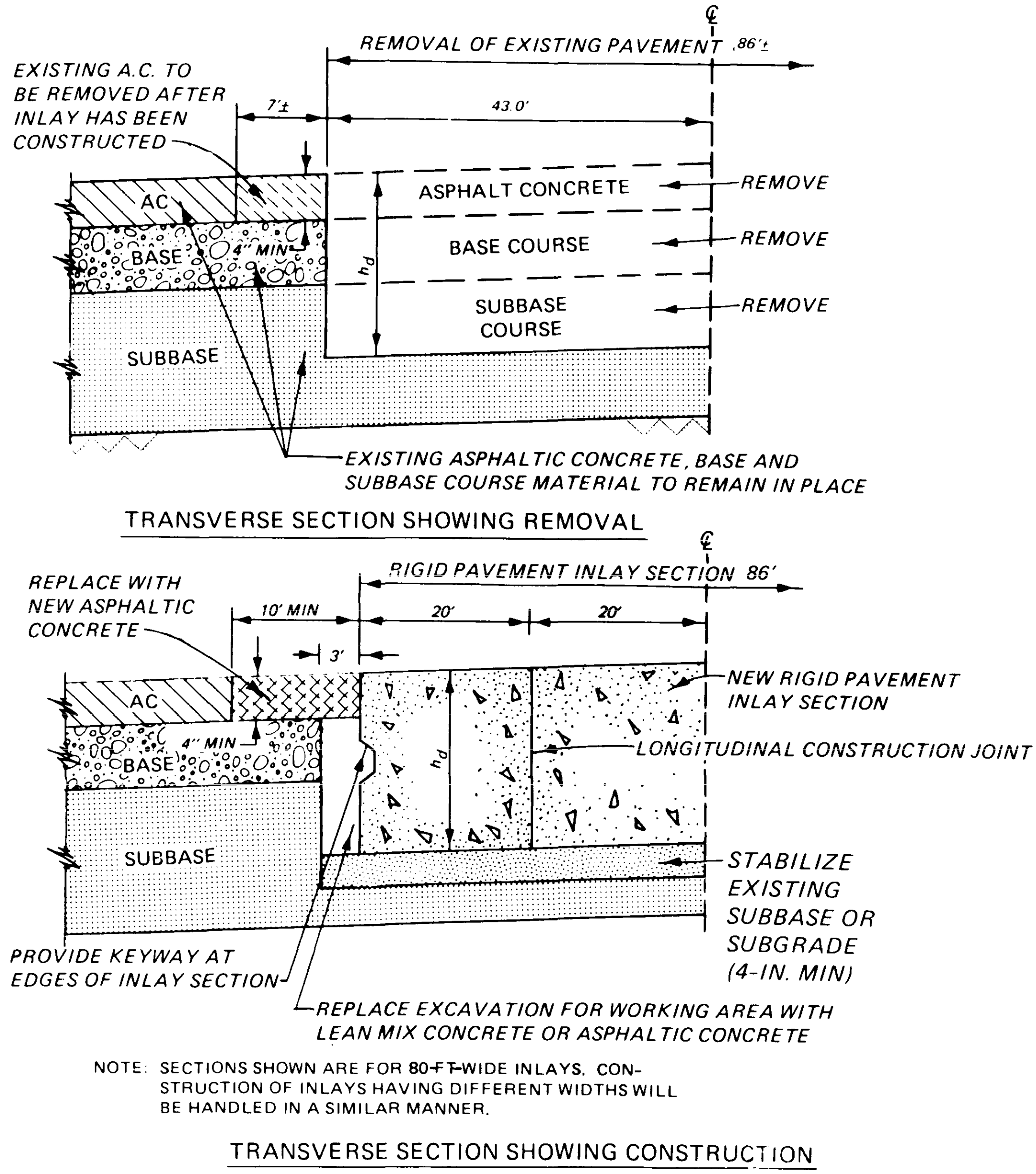


Figure 8-1. Typical rigid pavement inlay in existing flexible pavement.

b. The existing rigid pavement will be removed to the nearest longitudinal joints that will provide the design width of the rigid pavement inlay. Care will be exercised in the removal of the existing rigid pavement to preserve the load-transfer device (key, keyway, or dowel) in the longitudinal joint at the edge of the new inlay pavement. If the existing load-transfer devices can be kept intact, they will be used to provide load transfer between the rigid pavement inlay and the existing pavement except that a male key will be removed. If the load-transfer devices are damaged or destroyed, a thickened edge joint shown in figure 2-15 or 3-5 shall be used to protect against edge loading of the existing pavement or the face shall be sawed vertically and dowels installed. In addition to the removal of the existing pavement, the existing base and/or subgrade will be removed to the depth required for the design thickness of the rigid pavement inlay.

c. Paragraphs 8-2c through 8-2f also pertain to rigid pavement inlays in existing rigid pavements.

d. The design of the rigid pavement inlay, including joint types and spacing, will be in accordance with the chapter pertaining to the type of rigid pavement selected.

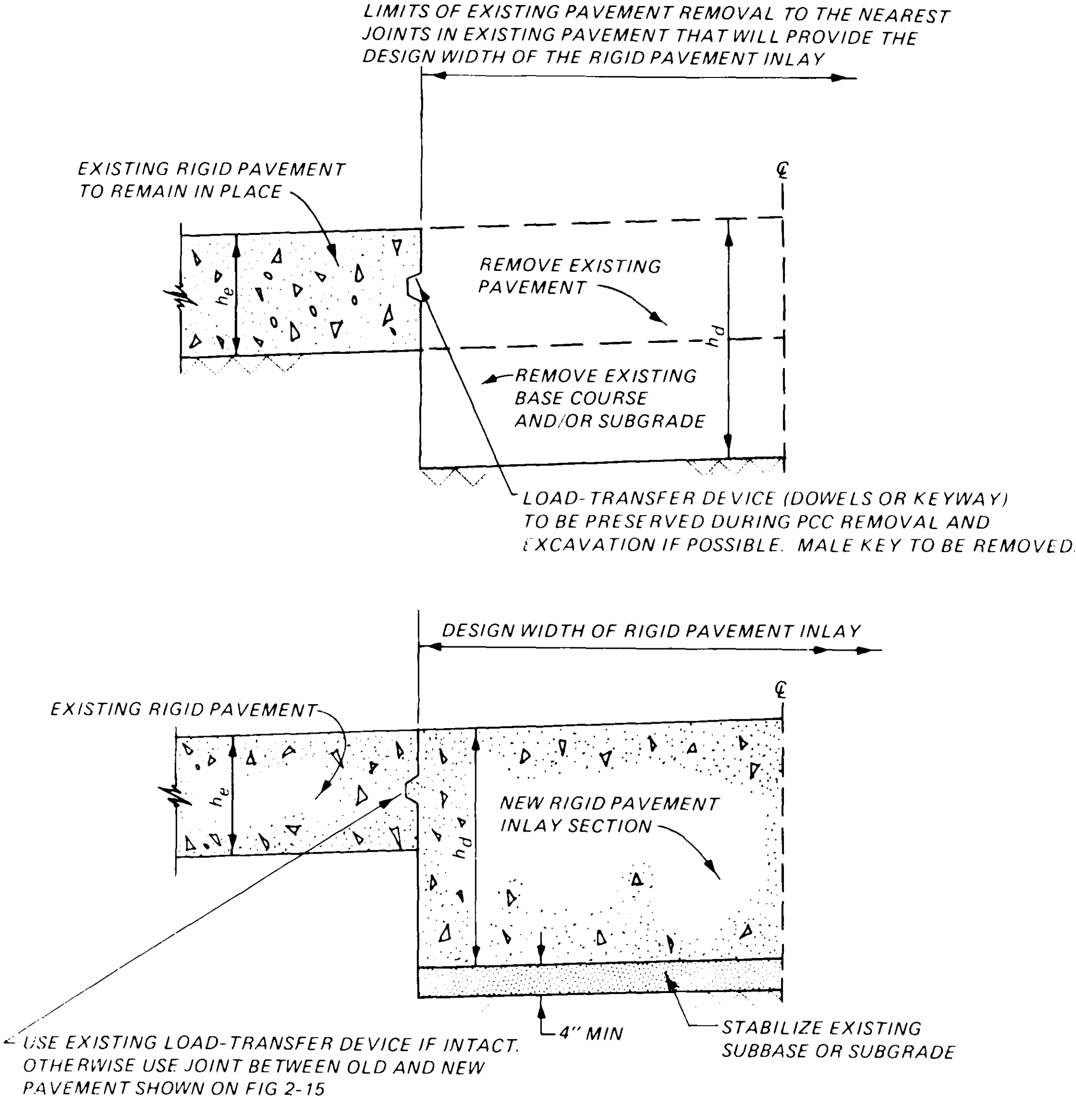


Figure 8-2. Typical rigid pavement inlay using existing rigid pavement.

APPENDIX A
REFERENCES

Government Publications

Department of Defense

MIL-R-3472	Roof–Coating, Asphalt–Base Emulsion
MIL-STD-619B	Unified Soil Classification for Roads, Airfields, Embankments, and Foundations
MIL-STD-621A	Test Method for Pavement Subgrade, Subbase, and Base-Course Materials

Departments of the Army, and the Airforce

TM 5-803-4	Planning of Army Aviation Facilities
TM-5-803-7/AFR 86-14/NAVFAC P-971	Civil Engineering Programming: Airfield and Heliport Planning Criteria
TM 5-818-1/AFM 88-3, Chap. 7	Soils and Geology: Procedures for Foundation Design of Buildings and Other Structures (Except Hydraulic Structures)
TM 5-818-2/AFM 88-6, Chap. 4	Pavement Design for Seasonal Frost Conditions
TM 5-818-3/AFM 88-24, Chap. 4	Pavement Evaluation for Frost Conditions
TM 5-820-1/AFM 88-5, Chap. 1	Surface Drainage Facilities for Airfields and Heliports
TM 5-820-2/AFM 88-5, Chap. 2	Subsurface Drainage Facilities for Airfield Pavements
TM-820-3/AFM 88-5, Chap. 3	Drainage and Erosion Control Structures for Airfields and Heliports
TM 5-822-4/AFM 88-7, Chap. 4	Soil Stabilization for Roads and Streets
TM 5-822-7/AFM 88-6, Chap. 8	Standard Practice for Concrete Pavements– Bituminous Pavements Standard Practice
TM 5-824-1/AFM 88-6, Chap. 1	Airfields Other Than Army: General Provisions for Airfield Design
TM 5-825-2/NAVFAC DM 21.3/AFM 88-6	Flexible Pavement Design for Airfields
TM 5-826-1	Army Airfield Pavement Evaluation Concepts
TM 5-826-2	Engineering and Design: Army Airfield Flexible Pavement Evaluation
TM 5-826-3	Engineering and Design: Army Airfield Rigid Pavement Evaluation
TM 5-826-4	Engineering and Design: Army Airfield-Heliport Pavement Reports

T 5-827-1/AFM 88-24, Chap. 1	Airfield Pavement Evaluation Concepts
TM 5-827-2/AFM 88-24, Chap. 2	Flexible Airfield Pavement Evaluation
TM 5-827-3/AFM 88-24, Chap 3.	Evaluation of Airfield Pavements Other Than Army: Rigid Airfield Pavement Evaluation
AFM 86-2	Standard Facility Requirements
AFR 86-5	Planning Criteria and Waivers for Airfield Support Facilities
AFR 93-5	Airfield Pavement Evaluation Program

General Services Administration

Fed. Spec. SS-S-200E	Sealing Compounds, Two–Component, Elastomeric, Polymer Type, Jet–Fuel–Resistant, Cold–Applied
Fed. Spec. SS-S-1401C	Sealing Compound, Hot–Applied, for Concrete and Asphalt Pavements
Fed. Spec. SS-S-1614A	Sealing Compound, Jet–Fuel–Resistant, Hot–Applied, One–Component, for Portland Cement and Tar Concrete Pavements

Nongovernment Publications

American Concrete Institute, P.O. Box 19150, Redford Station, Detroit, MI 48219

ACI 318	Building Code Requirements for Reinforced Concrete
ACI 544.IR-82	State of the Art Report on Fiber Reinforced Concrete

American Society for Testing and Materials (ASTM), 1916 Race Street, Philadelphia, PA 19103

A 82	Cold–Drawn Wire for Concrete Reinforcement
A 184	Fabricated Deformed Steel Bar Mats for Concrete Reinforcement
A 185	Welded Steel Wire Fabric for Concrete Reinforcement
A 416	Uncoated Seven–Wire Stress–Relieved Strand for Prestressed Concrete
A 421	Uncoated Stress-Relieved Wire for Prestressed Concrete
A 497	Welded Deformed Steel Wire Fabric for Concrete Reinforcement
A 615	Deformed and Plain Billet–Steel Bars for Concrete Reinforcement
A 616	Rail–Steel Deformed and Plain Bars for Concrete Reinforcement
A 617	Axle–Steel Deformed and Plain Bars for Concrete Reinforcement
C 78	Flexural Strength of Concrete (Using Single–Beam with Third–Point Loading)
D 2628	Preformed Polychloroprene Elastomeric Joint Seals for Concrete Pavements
D 2835	Lubricant for Installation of Preformed Compression Seals in Concrete Pavements
E 11	Wire–Cloth Sieves for Testing Purposes

APPENDIX B
DETERMINATION OF FLEXURAL STRENGTH AND MODULUS OF ELASTICITY OF BITUMINOUS CONCRETE

B-1. Scope

These procedures describe preparation and testing of bituminous concrete to determine flexural strength and modulus of elasticity. The procedures are an adaptation from tests conducted on portland cement concrete (PCC) specimens.

B-2. Applicable standards

The standard applicable to this procedure is ASTM C 78.

B-3. Apparatus

The following apparatus are required: (1) a testing machine capable of applying repetitive loadings for compaction of beam specimens 6 by 6 by 21 inches to the design density (an Instron electromechanical testing machine meets this requirement); (2) a steel mold, suitably reinforced to withstand compaction of specimens without distortion; (3) two linear variable differential transformers (LVDT's); (4) a 5,000-pound load cell; (5) an X-Y recorder; and (6) a testing machine for load applications conforming to ASTM C 78 (a Baldwin or Tinius Olsen hydraulic testing machine is suitable for this purpose).

B-4. Materials

Sufficient aggregate and bitumen meeting applicable specifications to produce six 6- by 6- by 21-inch test specimens are required. In the event the proportioning of aggregate and bitumen, bitumen content, and density of compacted specimens are not known, additional materials will be required to conduct conventional Marshall tests to develop the needed mix design data.

B-5. Sample preparation

a. Prepare in a laboratory mixer four portions of paving mixture for one 6- by 6- by 21-inch beam test specimen consisting of aggregate and bitumen in the proportions indicated for optimum bitumen content. The total quantity of paving mixture should be such that when compacted to a uniform 6- by 6-inch cross section, the density of the beam will be as specified from previous laboratory mix design tests or other sources. The temperature of the paving mixture at the time of mixing should be such that subsequent compaction can be accomplished at 250 ± 5 degrees F. Place two of the four portions in the 6- by 6- by 21-inch reinforced steel mold and compact to a 3-inch thickness with a 6- by 6-inch foot attached to the repetitive loading machine. Shift the mold between load applications to distribute the compaction effort uniformly. Add the remaining two portions and continue compaction until the paving mixture is compacted to exactly a 6- by 6-inch cross section. After compaction, place a 6- by 21-inch steel plate on the surface of the paving mixture, and apply a leveling load of 2,000 pounds to the plate. Prepare six beam test specimens in the manner described.

b. After cooling, remove the beams from the molds and rotate 90 degrees so that the smooth, parallel sides will become the top and bottom. Cement an L-shaped metal tab with quick-setting epoxy glue to each 6- by 21-inch side of the beams on the beams' neutral axes at midspan. The taps should be drilled for attachement of the LVDT's. Cure the beams at 50 degrees F. for four days prior to testing.

B-6. Test procedures

a. Condition three specimens each at 50 and 75 degrees F. for at least 12 hours prior to testing. If testing occurs immediately after curing the specimens at 50 degrees F. for four days, no additional conditioning is required for the specimens tested at this temperature.

b. Place the specimens in the test machine as described in ASTM C 78. Place thin Teflon strips at the point of contact between the test specimens and the load-applying and load-support blocks. While the beams are being prepared for testing, place an additional support block at midspan to prevent premature sagging of the beams. Remove this support block immediately prior to the initiation of load application. Mount the LVDTs on laboratory stands on each side of the beams, and attach the LVDTs to the L-shaped tabs on the sides of the beams. Connect the LVDTs and load cell to the X-Y recorder. Make final adjustments and checks on specimens and test equipment. Apply loading in accordance with ASTM C 78, omitting the initial 1,000-pound load.

B-7. Calculations

a. The modulus of rupture, R, is calculated from the following equation (from ASTM C 78):

$$R = PL/bd^2 \qquad \text{(eq B-1)}$$

where

R = modulus of rupture, psi
P = maximum applied load, pounds
L = span length, inches (18 inches)
b = average width of beam, inches
d = average depth (height) of beam, inches

b. The modulus of elasticity, E, is calculated from the following equation:

$$E = \frac{23PL^3}{1296\Delta I} k \qquad \text{(eq B-2)}$$

where

- E = static Young's modulus of elasticity, psi
- P = applied load, pounds
- L = span length, inches (18 inches)
- Δ = deflection of neutral axis, inches, under load, P
- I = moment of inertia, $inch^4$ ($= bd^3/12$)
- b = average width of beam, inches
- d = average depth (height) of beam, inches
- k = Pickett's correction for shear (third-point loading). (Values of E for bituminous beams should be calculated without using Pickett's correction, K, for shear.)

B-8. Report

The report shall include the following:

—Gradation of aggregate.
—Type and properties of bituminous cement.
—Bituminous concrete mix design properties.
—Bituminous concrete beam properties.
—Modulus of rupture.
—Modulus of elasticity.

The proponent agency of this publication is the Office of the Chief of Engineers, United States Army. Users are invited to send comments and suggested improvements on DA Form 2028 (Recommended Changes to Publications and Blank Forms) direct to HQDA (DAEN-ECE-G) 20 Massachusetts Ave., NW, Washington, DC 20314-1000.

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CHAPTER 9
COMPUTER PROGRAM FOR RIGID PAVEMENT DESIGN

9-1. General

This chapter provides guidance in the use of the computer program for the design of plain and reinforced concrete pavements. A computer disk containing the design program is attached to this manual.

9-2. Development of program

a. A computer program was developed to aid in the design of military airfield rigid pavements. The program was developed on an IBM PC-AT using FORTRAN 77 as the developmental language with Microsoft's FORTRAN Compiler (version 3.2) and MS-DOS (version 3.1) as the operating system. Normally, the program will be furnished as a compiled program which can be executed from floppy diskettes or hard drives. Thus far all the programs have been found to run on IBM PC-AT or IBM compatible microcomputers containing a minimum of 512K RAM.

b. In development of the computer program, an effort was made to provide a user friendly program requiring no external instructions for use of the program. Aside from instructions for initiating execution, which is standard for any executable program, the user is lead through the design procedure by a series of questions and informational screens. The input data required for pavement design by the program is identical to the data required by the design manual, and the results obtained from the program should be close to the results obtained from the design curves. Because the computer program recalculates data and approximates certain empiracal data, there may be some minor differences in results from the program and from the manual. If significant differences are obtained, contact CEEC-EG.

c. The computer programs are date named i.e, the date of the latest revision is contained in the program name. The first digit of the number in the program name is the last digit of year of the revision. The last two digits of the program name is the month of the revision. Thus, the program RAD 810 was revised October 1988.

d. Care is to be taken that the latest version of the computer programs is being used. If there is doubt concerning a program, contact CEEC-EG.

e. Accompanying each program is an aircraft data file RADCRAFT.DAT, for design of rigid pavements. These data files contain all the aircraft data used by the programs. The data file has the capacity to hold data for a total of 50 different aircraft.

HEADQUARTERS
DEPARTMENTS OF THE ARMY
AND THE AIR FORCE
Washington, DC, *15 December 1989*

Change
No. 1

RIGID PAVEMENTS FOR AIRFIELDS

TM 5-825-3/AFM 88-6, Chap. 3 has been changed as follows:

1. New or revised material is indicated by a vertical line in the margin.

2. Remove old pages and insert new pages as indicated below:

Remove Pages	*Insert Pages*
i and ii	i, ii, iii and iv
1-3 and 1-4	1-3 and 1-4
2-1 and 2-2	2-1 and 2-2
2-5 and 2-6	2-5 and 2-6
2-11 and 2-12	2-11 and 2-12
3-1 and 3-2	3-1 and 3-2
3-5 and 3-6	3-5 and 3-6
None	9-1

3. File this transmittal sheet in front of the publication for reference purposes.

The proponent agency of this manual is the Office of the Chief of Engineers, the United States Army. Users are invited to send comments and suggested improvements on DA Form 2028 to (CEEC-EG), WASH DC 20314-1000.