

(2) **Increasing C_b Factor.** A value of C_b lower than 0.75 represents a severely cracked base slab, which would not be advisable to overlay without modification due to the likelihood of severe reflection cracking. See paragraph 406 f. In some instances it may be advantageous to replace several slabs and restore load transfer along inadequate joints to raise the C_b value. Increasing the C_b value will decrease the required overlay thickness. A detailed condition survey of the existing pavement which examines the subsurface drainage conditions, structural capacity of the slabs, foundation strength, **flexural** strength of the concrete, load transfer along joints and thickness of the component layers is strongly encouraged to properly design a hot mix asphalt overlay.

c. **Example.** An example of the hot mix asphalt overlay design method is given below:

(1) **Assumptions.** Assume an existing rigid pavement 12 inches (305 mm) thick is to be strengthened to accommodate 3000 departures of a dual wheel aircraft weighing 180,000 pounds (81,800 kg). The **flexural** strength of the existing concrete is 725 psi (5.00 MN/m^2) and the foundation modulus is 300 pci (81.6 MN/m^3). The condition factor of the existing pavement is 0.95.

(2) **Single Slab Thickness.** Compute the single slab thickness required to satisfy the design conditions given in (1) above. Using Figure 3-17 the slab thickness is found to be 13.9 inches (353 mm). The F factor is determined from Figure 4-3 and equals 0.93. Applying the overlay formula given in paragraph 406 yields:

$$t = 2.5 (0.93 \times 13.9 - 0.95 \times 12)$$

$$t = 3.82 \text{ inches (97 mm)}$$

This thickness would be rounded up to 4 inches (100 mm) for practicality of construction.

d. **Previously Overlaid Rigid Pavement.** The design of a hot mix asphalt overlay for a rigid pavement which already has an existing hot mix asphalt overlay is slightly different. The designer should treat the problem as if the existing hot mix asphalt overlay were not present, calculate the overlay thickness required, and then adjust the calculated thickness to compensate for the existing overlay. If this procedure is not used, inconsistent results will often be produced.

e. **Example.** An example of a hot mix asphalt overlay design for a rigid pavement which already has an existing hot mix asphalt overlay is given below:

(1) **Assumptions.** An example of the procedure follows. Assume an existing pavement consists of a 10-inch (255 mm) rigid pavement with a 3-inch (75 mm) hot mix asphalt overlay. The existing pavement is to be strengthened to be equivalent to a single rigid pavement thickness of 14 inches (355 mm). Assume an "F" factor of 0.9 and " C_b " of 0.9 are appropriate for the existing conditions.

(2) **Ignore Existing Overlay.** Calculate the required thickness of hot mix asphalt overlay as if the existing 3-inch (75 mm) overlay were not present.

$$t = 2.5 (0.9 \times 14 - 0.9 \times 10)$$

$$t = 9 \text{ inches (230 mm)}$$

(3) **Thickness Allowance For Existing Overlay.** An allowance is then made for the existing hot mix asphalt overlay. In this example assume the existing overlay is in such a condition that its effective thickness is only 2.5 inches (64 mm). The required overlay thickness would then be $9 - 2.5 = 6.5$ inches (165 mm). The determination of the effective thickness of the existing overlay is a matter of engineering judgment.

e. **Limitations.** The formula for hot mix asphalt overlay thickness assumes the existing rigid pavement will support load through **flexural** action. As the overlay thickness becomes greater, at some point the existing rigid pavement will tend to act more like a high quality base material. When this condition is reached, the overlay should be designed as a flexible pavement with the existing pavement treated as a high quality base course.

f. **Crack and Seat.** If the condition of the existing rigid pavement is very poor, i.e., extensive structural

cracking, joint faulting, "D" cracking etc. consideration should be given to using the "crack and seat" technique. The crack and seat technique involves purposely breaking the existing rigid pavement and then rolling the broken pieces to firmly seat them in the foundation. A hot mix asphalt layer is then placed over the pavement. This type of section is designed as a flexible pavement treating the broken rigid pavement as base course. The severity of reflection cracking is often reduced with this type of construction. On the other hand, any life remaining in the existing rigid pavement is essentially destroyed.

407. NONSTRUCTURAL HOT MIX ASPHALT OVERLAYS. In some instances overlays are required to correct nonstructural problems such as restoration of crown, improve rideability, etc. Thickness calculations are not required in these situations, as thickness is controlled by other design considerations or minimum practical overlay thickness. Information concerning runway roughness correction can be found in FAA Report No. FAA-RD-75-110, Methodology for Determining, Isolating and Correcting Runway Roughness. See Appendix 4.

408. REFLECTION CRACKING IN HOT MIX ASPHALT OVERLAYS. Reflection cracking is often a problem in hot mix asphalt overlays particularly overlays of rigid pavement. Numerous materials and techniques have been tried attempting to solve the problem with varying degrees of success. The following methods have met with some success:

a. Coarse Aggregate Binders. The use of coarse aggregate binder course is recommended where economically feasible. Use of the largest practical size coarse aggregate in the hot mix asphalt layer immediately above the existing pavement is recommended. This practice provides some measure of protection against reflection cracking.

b. Engineering Fabrics. Recent research studies have shown that **nonwoven** fabric membranes are effective in retarding reflection cracking. See DOT/FAA/PM-84/9, I, Appendix 4. While fabrics probably will not eliminate reflection cracking all together, they do provide some degree of water-proofing beneath reflection cracks thus protecting the existing pavement and foundation. At present, the water-proofing capability of fabrics, assuming the capacity of the asphalt impregnated fabric to resist rupture is not lost, appears to be the most significant contribution fabrics provide in a hot mix asphalt overlay system. Existing pavements, whether flexible or rigid, that show evidence of excessive deflections, substantial thermal stresses, and/or poor drainage, probably will exhibit no improvement by including a fabric in a structural overlay. The following conditions are recommended for fabric usage:

(1) Fabric Properties. The fabric should have a tensile strength of at least 90 lbs (41 kg) when tested in accordance with ASTM D 1682 and a density in the range of 3 to 5.5 ozs per square yard (70 to 130 grams per square meter).

(2) Application. Fabric membranes should not be used where the horizontal displacements exceed 0.05 inch (1.3 mm) or where vertical displacements will exceed 0.02 inch (0.5 mm). Fabric should not be used when the overlay thickness is less than 3 inches (75 mm) or more than 7 inches (178 mm). To date only **nonwoven** fabrics have been studied in the above referenced research effort. It is anticipated that woven fabrics may also be used if the above conditions are satisfied.

(3) Tack Coat. The proper amount of tack coat applied to the fabric is critical. An emulsified asphalt applied at a rate of from 0.15 to 0.30 gallons per square yard (0.7 to 1.4 liters per square meter) is recommended. The optimum amount of tack coat will depend on the type of fabric and the surface on which the fabric is placed.

409. DESIGN OF CONCRETE OVERLAYS. Concrete overlays can be constructed on existing rigid or flexible pavements. The minimum allowable thickness for concrete overlays is 5 inches (127 mm) when placed on a flexible pavement, directly on a rigid pavement, or on a leveling course. The minimum thickness of concrete overlay which is bonded to an existing rigid pavement is 3 inches (75 mm). The design of concrete overlays is based on a thickness deficiency approach. The existing base pavement and overlay section are equated to a single slab thickness. The empirical formulas presented were developed from research on test track pavements and observations of in-service pavements.

410. CONCRETE OVERLAY ON FLEXIBLE PAVEMENT. The design of concrete overlays on existing flexible pavements assumes the existing flexible pavement is a foundation for the overlay slab. Overlay slab thickness is based on the design curves in Figures 3-17 through 3-40. The existing flexible pavement should be assigned a k value using Figure 2-5 or 3-16 or by conducting a plate bearing test on the existing flexible pavement or by NDT testing. In any case the k value assigned should not exceed 500. When frost conditions require additional thickness, the use of nonstabilized material below the rigid pavement overlay is not allowed as this would result in a sandwich pavement. Frost protection must be provided by stabilized material.

411. CONCRETE OVERLAY ON RIGID PAVEMENT. The design of concrete overlays on existing rigid pavements is also predicated on the rigid pavement design curves, Figures 3-17 through 3-40. The rigid pavement design curves indicate the thickness of concrete required to satisfy the design conditions for a single thickness of concrete pavement. Use of this method requires the designer to assign a k value to the existing foundation. The k value may be determined by field NDT tests or by bearing tests conducted in test pits cut through the existing rigid pavement, or may be estimated from construction records for the existing pavement. The design of a concrete overlay on a rigid pavement requires an assessment of the structural integrity of the existing rigid pavement. The condition factor should be selected after an extensive pavement condition survey. The selection of a condition factor is a matter of engineering judgment. The use of nondestructive testing (NDT) can be of considerable value in assessing the condition of an existing pavement. NDT can also be used to determine sites for test pits. NDT procedures are given in Advisory Circular 150/5370-1 1, Use of Nondestructive Testing Devices in the Evaluation of Airport Pavements. See Appendix 4. In order to provide a more uniform assessment of condition factors, the following values are defined:

- $C_r =$ 1.0 for existing pavement in good condition -- some minor cracking evident, but no structural defects.
 $C_r =$ 0.75 for existing pavement containing initial corner cracks due to loading but no progressive cracking or joint faulting.
 $C_r =$ 0.35 for existing pavement in poor structural condition, badly cracked or crushed and faulted joints.

The three conditions discussed above are used to illustrate the condition factor rather than establish the only values available to the designer. Conditions at a particular location may require the use of an intermediate value of C_r within the recommended range. Sketches of three different values of C_r are shown in Figures 4-6, 4-7, and 4-8.

a. **Concrete Overlay Without Leveling Course.** The thickness of the concrete overlay slab applied directly over the existing rigid pavement is computed by the following formula.

$$h_c = 1.4 \sqrt[4]{h^{1.4} - C_r h_e^{1.4}}$$

where:

- h_c = required thickness of concrete overlay
 h = required single slab thickness determined from design curves
 h_e = thickness of existing rigid pavement
 C_r = condition factor

Due to the inconvenient exponents in the above formula, graphic solutions are given in Figures 4-9 and 4-10. These graphs were prepared for only two different condition factors, $C_r = 1.0$ and 0.75 . The use of a concrete overlay pavement directly on an existing rigid pavement with a condition factor of less than 0.75 is not recommended because of the likelihood of reflection cracking. The above equation assumes the **flexural** strength of the concrete used for the overlay will be approximately equal to that of the base pavement. If the **flexural** strengths differ by more than 100 psi (0.7 MN/m^2), the following modified equation should be used to determine the required thickness of the overlap

$$h_c = \sqrt[4]{1.4h - C_r h_b^{1.4} h_e}$$

where:

h_b = required single slab thickness determined from design curves based on the **flexural** strength of the base pavement.

Other factors are the same as previous formula.

b. Concrete Overlay With Leveling Course. In some instances it may be necessary to apply a leveling course of hot mix asphalt concrete to an existing rigid pavement prior to the application of the concrete overlay. Under these conditions a different formula for the computation of the overlay thickness is required. When the existing pavement and overlay pavement are separated, the slabs act more independently than when the slabs are in contact with each other. The formula for the thickness of an overlay slab when a leveling course is used is as follows:

$$h_c = \sqrt{h^2 - C_r h_e^2}$$

where: h_c = required thickness of concrete overlay
 h = required single slab thickness determined from design curves
 h_e = thickness of existing rigid pavement
 C_r = condition factor

When the **flexural** strength of the overlay and of the existing pavements differ by more than 100 psi (0.7 MN/m²), the equation is modified as follows:

$$h_c = \sqrt{2h - 2C_r \frac{h}{h_b} h_e}$$

where: h_b = required single slab thickness determined from design curves based on the **flexural** strength of the base pavement.

The leveling course must be constructed of highly stable hot mix asphalt concrete. A granular separation course is not allowed as this would constitute sandwich construction. Graphic solutions of the above equation are shown in Figures 4-11 and 4-12. These graphs were prepared for condition factors of 0.75 and 0.35. Other condition factors between these values can normally be computed to sufficient accuracy by interpolation.

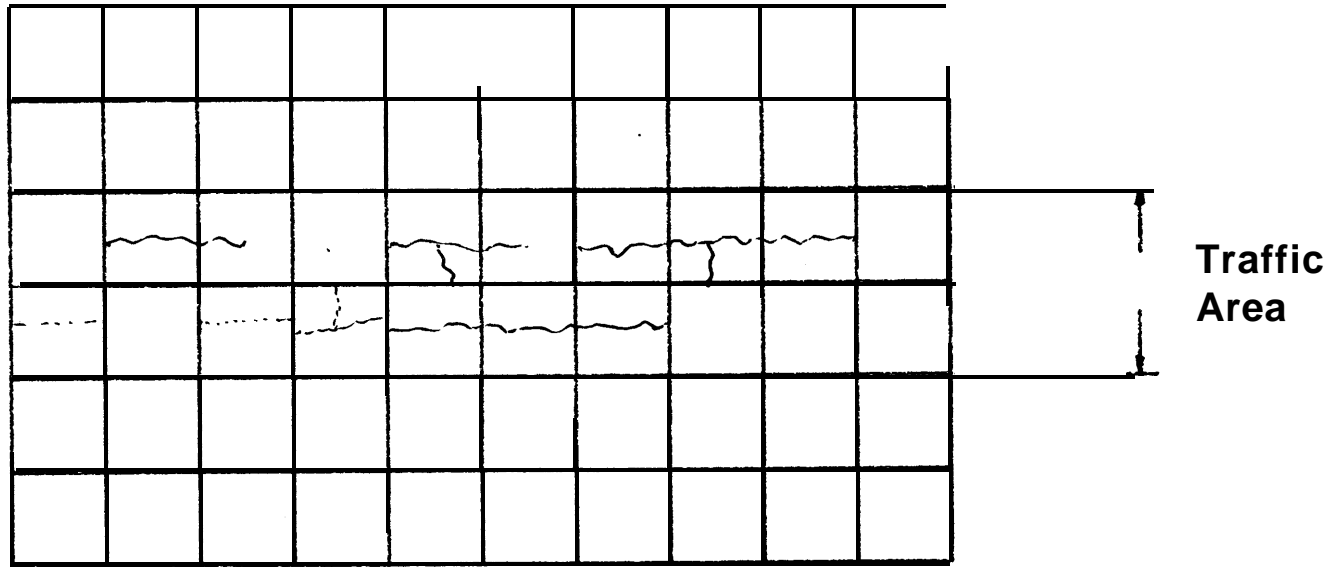
412. BONDED CONCRETE OVERLAYS. Concrete overlays bonded to existing rigid pavements are sometimes used under certain conditions. By bonding the concrete overlay to the existing rigid pavement, the new section behaves as monolithic slab. The thickness of bonded overlay required is computed by subtracting the thickness of the existing pavement from the thickness of the required slab thickness determined from design curves.

$$h_c = h - h_e$$

where: h_c = required thickness of concrete overlay.
 h = required single slab thickness determined from design curves using the **flexural** strength of the existing concrete.
 h_e = thickness of existing rigid pavement.

Bonded overlays should be used only when the existing rigid pavement is in good condition. Defects in the existing pavement are more likely to reflect through a bonded overlay than other types of concrete overlays. The major problem likely to be encountered with bonded concrete overlays is achieving adequate bond. Elaborate surface preparation and exacting construction techniques are required to insure bond.

413. JOINTING OF CONCRETE OVERLAYS. Where a rigid pavement is to receive the overlay, some modification to jointing criteria may be necessary because of the design and joint arrangement of the existing pavement. The following points may be used as guides in connection with the design and layout of joints in concrete overlays.



Legend:

Crack Width

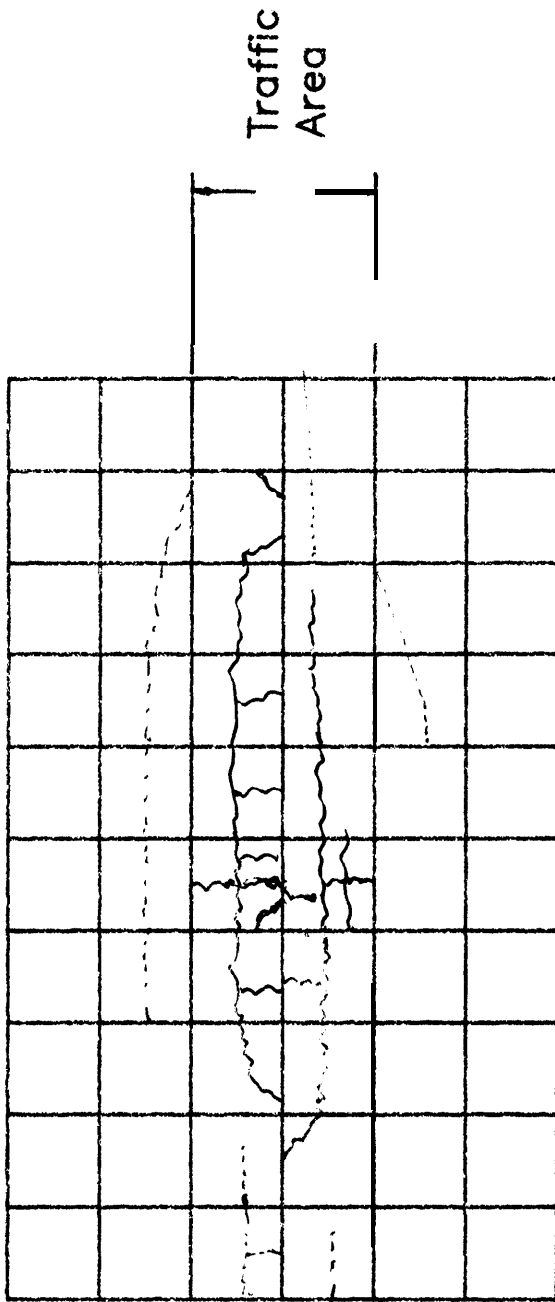
- - - - Less Than 1/4 inch (6mm)

—— Greater Than 1/4 inch (6mm)

Note:

50% of Slabs Within Traffic Area Broken Into 2 to 3 Pieces. No Working Cracks, Corner Breaks, or Faulted Joints.

FIGURE 4-6. ILLUSTRATION OF A "Cr" FACTOR OR 1.0



Legend:

Crack Width

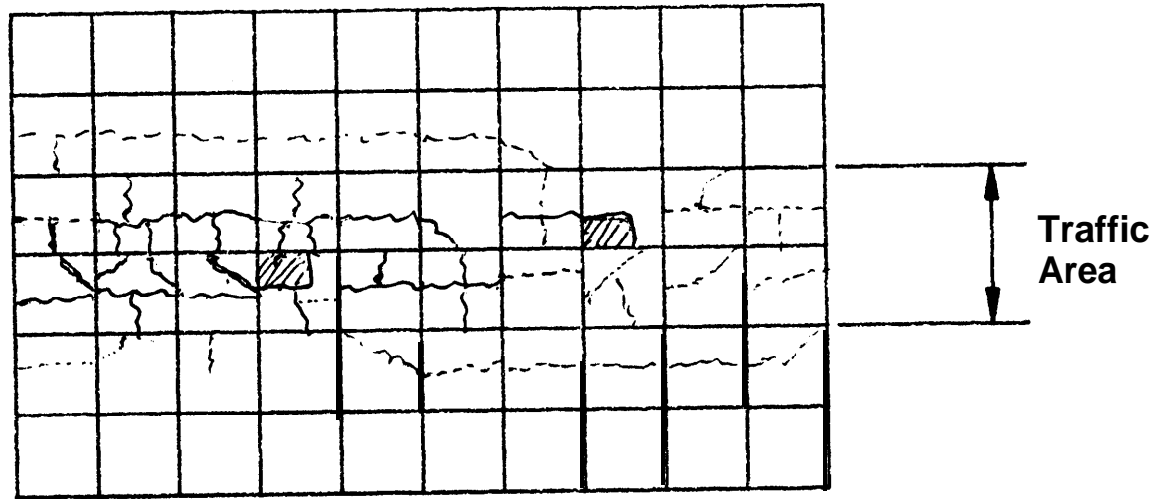
- - - - Less Than 1/4 inch (6mm)

— Greater Than 1/4 inch (6mm)

Note:

Within Traffic Area, 10% of Slabs Broken Into 6 Pieces, 75% of Slabs Broken Into 2 or More Pieces. Some Corner Breaks, Working Cracks, and Spalling Are Evident

FIGURE 4-7. ILLUSTRATION OF A "C" FACTOR OF .6



Legend:

Crack Width

A - - -Less Than 1/4 inch (6mm)

—— Greater Than 1/4 inch (6mm)

 Patch

Note:

**Within Traffic Area, 50% of Slabs Broken Into 6 Pieces,
50% of Slabs Broken Into 2 or More Pieces. Corner
Breaks, Working Cracks, Spalling, and/or Faulted Joints
and Patching Are Evident**

FIGURE 4-8. ILLUSTRATION OF A "C" FACTOR OF 0.35

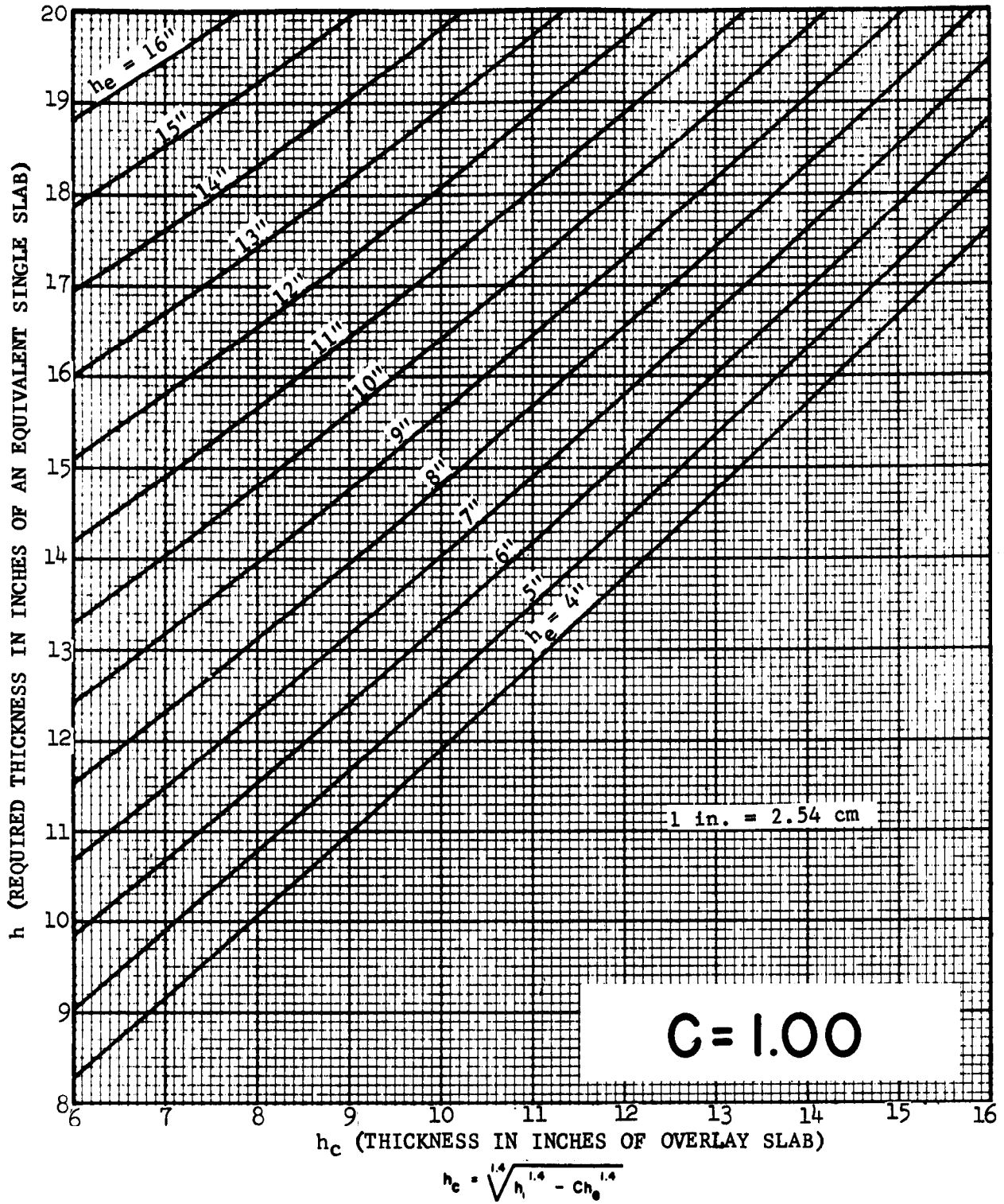


FIGURE 4-9. CONCRETE OVERLAY ON RIGID PAVEMENT

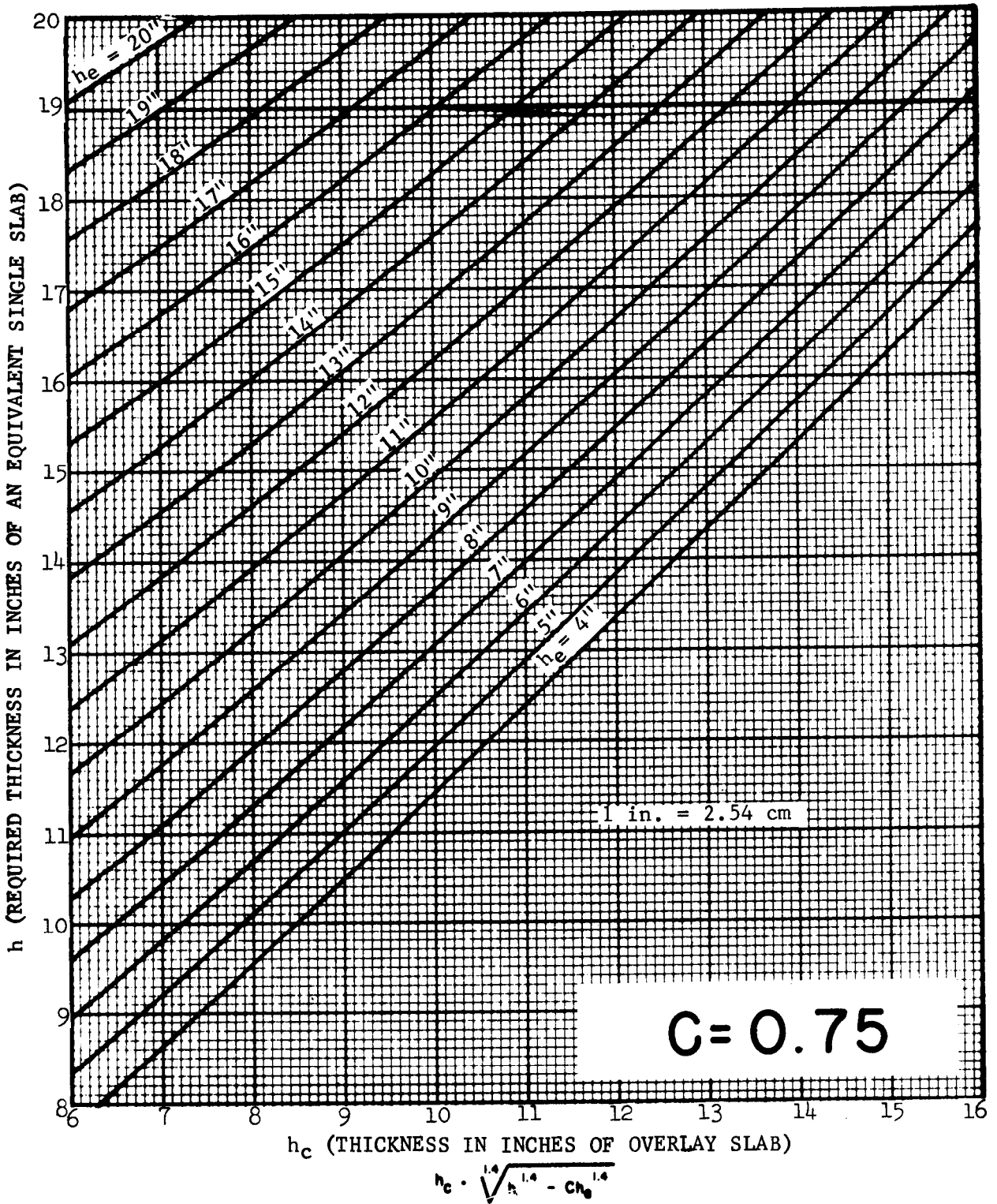


FIGURE 4-10. CONCRETE OVERLAY ON RIGID PAVEMENT

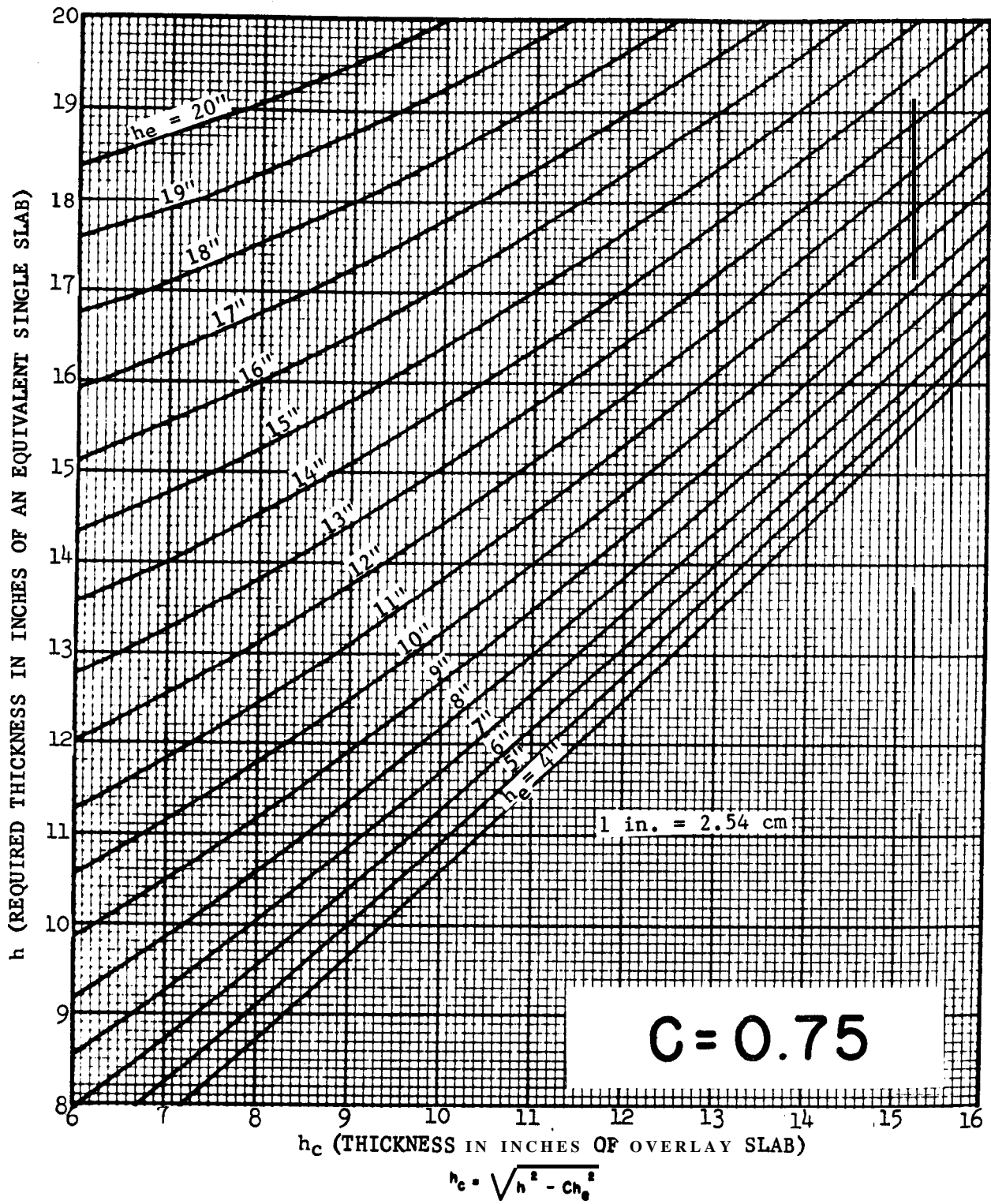


FIGURE 4-11. CONCRETE OVERLAY ON RIGID PAVEMENT

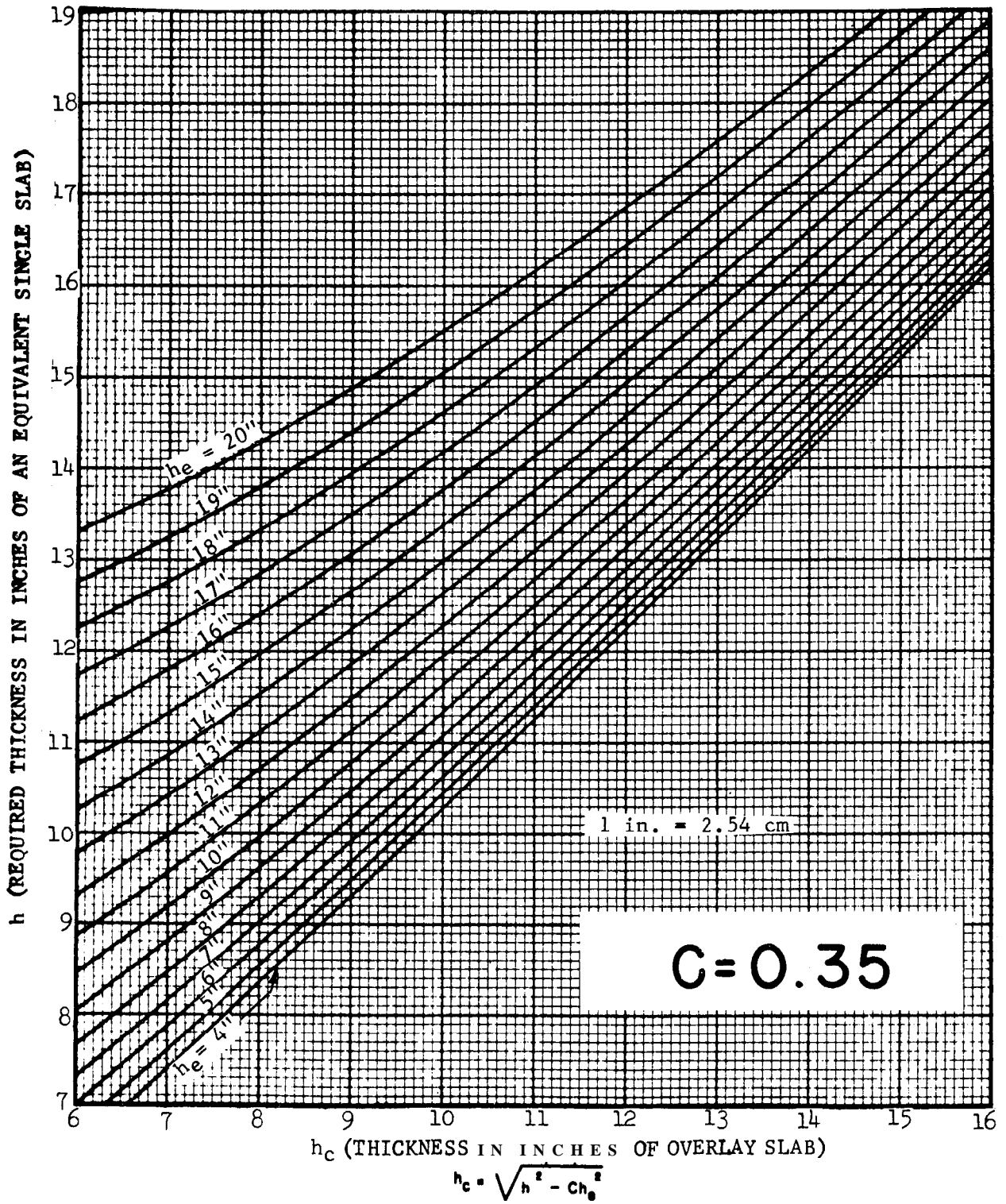


FIGURE 4-12. CONCRETE OVERLAY ON RIGID PAVEMENT

- a. **Joint Types.** Joints need not be of the same type as in the old pavement except for some bonded overlay applications.
- b. **Expansion Joints.** It is not necessary to provide an expansion joint for each expansion joint in the old pavement; however, a saw cut or plane of weakness should be provided within 1 foot (0.3 m) of the existing expansion joint.
- c. **Timing.** The timing for sawing joints is extremely critical on concrete overlays.
- d. **Contraction Joints.** Contraction joints in partially bonded or unbonded overlays may be placed directly over or within 1 foot (0.3 m) of existing expansion, construction, or contraction joints. Joints in bonded overlays should be located within 1/2 inch (12 mm) of joints in the existing base pavement. Should spacing result in slabs too long to control cracking, additional intermediate contraction joints may be necessary.
- e. **Joint Pattern.** If a concrete overlay with a leveling course is used, the joint pattern in the overlay does not have to match the joint pattern in the existing pavement.
- f. **Reinforcement.** Overlay slabs longer or wider than 20 feet (6.1 m) should be reinforced regardless of overlay thickness.

414. PREPARATION OF THE EXISTING SURFACE FOR THE OVERLAY. Before proceeding with construction of the overlay, steps should be taken to correct all defective areas in the existing surface, base, subbase, and subgrade. Careful execution of this part of an overlay project is essential as a poorly prepared base pavement will result in an unsatisfactory overlay. Deficiencies in the base pavement will often be reflected in the overlay.

- a. **Existing Flexible Pavements.** Failures in flexible pavements may consist of pavement breakups, potholes and surface irregularities, and depressions.
 - (1) **Removal And Replacement.** Localized areas of broken pavement will have to be removed and replaced with new pavement. This type of failure is usually encountered where the pavement is deficient in thickness, the **subgrade** consists of unstable material, or poor drainage has reduced the supporting power of the subgrade. To correct this condition, the **subgrade** material should be replaced with a select **subgrade** soil or by installation of proper drainage facilities; this is the first operation to be undertaken in repairing this type of failure. Following the correction of the **subgrade** condition, the subbase, base, and surface courses of the required thickness should be placed. Each layer comprising the total repair should be thoroughly compacted before the next layer is placed.
 - (2) **Irregularities And Depressions.** Surface irregularities and depressions, such as shoving, rutting, scattered areas of settlement, and occasional “birdbaths” should be leveled by rolling, where practical, or by filling with suitable hot mix asphalt mixtures. If the “birdbaths” and settlements are found to exist over extensive areas, a hot mix asphalt leveling course may be required as part of the overlay. The leveling course should consist of a high-quality hot mix asphalt concrete. Scattered areas requiring leveling or patching may be repaired with hot mix asphalt patch mixtures.
 - (3) **Bleeding Surface.** A bleeding surface may detrimentally affect the stability of the overlay and for this reason any excess hot mix asphalt material accumulated on the surface should be bladed off if possible. In some instances, a light application of fine aggregates may blot up the excess material, or a combination of the two processes may be necessary.
 - (4) **Cracks And Joints.** For cracks, and joints, 3/8 inch (10 mm) or more in width, old joint and crack filler should be removed and, if vegetation is present, a sterilant applied. The cracks and joints should then be filled with a lean mixture of sand and liquid bituminous material. This mixture should be well tamped in place, leveled with the pavement surface and any excess removed. The material should be allowed to dry to a hardened condition prior to overlay placement.

(5) **Potholes.** Potholes should be thoroughly cleaned and filled with a suitable bituminous mixture and tamped in place.

b. **Existing Rigid Pavements.** In rigid pavements, narrow transverse, longitudinal, and corner cracks will need no special attention unless there is an appreciable amount of displacement and faulting between the separate slabs. If the **subgrade** is stable and no pumping has occurred, the low areas can be taken care of as part of the overlay and no other corrective measures are needed. On the other hand, if pumping has occurred at the slab ends or the slabs are subject to rocking under the movement of aircraft, **subgrade** support should be improved by pumping cement grout or asphalt cement under the pavement to fill the voids that have developed. Pressure grouting requires considerable skill to avoid cracking slabs or providing uneven support for the overlay.

(1) **Slab Removal And Replacement.** If the pavement slabs are badly broken and subject to rocking because of uneven bearing on the subgrade, the rocking slabs can be broken into smaller slabs to obtain a more firm seating. Badly broken slabs that do not rock will not require repairs since the criteria make adjustments for such a condition in the pavement thickness. In some cases, it may be desirable to replace certain badly broken slabs with new slabs before starting construction of the overlay. The decision in such cases will have to be made according to the merits of the individual project.

(2) **Leveling Course.** Where the existing pavement is rough due to slab distortion, faulting, or settlement, a provision should be made for a leveling course of hot mix asphalt concrete before the overlay is commenced.

(3) **Cracks And Joints.** Cracks, and joints, $\frac{3}{8}$ inch (10 mm) or more in width, should be filled with a lean mixture of sand and liquid bituminous material. This mixture should be tamped firmly in place, leveled with the pavement surface and any excess removed.

(4) **Surface Cleaning.** After all repairs have been completed and prior to the placing of the overlay, the surface should be swept clean of all dirt, dust, and foreign material that may tend to break the bond between the overlay and the existing pavement. Any extruding joint-sealing material should be trimmed from rigid pavements.

(5) **Bonded Concrete Overlays.** Bonded concrete overlays will require special attention to insure bond with the existing pavement. Surface cleaning and preparation by shot peening or mechanical texturing by cold milling are two techniques which have been used to provide a surface which will allow bonding. Adequate bond has been achieved by placing the overlay directly on the dry prepared surface. In other instances, bond was achieved by placing a neat cement grout on the prepared surface immediately ahead of the overlay placement.

415. MATERIALS AND METHODS. With regard to quality of materials and mixes, control tests, methods of construction, and workmanship the overlay pavement components are governed by AC 150/5370-10, Standards for Specifying Construction of Airports.

a. **Tack Coat.** If a hot mix asphalt overlay is specified, the existing pavement should receive a light tack coat (Item P-603) or fog coat immediately after cleaning. The overlay should not extend to the edges of the pavement but should be cut off approximately 3 inches (75 mm) from each edge.

b. **Forms.** Should the existing pavement require drilling to provide anchorage for the overlay pavement forms, the size and number of holes should be the minimum necessary to accomplish that purpose. Holes should not be located close to joints or cracks. Location of holes for form anchors should be such as to avoid causing additional cracking or **spalling**.

416. NEW OVERLAY MATERIALS. In recent years, some new pavement overlay materials have been used with varying degrees of success. These materials include fibrous concrete, roller compacted concrete, and rubberized asphalt. Use of materials other than conventional **portland** cement concrete (Item P-501) or Plant Mix Bituminous Surface (Item P-401) require special approval on a case-by-case basis.

417. POSSIBLE ANOMALIES. The basic design concepts applied to rigid and flexible pavements are different because of differences in behavior and in failure mechanisms for these pavements. These differences can produce anomalous results for rigid and hot mix asphalt overlay designs using the above overlay design procedures. These cases sometimes occur with strong **subgrade** soil or with existing composite pavements, i.e., flexible over rigid pavement. Engineering judgment should be applied to ensure adequate performance of the overlay, regardless of type, for the particular pavement and design conditions.

CHAPTER 5. PAVEMENTS FOR LIGHT AIRCRAFT

500. GENERAL. Pavements for light aircraft are defined as those intended to serve aircraft with gross weights of less than 30,000 lbs (13 000 kg). Aircraft of this size are usually engaged in nonscheduled activities such as agricultural, instructional, or recreational flying. Pavements designed to serve these aircraft may be flexible or rigid-type pavements. The design of pavements serving aircraft of 30,000 pounds (13 000 kg) gross weight or more should be based on the criteria contained in Chapter 3 of this publication. Some areas of airports serving light aircraft may not require paving. In these areas the development of an aggregate-turf or turf surface may be adequate for limited operations of these light aircraft. Aggregate-turf surfaces are constructed by improving the stability of a soil with the addition of aggregate prior to development of the turf. Aggregate-turf construction is covered in some detail in the latter part of this chapter. Information on stabilization of soils can be found in Chapter 2 of this circular and in AC 150/5370-10.

501. TYPICAL SECTIONS, Typical cross sections for light aircraft pavements are shown in Figure 5-1. No distinction is made between critical and noncritical pavement sections for pavements serving light aircraft.

502. FLEXIBLE PAVEMENT MATERIALS. Flexible pavements for light aircraft are composed of hot mix asphalt surfacing, base course, subbase and prepared subgrade. The functions of these layers and applicable specifications are discussed below:

a. Hot Mix Asphalt Surfacing. The function of the hot mix asphalt surface or wearing course is the same as discussed earlier in Chapter 3. Specifications covering the composition and quality of hot mix asphalt mixtures is given in Item P-401, Plant Mix Bituminous Mixtures. Note that under certain conditions state highway hot mix asphalt mixtures may be used for pavements intended to serve aircraft weighing 12,500 pounds (5 700 kg) or less.

b. Base Course. As in heavy load pavements, the base course is the primary load carrying component of a flexible pavement. Specifications covering materials suitable for use as base courses for light load pavements are as follows:

- (1) Item P-208 - Aggregate Base Course
- (2) Item P-209 - Crushed Aggregate Base Course
- (3) Item P-210 - Caliche Base Course
- (4) Item P-211 - Lime Rock Base Course
- (5) Item P-212 - Shell Base Course
- (6) Item P-213 - Sand-Clay Base Course
- (7) Item P-301 - Soil Cement Base Course
- (8) Item P-304 - Cement Treated Base Course
- (9) Item P-306 - Econocrete Subbase Course
- (10) Item P-401 - Plant Mix Bituminous Pavements

Note: Use of some of the above materials in areas where frost penetrates into the base course may result in some degree of frost heave and/or may require restricted loading during spring thaw.

c. Subbase Course. A subbase course is usually required in flexible pavement except those on subgrades with a CBR value of 20 or greater (usually GW or GP type soils). Materials conforming to specification Item P-154 may be used as subbase course. Also any items listed above in paragraph 83b may be used as subbase course if economy and practicality dictate. Since the loads imposed on these pavements are much less than those on pavements designed for heavier aircraft, compaction control for base and subbase layers should be based on ASTM D 698, Tests for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures, Using 5.5-pound (2.5 kg) Rammer and 12-inch (300 mm) Drop.

d. Stabilized Base and Subbase. Stabilized base and subbase courses may be used in light load pavements. Reduced thicknesses of base and subbase may result. Thickness equivalencies for stabilized materials are given in Chapter 3.

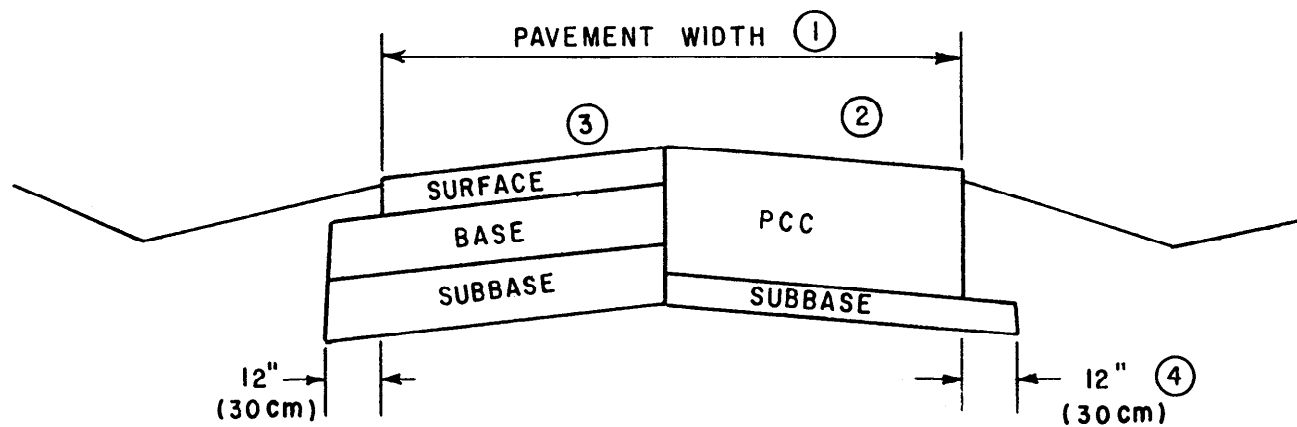
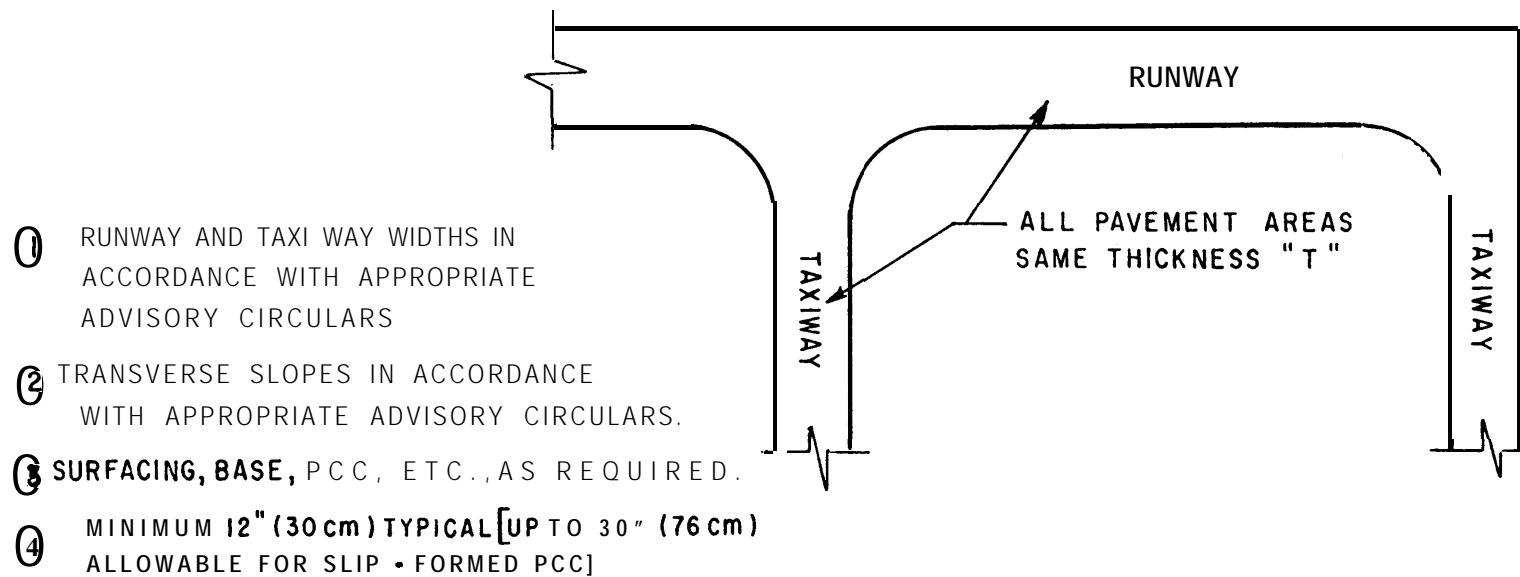


FIGURE 5-1. TYPICAL SECTIONS FOR LIGHT AIRCRAFT PAVEMENTS

- e. **Subgrade.** Subgrade materials should be compacted in accordance with Item P-152 to the depths shown on Table 5-1.

TABLE 5-1. SUBGRADE COMPACTION REQUIREMENTS FOR LIGHT LOAD FLEXIBLE PAVEMENTS

Design Aircraft Gross Weight lbs.	Noncohesive Soils				Cohesive Soils			
	Depth of Compaction (in.)				Depth of Compaction (in.)			
	100%	95%	90%	85%	95%	90%	85%	80%
12,500 or less	6	6-9	9-18	18-24	4	4-8	8-12	12-15
12,501 or more	8	8-12	12-24	24-36	6	6-9	9-12	12-15

Notes:

1. Noncohesive soils, for the purpose of determining compaction control, are those with a plasticity index (P.I.) of less than 6.
2. Tabulated values denote depths below the finished **subgrade** above which densities should equal or exceed the indicated percentage of the maximum dry density as specified in Item P- 152.
3. The **subgrade** in cut areas should have natural densities shown or should (a) be compacted from the surface to achieve the required densities, (b) be removed and replaced at the densities shown, or (c) when economics and grades permit, be covered with sufficient select or subbase material so that the uncompacted **subgrade** is at a depth where the in-place densities are satisfactory.
4. For intermediate aircraft weights use linear interpolation.
5. For swelling soils refer to paragraph 314.
6. 1 inch = 25.4 mm, 1 lb. = 0.454 kg

503. **FLEXIBLE PAVEMENT DESIGN.** Figure 5-2 shows the pavement thickness requirements for aircraft weighing up to 30,000 pounds (13 000 kg) gross weight. The pavement thickness determined from Figure 5-2 should be used on all areas of the airport pavement. No reduction in thickness should be made for “noncritical” areas of pavements. For very light load pavements, the design should also consider the weight of maintenance and fueling equipment. It is possible that these types of equipment may require a thicker pavement section than the aircraft.

a. **Total Pavement Thickness.** Use of the curve requires a CBR value for the **subgrade** and the gross weight of the design aircraft. The preferred method of establishing the **subgrade** CBR is by testing. The testing procedures described in Chapter 3 should also be applied to light load pavements. In instances where CBR tests are not practical, the values listed in Table 2-3 may be used.

b. **Thickness of Surfacing and Base.** The thickness of surfacing and base is determined by using the CBR-20 line. The difference between the total pavement thickness required and the CBR-20 line thickness, composed of surfacing and base, yields the thickness of subbase. Note that the minimum thickness of hot mix asphalt surfacing over a granular base is 2 inches (50 mm).

c. **Thin Lifts.** The reason for the minimum surfacing thickness is that layers thinner than 2 inches (50 mm) are difficult to place and compact on granular bases. Hot mix asphalt surfacing thickness of less than 2 inches (50 mm) is permissible on stabilized base materials if proper **laydown** and compaction can be achieved. The base course thicknesses in Figure 5-2 range from 3 inches (75 mm) to 6 inches (150 mm) while the subbase thicknesses vary from 0-14 inches (0-355 mm). In some instances difficulties may be encountered in compacting thin bases or subbases. In these cases the base or subbase thicknesses may be increased to facilitate construction even though the additional thickness is not needed for structural capacity.

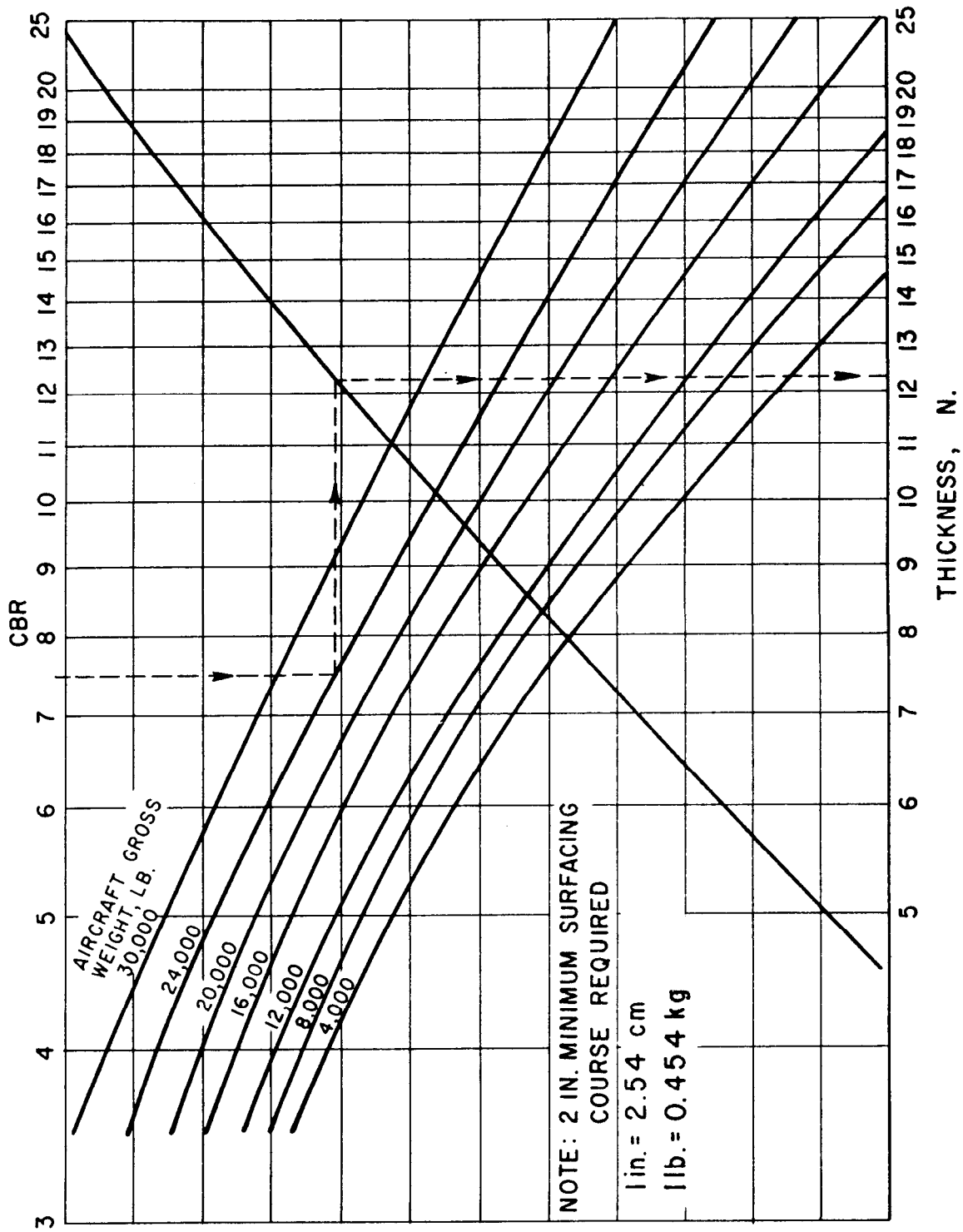


FIGURE 5-2. DESIGN CURVES FOR FLEXIBLE PAVEMENTS - LIGHT AIRCRAFT

d. **Example.** As an example of the use of Figure 5-2, assume a pavement is to be designed for the following conditions.

Aircraft gross weight = 20,000 lbs. (9100 kg)

Subgrade CBR = 7

(1) **Total Pavement Thickness.** Enter the upper abscissa of Figure 5-2 with the **subgrade** CBR value of 7. Make a vertical projection downward to the aircraft gross weight line of 20,000 lbs. (9100 kg). At the point of intersection of the vertical projection and the aircraft gross weight line, make a horizontal projection to the pivot line. At the point of intersection of the horizontal projection and the pivot line, make a vertical projection down to the lower abscissa and read the total pavement thickness required, in this example 11.8 inches (300 mm).

(2) **Thickness of Surfacing and Base.** To determine the thickness of surfacing and base proceed as in the steps above using a CBR value of 20. In this example, a thickness of 5 inches (127 mm) is read on the lower abscissa. This represents the combined thickness of surfacing and base.

(3) **Final Design Section.** The design section would thus consist of 2 inches (50 mm) of hot mix asphalt surfacing, 3 inches (75 mm) of base, and 7 inches (178 mm) of subbase. Should difficulties be anticipated in compacting the 3-inch (75 mm) base course, the base course thickness should be increased. The thickness increase can be accomplished by substituting some of the subbase material with base course. If base material is substituted for subbase material, a thickness credit can be taken. The thickness credit should be determined using the equivalency factors given in Table 3-7.

e. **Omission of Hot Mix Asphalt Surfacing.** Under certain conditions, it may be desirable to utilize a bituminous surface treatment on a prepared base course in lieu of hot mix asphalt. In such instances the strength of the pavement is furnished by the base, subbase, and subgrade. Additional base course thickness will be necessary to make up for the missing surface course. Additional base should be provided at a ratio of 1.2 to 1.6 inches (30 - 41 mm) of base for each 1 inch (25 mm) of surfacing.

f. **Full-Depth Asphalt Pavements.** Pavements to serve light aircraft may be constructed of full-depth asphalt using the criteria specified in paragraph 323. The Asphalt Institute has published guidance on the design of full depth asphalt pavements for light aircraft in Information Series No. 154. See Appendix 4. Use of the Asphalt Institute method of design for full-depth asphalt pavements requires approval on a case-by-case basis.

g. **Local Materials.** Since the base and subbase course materials discussed in Chapter 3 are more than adequate for light aircraft, full consideration should be given to the use of locally available, less expensive materials. These locally available materials may be entirely satisfactory for light load pavements. These materials may include locally available granular materials, soil aggregate mixtures, or soils stabilized with **portland** cement, bituminous materials, or lime. The designer is cautioned, however, if the ultimate design of the pavement is greater than 30,000 lbs (13 000 kg), higher quality materials should be specified at the outset.

504. RIGID PAVEMENT MATERIALS. Rigid pavements for light aircraft are composed of **portland** cement concrete surfacing, subbase, and prepared subgrade. The functions of these layers and applicable specifications are discussed below:

a. **Portland Cement Concrete.** Specifications concerning the quality and placement of **portland** cement concrete should be in accordance with Item P-501, Portland Cement Concrete Pavement. Local state highway specifications for paving quality concrete may be substituted for Item P-501 if desired.

b. **Subbase.** Rigid pavements designed to serve aircraft weighing between 12,500 pounds (5700 kg) and 30,000 pounds (13000 kg) will require a minimum subbase thickness of 4 inches (100 mm) except as shown in Table 3-4 of Chapter 3. No subbase is required for designs intended to serve aircraft weighing 12,500 pounds (5 700 kg) or less, except when soil types OL, MH, CH or OH are encountered. When **the** above soil types are present, a minimum 4-inch (100 mm) subbase should be provided. The materials suitable for subbase courses are covered in Item P-154, Subbase Course.

c. **Subgrade.** Subgrade materials should be compacted in accordance with Item P-152 to the following depths. For cohesive soils used in fill sections, the entire fill shall be compacted to 90 percent maximum density. For cohesive soils in cut sections, the top 6 inches (150 mm) of the subgrade shall be compacted to 90% maximum density. For noncohesive soils used in fill sections, the top 6 inches (150 mm) of fill shall be compacted to 100 percent maximum density, and the remainder of the fill shall be compacted to 95 percent maximum density. For cut sections in noncohesive soils, the top 6 inches (150 mm) of subgrade shall be compacted to 100 percent maximum density and the next 18 inches (460 mm) of subgrade shall be compacted to 95 percent maximum density. For treatment of swelling soils refer to paragraph 3 14.

505. RIGID PAVEMENT THICKNESS. No design curves for light duty rigid pavements are presented since there are only two thickness requirements. Rigid pavements designed to serve aircraft weighing 12,500 pounds (5 700 kg) or less should be 5 inches (127 mm) thick. Those designed to serve aircraft weighing between 12,501 pounds (5 700 kg) and 30,000 pounds (13 000 kg) should be 6 inches (150 mm) thick.

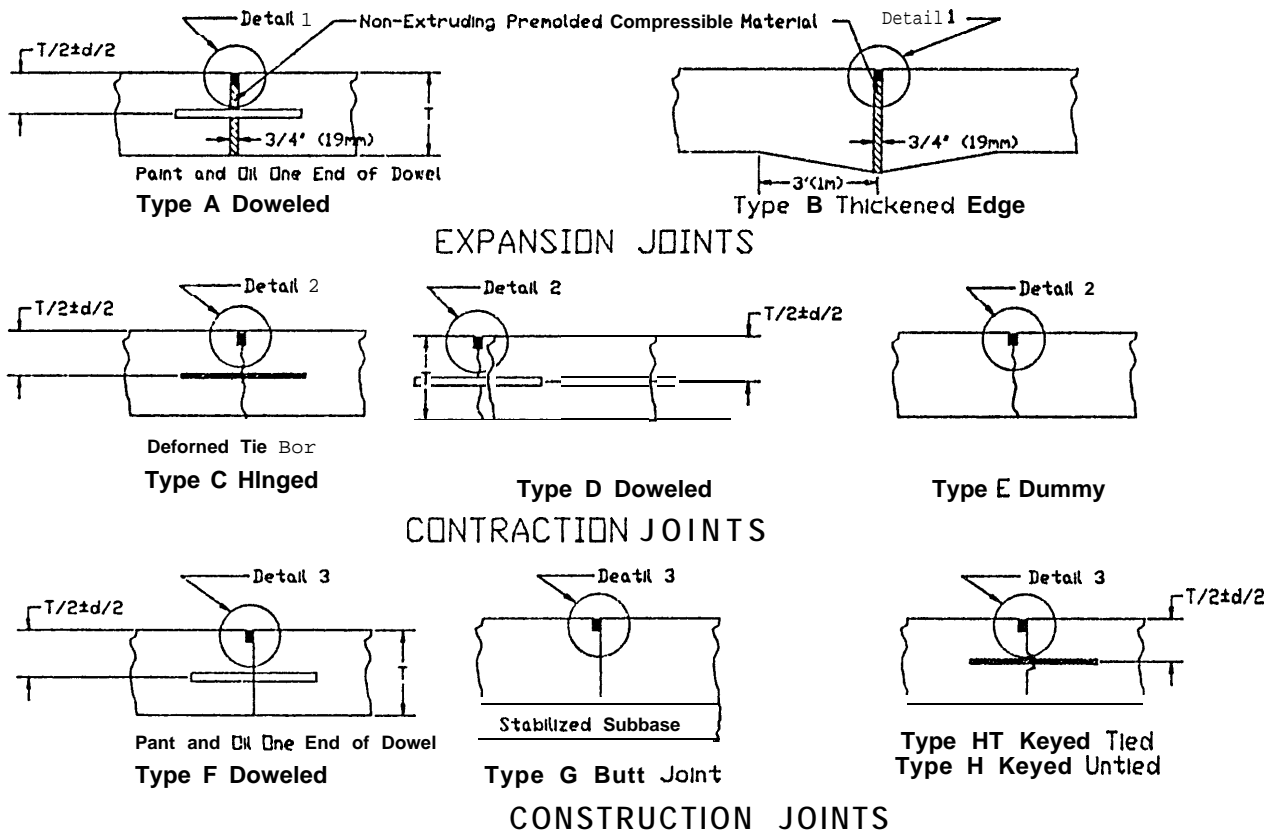
a. **Jointing of Light Load Rigid Pavements.** The maximum spacing of joints for light load rigid pavements should be 12.5 feet (3.8 m) for longitudinal joints and 15 feet (4.6 m) for transverse joints. Jointing details are shown in Figure 5-3. Note that several differences exist between light load and heavy load rigid pavement joints. Such as butt-type construction and expansion joints are permitted when an asphalt or cement stabilized subbase is provided. Also half round keyed joints are permitted even though the slab thicknesses are less than 9 inches (230 mm). Odd-shaped slabs should be reinforced with 0.05% steel in both directions. Odd-shaped slabs are defined as slabs which are not rectangular in shape or rectangular slabs which length-to-width ratios exceed 1.25. Two recommended joint layout patterns are shown in Figure 5-4 for 60 foot (18 m) and Figure 5-5 for 50 foot (15 m) wide pavements. The concept behind the jointing patterns shown is the creation of a "tension ring" around the perimeter of the pavement to hold joints within the interior of the paved area tightly closed. A tightly closed joint will function better than an open joint. The last three contraction joints and longitudinal joints nearest the free edge of the pavement are tied with #4 deformed bars, 20 inches (5 10 mm) long, spaced at 36 inches (1 m) center to center. At the ends of the pavement and in locations where aircraft or vehicular traffic would move onto or off the pavement, a thickened edge should be constructed. The thickened edge should be 1.25 times the thickness of the slab and should taper to the slab thickness over a distance of 3 feet (1 m).

506. AGGREGATE TURF. Aggregate-turf differs from normal turf in that the stability of the underlying soil is increased by the addition of granular materials prior to establishment of the turf. The objective of this type of construction is to provide a landing areas that will not soften appreciably during wet weather and yet has sufficient soil to promote the growth of grass. Aggregate-turf should be considered only for areas designed to serve aircraft having gross weights of 12,500 pounds (5 700 kg) or less.

a. **Materials.** Construction details and material requirements are covered in Item P-217, Aggregate--Turf Pavement. A minimum CBR of 20 is recommended for aggregate/soil layers.

b. **Thickness.** The thickness to be stabilized with the granular materials varies with the type of soil and the drainage and climatic conditions. The total thickness of aggregate stabilized soil should be read directly from the thickness scale of Figure 5-2 using the CBR of the subgrade, disregard note concerning surfacing course.

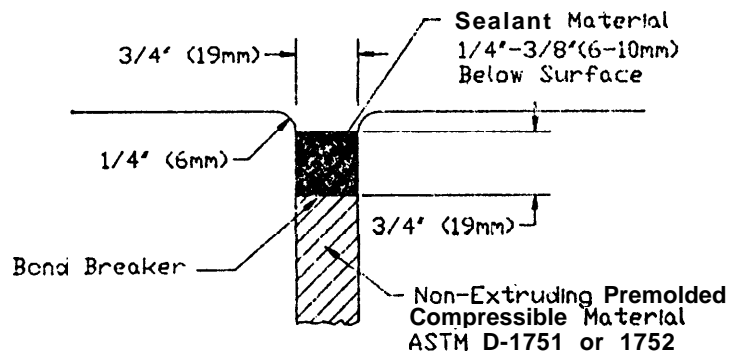
507. OVERLAYS. Overlays of pavements intended to serve light aircraft are designed in the same manner as overlays for heavy aircraft.



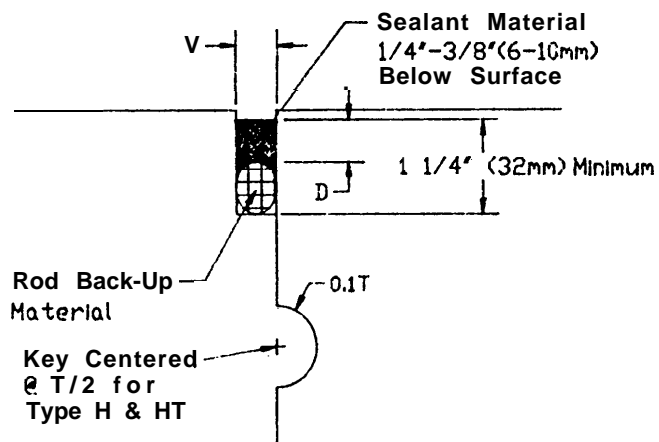
- Notes**
1. For Details 1, 2, & 3 See Next Page,
 2. All Dowels $3/4'$ (19mm) Dia, 18' (460 mm) Long, Spaced 12' (300 mm) on Centers
 3. All Tie Bars No. 4 Deformed Bars 20' (510 mm) Long, Spaced 36' (0.9m) on Centers

FIGURE 5-3. JOINTING DETAIL FOR LIGHT LOAD RIGID PAVEMENTS

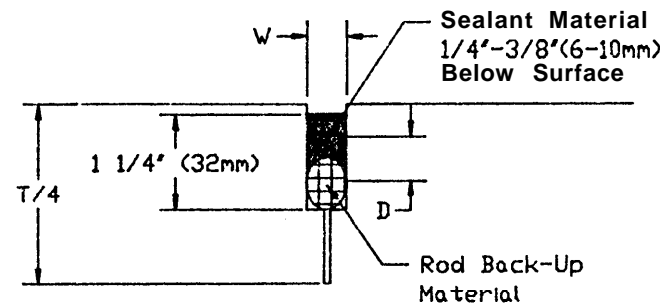
FIGURE S-4. CONT JOINTING DETAILS FOR LIGHT LOAD RIGID PAVEMENTS



Detail 1 Expansion Joints



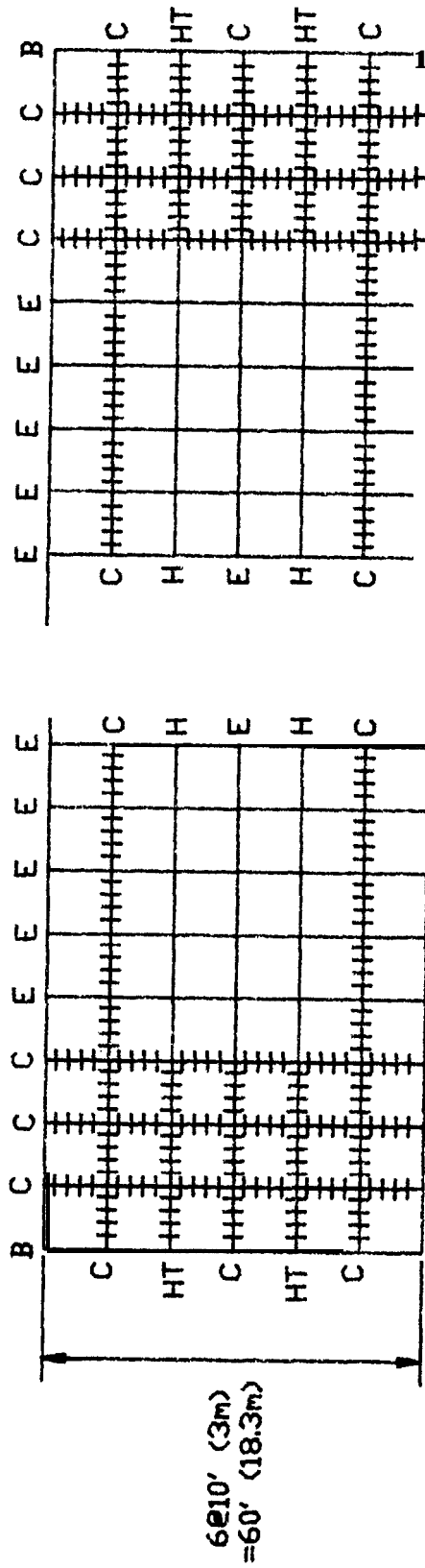
Detail 3 Construction Joints



Detail 2 Contraction Joints

Notes:

1. Sealant Reservoir Sized to Provide Proper Shape Factor, W/D, field Poured and Preformed Sealants Require Different Shape Factors for Optimum Performance.
2. Rod Back-Up Material Must Be Compatible With the Type of Liquid Sealant Used and Sized to Provide the Desired Shape Factor.



- B-Thickened Edge
- E-Dummy Groove
- C-Tied Dummy Groove
- H-Keyed Untied
- HT-Keyed Tied

FIGURE 5-5. JOINT LAYOUT PATTERNS FOR LIGHT LOAD RIGID PAVEMENTS - 60 FEET WIDE

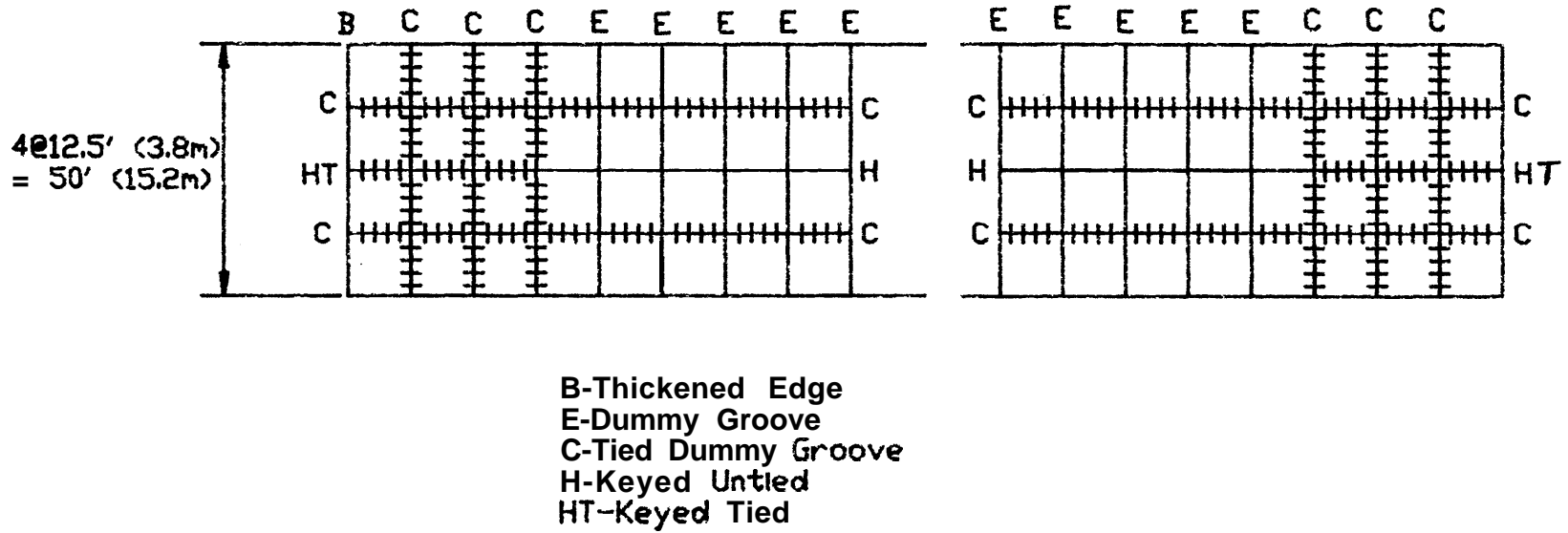


FIGURE 5-6. JOINT LAYOUT PATTERNS FOR LIGHT LOAD RIGID PAVEMENTS - 50 FEET WIDE

CHAPTER 6. PAVEMENT EVALUATION

600. PURPOSES OF PAVEMENT EVALUATION. Airport pavement evaluations are necessary to assess the ability of an existing pavement to support different types, weights, or volumes of aircraft traffic. The load carrying capacity of existing bridges, culverts, storm drains, and other structures should also be considered in these evaluations. Evaluations may also necessary to determine the condition of existing pavements for use in the planning or design of improvements to the airport. Evaluation procedures are essentially the reversal of design procedures. This chapter covers the evaluation of pavements for all weights of aircraft.

601. EVALUATION PROCESS, The evaluation of airport pavements should be a methodical step-by-step process. The recommended steps in the evaluation process are given in the subsequent paragraphs regardless of the type of pavement.

a. Records Research. A thorough review of construction data and history, design considerations, specifications, testing methods and results, as-built drawings, and maintenance history should be performed. Weather records and the most complete traffic history available are also parts of a usable records file.

b. Site Inspection. The site in question should be visited and the condition of the pavements noted by visual inspection. This should include, in addition to the inspection of the pavements, an examination of the existing drainage conditions and drainage structures at the site. Evidence of the adverse effects of frost action, swelling soils, reactive aggregates, etc. should also be noted. The principles set forth in Chapter 2 of this circular and in AC 150/5320-5, Airport Drainage, apply.

c. Sampling And Testing. The need for and scope of physical tests and materials analyses will be based on the findings made from the site inspection, records research, and type of evaluation. A complete evaluation for detailed design will require more sampling and testing than, for example, an evaluation intended for use in a master plan. Sampling and testing is intended to provide information on the thickness, quality, and general condition of the pavement elements.

(1) Direct Sampling Procedures. The basic evaluation procedure for planning and design will be visual inspection and reference to the FAA design criteria, supplemented by the additional sampling, testing, and research which the evaluation processes may warrant. For relatively new pavement constructed to FAA standards and without visible sign of wear or stress, strength may be based on inspection of the FAA Form 5100-1, Airport Pavement Design, and the as-constructed sections, with modification for any material variations or deficiencies of record. Where age or visible distress indicates the original strength no longer exists, further modification should be applied on the basis of judgment or a combination of judgment and supplemental physical testing. For pavements which consist of sections not readily comparable to FAA design standards, evaluation should be based on FAA standards after material comparison and **equivalencies** have been applied.

(2) Nondestructive Testing. Several methods of nondestructive testing (**NDT**) of pavements are available. For purposes of this discussion, NDT means of observing pavement response to a controlled loading, provides a means of evaluating pavements which tends to remove some of the subjective judgment needed in other evaluation procedures. FAA Advisory Circular 150/5370-1 1, Use of Nondestructive Testing Devices in the Evaluation of Airport Pavements, contains guidance on nondestructive testing. The major advantages of nondestructive testing are: the pavement is tested in place under actual conditions of moisture, density, etc.; the disruption of traffic is minimal; and the need for destructive tests is minimized. Research efforts are continuing in the area of nondestructive testing to broaden its application. Several different NDT procedures are available in addition to that described in AC 150/5370-1 1. These other procedures may be used when approved by FAA.

d. Other Evaluation Tools. There are a number of other tools available to assist the evaluator. These tools include: pavement condition index, ground penetrating radar, infrared thermography, etc.

(1) Pavement Condition Index. The determination of the Pavement Condition Index (PCI) is often a useful tool in the evaluation of airport pavements. The **PCI** is a numerical rating of the surface condition of a

pavement and is a measure of functional performance with implications of structural performance. PCI values range from 100 for a pavement with no defects to 0 for a pavement with no remaining functional life. The index is useful in describing distress and comparing pavements on an equal basis. Advisory Circular 150/5380-6, Guidelines and Procedures for Maintenance of Airport Pavements, contains detailed information on PCI surveys.

(2) **Ground Penetrating Radar.** Ground penetrating radar can be useful in studying subsurface conditions nondestructively. Ground penetrating radar depends on differences in dielectric constants to discriminate between materials. The technique is sometimes used to locate voids or foreign objects, such as, abandoned fuel tanks, tree stumps, etc. in embankments.

(3) **Infrared Thermography.** Infrared thermography is a nondestructive testing procedure whereby differences in infrared emissions are observed allowing certain physical properties of the pavement to be determined. Infrared thermography is purportedly capable of detecting delaminations in bonded rigid overlay pavements and in reinforced rigid pavements.

e. **Evaluation Report.** The analyses, findings, and test results should be incorporated in an evaluation report which becomes a permanent record for future reference. While evaluation reports need not be in any particular form, it is recommended that a drawing identifying limits of the evaluation be included. Analysis of information gained in the above steps should culminate in the assignment of load carrying capacity to the pavement sections under consideration. When soil, moisture, and weather conditions conducive to detrimental frost action exist, an adjustment to the evaluation may be required.

602. FLEXIBLE PAVEMENTS. Evaluation of flexible pavements requires, as a minimum, the determination of the thickness of the component layers, and the CBR of the subgrade.

a. **Layer Thicknesses.** The thickness of the various layers in the flexible pavement structure must be known in order to evaluate the pavement. Thicknesses may be determined from borings or test pits. As-built drawings and records can also be used to determine thicknesses if the records are sufficiently complete and accurate.

b. **Subgrade CBR.** Laboratory CBR tests should be performed on soaked specimens in accordance with ASTM D 1883, Bearing Ratio of Laboratory-Compacted Soils. Field CBRs should be performed in accordance with the procedure given in The Asphalt Institute Manual Series 10 (MS-10), Soils Manual. Field CBR tests on existing pavements less than 3 years old may not be representative unless the **subgrade** moisture content has stabilized. The evaluation process assumes a soaked CBR is and will not give reliable results if the **subgrade** moisture content has not reached the ultimate in situ condition. In situations where it is impractical to perform laboratory or field CBR tests, an estimate of CBR based on soil classification is possible. Table 2-3 may be used to estimate CBR on the basis of the Unified Soil Classification System. Prior to adoption of the Unified Soil Classification System, soils were classified using the FAA classification system. Some old records may contain data using the FAA classification system. Figure 6-1 shows the approximate relationship between the FAA soil classification and CBR.

c. **Material Comparisons and Equivalencies.** For the purposes of design and evaluation, flexible pavements are assumed to be constructed of asphaltic concrete surfacing, granular base, and granular subbase courses of a predetermined quality. When the materials in a pavement structure to be evaluated are at variance with these assumptions, the materials have to be compared and equated to a standard section. The nonstandard sections after conversion have to be checked for load carrying capacity based on the following considerations:

- (1) Total pavement section thickness.
- (2) Surface plus base course thickness.
- (3) Minimum base course thickness.
- (4) Minimum surface thickness.

The requirement yielding the lesser strength will control the evaluation.

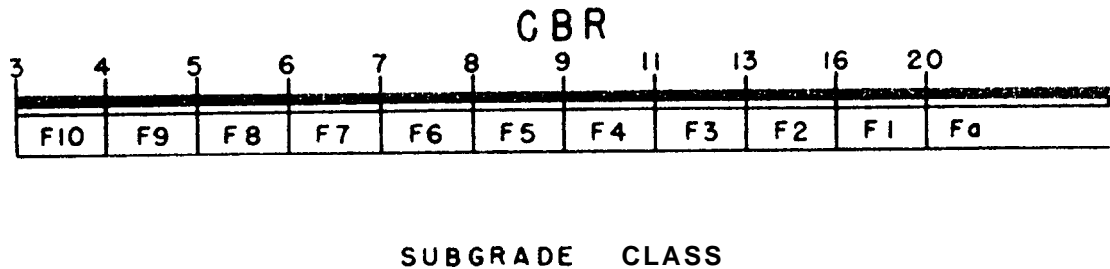


FIGURE 6-1. CBR - FAA SUBGRADE CLASS COMPARISONS

(1) **Subbase And Base Equivalencies.** Equivalency factor ranges shown in Tables 3-6 through and 3-9 for subbase and base are recommended for evaluation purposes. The actual value selected will depend on the composition, quality, and condition of the layer. In instances where experience or physical test results show that other values are valid, they may be used in lieu of the values recommended here. Subbase or base courses should not be assigned a higher equivalency factor than a layer above it in the pavement structure. Conversion of material to a higher classification, such as subbase to base, will not be permitted, except where excess stabilized base course (P-401 or P-304) exists immediately under a flexible surface, in this instance, the stabilized material may be counted as an equal thickness of surface.

(2) **Surfacing.** Broken hot mix asphalt surface course (shrinkage cracks due to age and weathering, without evidence of base failure) shall be evaluated as an equal thickness of nonstabilized base. A hot mix asphalt surface, with limited cracking and well maintained, may justify use of an equivalency between the limits noted.

603. APPLICATION OF FLEXIBLE PAVEMENT EVALUATION PROCEDURES. After all of the evaluation parameters of the existing flexible pavement have been established using the guidance given in the above paragraphs, the evaluation process is essentially the reverse of the design procedure. The design curves presented in Chapter 3 or 5 are used to determine the load carrying capacity of the existing pavement. Required inputs are **subgrade** and subbase CBR values, thicknesses of surfacing, base and subbase courses and an annual departure level. Several checks must be performed to determine the load carrying capacity of a flexible pavement. The calculation which yields the lowest allowable load will control the evaluation.

a. **Total Pavement Thickness.** Enter the lower abscissa of the appropriate design curve in Chapter 3 or 5 with the total pavement thickness of the existing pavement. Make a vertical projection to the annual departure level line. For light load pavements, Chapter 5, a single pivot line is used. At the point of intersection between the vertical projection and the departure level line, or single pivot line in the case of light load pavements, make a horizontal projection across the design curve. Enter the upper abscissa with the CBR value of the subgrade. Make a vertical projection downward until it intersects the horizontal projection made previously. The point of intersection of these two projections will be in the vicinity of the load lines on the design curves. An allowable load is read by noting where the intersection point falls in relation to the load lines.

b. Thickness of Surfacing and Base. The combined thickness of surfacing and base must also be checked to establish the load carrying capacity of an existing flexible pavement. This calculation requires the CBR of the subbase, the combined thickness of surfacing and base and the annual departure level as inputs. The procedure is the same as that described in subparagraph a above, except that the subbase CBR and combined thickness of surfacing and base are used to enter the design curves.

c. Minimum Base Course Thickness. The thickness of the existing base course should be compared with the minimum base course thicknesses Table 3-4 or from Figure 5-2. Notice that the minimum base course thickness is 4 inches (100 mm) for heavy load pavements and 3 inches (75 mm) for light load pavements. If there is a deficiency in the thickness of the existing base course, the pavement should be closely monitored for signs of distress. The formulation of plans for overlaying the pavement to correct the deficiency should be considered.

d. Minimum Surface Thickness. The thickness of the existing surface course should be compared with that shown on the appropriate design curve. If the existing surface course is thinner than that given on the design curve, the pavement should be closely observed for surface failures. It is recommended that correction of the deficiency in surfacing thickness be considered.

604. RIGID PAVEMENTS. Evaluation of rigid pavements requires, as a minimum, the determination of the thickness of the component layers, the flexural strength of the concrete, and the modulus of subgrade reaction.

a. Layer Thicknesses. The thickness of the component layers is sometimes available from construction records. Where information is not available or of questionable accuracy, thicknesses may be determined by borings or test pits in the pavement.

b. Concrete Flexural Strength. The flexural strength of the concrete is most accurately determined from test beams sawed from the existing pavement and tested in accordance with ASTM C 78. Quite often this method is impractical as sawed beams are expensive to obtain and costs incurred in obtaining sufficient numbers of beams to establish a representative sample is prohibitive. Construction records, if available, may be used as a source of concrete flexural strength data. The construction data will probably have to be adjusted for age as concrete strength increases with time. Strength-age relationships can be found in Portland Cement Association, Engineering Bulletin, Design of Concrete Airport Pavement.

(1) Correlations With Other Strength Tests. Correlations between concrete flexural strength and other concrete strength tests are available. It should be noted that correlations between flexural strength and other strength tests are approximate and considerable variations are likely.

(i) Tensile Split Strength. An approximate relationship between concrete flexural strength and tensile splitting strength (ASTM C 496) exists and can be computed by the following formula:

$$R = 1.02(f_t + 200 \text{ psi})$$

where:

R = flexural strength, psi

f_t = tensile split strength, psi

Note: For conversions in metric units the above formula remains the same, except the +200 psi constant should be changed to + 1.38 Mpa.

(ii) Compressive Strength. Flexural strength can be estimated from compressive strength (ASTM C 39) using the formula below:

$$R = 9\sqrt{f'_c}$$

where:

R = flexural strength

f'_c = compressive strength

c. **Modulus of Subgrade Reaction.** The modulus of subgrade reaction is determined by plate bearing tests performed on the subgrade. These tests should be made in accordance with the procedures established in AASHTO T 222. An important part of the test procedure for determining the subgrade reaction modulus is the correction for soil saturation which is contained in the prescribed standard. The normal application utilizes a correction factor determined by the consolidation testing of samples at in situ and saturated moisture content. For evaluation of older pavement, where evidence exists that the subgrade moisture has stabilized or varies through a limited range, the correction for saturation is not necessary. If a field plate bearing test is not practical, the modulus of subgrade reaction may be determined by nondestructive testing, or estimated by using Table 2-3 in Chapter 2 of this circular. Fortunately, pavement evaluation is not too sensitive to the modulus of subgrade reaction.

(1) **Adjustment For Subbase.** An adjustment to the modulus of subgrade reaction will be required if a subbase exists beneath the existing pavement. The thickness of the subbase is required to calculate an adjusted k value. The subbase thickness can be determined from construction records or from borings. The guidance contained in Chapter 3, Section 3 should be used in assigning a k value to a subbase.

605. APPLICATION OF RIGID PAVEMENT EVALUATION PROCEDURES. The evaluation of rigid pavements for aircraft weighing in excess of 30,000 pounds (13 600 kg) requires concrete *flexural* strength, k value of the foundation, slab thickness, and annual departure level as inputs. The rigid pavement design curves in Chapter 3 are used to establish load carrying capacity. The design curves are entered on the left ordinate with the *flexural* strength of the concrete. A horizontal projection is made to the k value of the foundation. At the point of intersection of the horizontal projection and the k line, a vertical projection is made into the vicinity of the load lines. The slab thickness is entered on the appropriate departure level scale on the right side of the chart. A horizontal projection is made from the thickness scale until it intersects the previous vertical projection. The point of intersection of these projections will **be in** the vicinity of the load lines. The load carrying capacity is read by noting where the intersection point falls in relation to the load lines.

606. USE OF RESULTS. If the evaluation is being used for planning purposes and the existing pavement is found to be deficient in accordance with the design standards given in Chapter 3 or 5, the sponsor should be notified as to the deficiency and consideration should be given to corrective action. If the evaluation is being used a part of the design for a project to reconstruct or upgrade the facility, the procedures given in Chapters 3, 4, or 5 should be used to design the reconstruction or overlay project. In this instance the main concern is not the load carrying capacity but rather the difference between the existing pavement structure and the section that is needed to support forecast traffic.

607. REPORTING PAVEMENT STRENGTH. The International Civil Aviation Organization (ICAO) developed a standardized method of reporting airport pavement strength known as the Aircraft Classification Number/Pavement Classification Number ACN/PCN. This method of reporting is based on the concept of reporting strength in terms of a standardized equivalent single wheel load. This method of reporting pavement strength is discussed in FAA Advisory Circular 150/5335-5, Standardized Method of Reporting Airport Pavement Strength - PCN.

APPENDIX 1. ECONOMIC ANALYSIS

1. **BACKGROUND.** The information presented in this appendix was developed from research report DOT/FAA/RD-81/78. The cost data used are probably not current, however, the principles and procedures are applicable. An example is given for illustrative purposes.

2. **ANALYSIS METHOD.**

a. Present worth or present value economic analyses are considered the best methods for evaluating airport pavement design or rehabilitation alternatives. A discount rate of 4 percent is suggested together with an analysis period of 20 years. Residual salvage values should be calculated on the straight-line depreciated value of the alternative at the end of the analysis period. The initial cost and life expectancy of the various alternatives should be based on the engineer's experience with consideration given to local materials, environmental factors and contractor capability.

b. The basic equation for determining present worth is shown below:

$$PW = C + \sum_{i=1}^m M_i \left(\frac{1}{1+r} \right)^{n_i} - S \left(\frac{1}{1+r} \right)^z$$

Where:

PW = Present Worth

C = Present Cost of initial design or rehabilitation activity

m = Number of maintenance or rehabilitation activities

M_i = Cost of the i th maintenance or rehabilitation alternative in terms of present costs, i.e., constant dollars

r = Discount rate (four percent suggested)

n_i = Number of years from the present of the i th maintenance or rehabilitation activity

S = Salvage value at the end of the analysis period

z = Length of analysis period in years (20 years suggested)

The term: $\left(\frac{1}{1+r} \right)^n$

is commonly called the single payment present worth factor in most engineering economic textbooks. From a practical standpoint, if the difference in the present worth of costs between two design or rehabilitation alternatives is 10 percent or less, it is normally assumed to be insignificant and the present worth of the two alternatives can be assumed to be the same.

3. **STEP BY STEP PROCEDURE.** The information presented in this appendix is intended to demonstrate how to calculate cost comparisons for airport pavement alternatives using the present worth method. The following is a step by step procedure illustrating the analysis method.

a. Identify and record key project descriptions such as:

(1) Project Number and Location

(2) Type of Facility

- (3) Design Aircraft
 - (4) Annual Departure of Design Aircraft
 - (5) Subgrade Strength**
- b. If appropriate, determine the condition of existing pavement and record data such as:
- (1) Existing Pavement Layers (thicknesses, etc.)**
 - (2) Condition of Pavement (description of distress, pavement condition index, P.C.I., [see AC 150/5380-6], etc.)**
 - (3) Skid Resistance
 - (4) Required Thickness of New Pavement
- c. Identify what feasible alternatives are available:
- d. Determine costs associated with each feasible alternative in terms of present day costs.
- (1) Initial Cost**
 - (2) Maintenance**
 - (3) Future Rehabilitation
- e. Calculate life-cycle cost for each alternative to be evaluated.
- f. Summarize life-cycle costs, length of time required to perform and the chance for success for each alternative.
- g. Evaluated the most promising alternatives based on costs, time required, operational constraints, chance for success, etc.
- h. If the selection cannot be narrowed to one alternative in the evaluation process, the most promising alternatives should each be bid and the selection made on the basis of the lowest bid.

4. **EXAMPLE PROBLEM - LIGHT-LOAD GENERAL AVIATION AIRPORT.** An example problem is discussed below which illustrates the use of the present worth life-cycle costing techniques described above.

a. A general aviation airport runway is in need of rehabilitation. The existing pavement contains alligator, **transverse**, and longitudinal cracking. The design aircraft for the facility has a gross weight of 24,000 lbs. (10 890 kg). Using the procedures in Chapter 5 of this circular, a 3 inch (76 mm) thick bituminous overlay is required to rehabilitate the pavement. Pertinent data are presented in the Project Summary.

PROJECT SUMMARY

Location - Muddville, TX

Design Aircraft: 24,000 **lbs.** (10 890 kg)

Number - A.I.P. 12-34-567

Annual Departures of Design Aircraft: 3,000

Type of Facility: General Aviation Runway **Subgrade Strength: CBR = 4**
length = 3,200 ft. (75 m)

width = 75 ft. (23 m)

Existing Pavement:

Layer and Type	Thickness	Condition
AC Surface	4in. (102 mm)	Poor
Untreated Base	10in. (254 mm)	Good

Condition of Existing Pavement:

Condition Survey: Alligator cracking, moderate 15% of area
Trans. cracking, moderate, **350'/station**
Long. cracking, moderate, **400'/station**
P.C.I. = 35

Skid Resistance: Good

Req'd Thickness New Pave. = 18 in. (487 mm) total
2 in. (51 mm) surf.
5 in. (127 mm) base
11 in. (279 mm) subbase

b. Seven rehabilitation alternatives including surface, in-place, and hot-mix recycling are considered feasible. The alternatives under consideration are:

- (1) Asphalt-rubber chip seal to delay overlay
- (2) Full width **3-inch** (76 mm) direct overlay
- (3) Surface recycle 1-inch (25 mm) deep + **2-inch** (51 mm) overlay
- (4) Asphalt-rubber interlayer + **3-inch** (76 mm) overlay
- (5) Fabric interlayer + **3-inch** (76 mm) overlay
- (6) Cold recycle with asphalt emulsion **6-inch** (152 mm) deep + **2-inch** (51 mm) overlay
- (7) Hot recycle and rework base

c. The present day costs of various activities associated with these alternatives are estimated as shown in Table 1.

TABLE 1. COSTS OF REHABILITATION ACTIVITIES

Rehabilitation Activity	cost	
	\$/yd ²	\$/m ²
Asphalt-Rubber Chip Seal	1.25	(1.50)
Asphalt-Rubber Interlayer	1.25	(1.50)
Fabric Interlayer	1.20	(1.44)
Surface Recycling	0.90	(1.08)
Asphaltic Concrete - 1 in. (25 mm)	1.65	(1.97)
Cold Recycle + 2 in. (51 mm) Overlay	6.60	(7.89)
Hot Recycle + Rework Base	8.10	(9.69)

d. The life-cycle costs for each alternative are calculated. This example shows the calculations for only one alternative, the asphalt-rubber chip seal. The calculations are shown in Table 2. Some of the important aspects of this analysis are discussed further below.

**TABLE 2. PRESENT WORTH LIFE-CYCLE COSTING
EXAMPLE 1. ALTERNATIVE 1 ASPHALT-RUBBER CHIP SEAL**

Year	Cost, \$/yd ²	Present Worth Factor, 4%	Present Worth Dollars
0 A-R Chip Seal	1.25	1.0000	1.25
1		0.9615	
2		0.9246	
3 Maintenance	0.25	0.8890	0.22
4 3" Overlay	4.95	0.8548	4.23
5		0.8219	
6		0.7903	
7		0.7599	
8		0.7307	
9		0.7026	
10 Maintenance	0.10	0.6756	0.07
11 Maintenance	0.10	0.6496	0.06
12 Maintenance	0.10	0.6246	0.06
13 Maintenance	0.10	0.6006	0.09
14 Maintenance	0.25	0.5775	0.14
15 1 1/2" Overlay	2.48	0.5553	1.38
16		0.5339	
17		0.5134	
18		0.4936	
19 Maintenance	0.10	0.4746	0.05
20 Maintenance	0.15	0.4564	0.07
Sub Total	9.88		
Salvage Value	-0.71	0.4564	-0.32
Total	9.17		7.300

Note: To convert from \$/yd.² to \$/m², divide by 0.8361.

(1) The asphalt-rubber chip seal is estimated to delay the need for an overlay for 4 years. In the third year the asphalt-rubber chip seal will need maintenance costing \$0.25/yd² (\$0.29/m²).

(2) In the fourth year a 3-inch (76 mm) overlay will be required. This overlay will require maintenance starting in the 10th year and will require progressively more maintenance as time goes on. In the 14th year maintenance will reach \$0.25/yd² (\$0.29/m²).

(3) In the 15th year a 1.5-inch (38mm) leveling course will be required. This leveling course will not require maintenance until the 19th year. Maintenance costs begin to escalate again as time goes on.

(4) The 20th year marks the end of the analysis period. The salvage value of the leveling course is: the ratio of the life remaining/to how long it will last; multiplied by its costs. The leveling course, constructed in the 15th year, is expected to have a life of 7 years. It was used for only 5 years during the analysis period. Thus, the leveling course had 2 years of life remaining at the end of the analysis period. The salvage value is $\frac{2}{7} \times \$2.48 = \0.71 . Discounting the salvage value to the 20th year yields a salvage value of \$0.32. Since the salvage value is an asset rather than a cost, it is shown as a negative cost in Table 2. All other activities are assumed to have no salvage value since their useful lives have been exhausted during the analysis period. In this example, a discount rate of 4% was assumed. The present worth calculations for the other six alternatives should be calculated in a similar fashion.

e. A final summary of all alternatives considered in this example is shown in Table 3. This summary

shows initial costs, life-cycle costs, construction times, and the probability for success in percent. This final summary is a convenient method of presenting all alternatives for evaluation. In this example a discount rate of 4% was used in all calculations. Maintenance and need for rehabilitation in future years are the engineer's estimates.

TABLE 3. SUMMARY OF ALTERNATIVES

Alternatives	First Cost \$/yd. ²	Present Worth Life Cycle \$/yd. ²	Time	Success Chance for %
#1 Asph-Rub Chip Seal	1.25	7.30	2 days	90
#2 3-in. Direct Overlay	4.95	7.29	5 days	95
#3 Surf. Recycle + Overlay	4.20	6.22	4 days	97
#4 A-R Layer + Overlay	6.20	7.39	4 days	97
#5 Fabric + Overlay	6.15	7.74	4 days	97
#6 Cold Recycle	6.60	7.41	6 days	97
#7 Hot Recycle	8.10	8.46	6 days	99

Note: To convert from \$/yd.² to \$/m², divide by 0.8361.

- f. Comparing and ranking the various alternatives shown in Table 3 yields the following results:

TABLE 4. COMPARATIVE RANKING OF ALTERNATIVES

First Cost	Life-Cycle Cost	Time	Chance for Success
#1	#3	#1	#7
#3	#2	#3	#3
#2	#1	#4	#4
#5	#4	#5	#5
#4	#6	#2	#6
#6	#5	#6	#2
#7	#7	#7	#1

The average life-cycle cost of all 7 alternatives is \$7.40/yd.² (\$8.85/m²). Adding and subtracting 10% to the average life-cycle cost yields a range of \$6.66/yd.² to \$8.14/yd.² (\$7.97/m² to \$9.74/m²). Alternative #3, surface recycling with an overlay, is lowest in life-cycle costs. Life-cycle costs for alternatives #1, 3, 4, 5, and 6 are within the 10% range of the average cost. Alternative #7 is the most costly and exceeds 10% of the average costs. Alternative #3 appears to be the most promising as it ranks high in three of the four categories considered. The decision to select alternative #3 must consider the availability of contractors capable of performing surface recycling and the time required for completion.

5. **SUMMARY** This appendix presents an economic procedure for evaluating a wide variety of airport pavement design strategies. While the design example addresses a rehabilitation project, the principles are applicable to designs of *new* pavements as well. Cost data used in the example are out of date and should be updated with more current local costs before individual evaluations leading to strategy selection are undertaken. Whenever possible, local costs should be used in all alternative analyses as local conditions sometimes vary considerably from broad overall averages.

APPENDIX 2. DEVELOPMENT OF PAVEMENT DESIGN CURVES

1. **BACKGROUND.** The pavement design curves presented in this circular were developed using the California Bearing Ratio (CBR) method for flexible pavements and Westergaard edge loading analysis for rigid pavements. The curves are constructed for the gross weight of the aircraft assuming 95% of the gross weight is carried on the main landing gear assembly and the remaining 5% is carried on the nose gear assembly. Aircraft traffic is assumed to be normally distributed across the pavement in the transverse direction. See FAA Research Report No. FAA-RD-74-36, Field Survey and Analysis of Aircraft Distribution of Airport Pavement. Pavements are designed on the basis of static load analysis. Impact loads are not considered to increase the pavement thickness requirements. See FAA Research Report No. FAA-RD-74-39, Pavement Response to Aircraft Dynamic Loads.

a. **Generalized Design Curves.** Generalized design curves are presented in Chapter 3 for single, dual, and dual tandem main landing gear assemblies. These generalized curves apply to families of aircraft rather than particular aircraft. Generally speaking the assumed characteristics are representative of older aircraft. The aircraft characteristics assumed for each landing gear assembly are shown in Tables 1, 2, and 3.

TABLE 1. SINGLE WHEEL ASSEMBLY

Gross Weight		Tire Pressure	
lbs.	(kg)	psi	(MN/m ²)
30,000	(13 600)	75	(0.52)
45,000	(20400)	90	(0.62)
60,000	(27 200)	105	(0.72)
75,000	(34 000)	120	(0.83)

TABLE 2. DUAL WHEEL ASSEMBLY

Gross Weight		Tire Pressure		Dual Spacing	
lbs.	(kg)	psi	(MN/m ²)	in.	(mm)
50,000	(22 700)	80	(0.55)	20	(51)
75,000	(34 000)	110	(0.76)	21	(53)
100,000	(45 400)	140	(0.97)	23	(58)
150,000	(68 000)	160	(1.10)	30	(76)
200,000	(90700)	200	(1.38)	34	(86)

TABLE 3. DUAL TANDEM ASSEMBLY

Gross Weight		Tire Pressure		Dual Spacing		Tandem Spacing	
lbs.	(kg)	psi	(MN/m ²)	in.	(mm)	in.	(mm)
100,000	(45 400)	120	(0.83)	20	(51)	45	(114)
150,000	(68 000)	140	(0.97)	20	(51)	45	(114)
200,000	(90700)	160	(1.10)	21	(53)	46	(117)
300,000	(136 100)	180	(1.24)	26	(66)	51	(130)
400,000	(181 400)	200	(1.38)	30	(76)	55	(140)

b. **Specific Design Curves.** Design curves for specific aircraft are presented in Chapter 3 for aircraft which have characteristics different from those assumed in Table 1, 2, or 3. Newer aircraft sometimes have different characteristics than those assumed for the generalized curves. The landing gear characteristics associated with each specific design curve is given on the curve.

2. **RIGID PAVEMENTS.** The design of rigid airport pavements is based on the Westergaard analysis of an edge loaded slab resting on a dense liquid foundation. The edge loading stresses are reduced by 25 percent to account for load transfer across joints. Two different cases of edge loading are covered by the design curves. Figures 3-17 through 3-29 assume the landing gear assembly is either tangent to a longitudinal joint or perpendicular to a transverse joint, whichever produces the largest stress. Figures 3-30 through 3-40 are for dual tandem assemblies and have been rotated through an angle to produce the maximum edge stress. Computer analyses were performed for angles from 0 to 90 degrees in 10-degree increments. Single and dual wheel assemblies were analyzed for loadings tangent to the edge only since the stress is maximum in that position. Sketches of the various assembly positions are shown in Figure 1.

a. **Load Repetitions.** Fatigue effects are considered in the design process by increasing slab thickness for increased numbers of load repetitions. Load repetitions are expressed in coverages. For rigid pavements, coverages equal the number of times a pavement slab experiences a maximum stress application due to applied traffic. One coverage occurs when each point in the pavement within the limits of the traffic lane has experienced a maximum stress, assuming the stress is equal under the full tire print. The coverage concept provides a means of normalizing pavement performance data which can consist of a variety of wheel sizes, spacings and loads for pavements of different cross sections. Each pass (departure) of an aircraft can be converted to coverages using a single pass-to-coverage ratio which is developed assuming a normal distribution and applying standard statistical techniques. The pass-to-coverage ratios used in developing the rigid pavement design curves in Chapter 3 are given in Table 4. Annual departures are converted to coverages assuming a 20-year design life. Coverages are determined by multiplying annual departures by 20 and dividing that product by the pass-to-coverage ratio shown in Table 4.

TABLE 4. PASS-TO-COVERAGE RATIOS FOR RIGID PAVEMENTS

Design Curve	Pass-to-Coverage Ratio
Single Wheel	5.18
Dual Wheel	3.48
Dual Tandem	3.68
A-300 Model B2	3.5 1
A-300 Model B4	3.45
B-747	3.70
B-757	3.88
B-767	3.90
c-130	4.15
DC 10-10	3.64
DC 10-30	3.38
L-101 I	3.62

b. **Basic Thickness Calculation.** Pavement thickness requirements for 5,000 coverages are computed for various concrete strengths and subgrade moduli. Allowable concrete stress for 5,000 coverages is computed by dividing the concrete flexural strength by 1.3 (analogous to a safety factor). The thickness of pavement required to sustain 5,000 coverages of the design loading is considered to be 100 percent thickness.

c. **Thickness Adjustment.** The basic slab thicknesses are multiplied by the percent thickness shown in Figure 2 for other coverage levels, accordance with the fatigue curve developed by the Corps of Engineers from test track data and observation of in-service pavements. The fatigue relationship is applicable to the pavement structure; i.e., the slab and foundation are both included in the relationship. Any coverage level could have been selected as the 100 percent thickness level as long as the relative thicknesses for other coverage levels shown in Figure 2 is maintained.

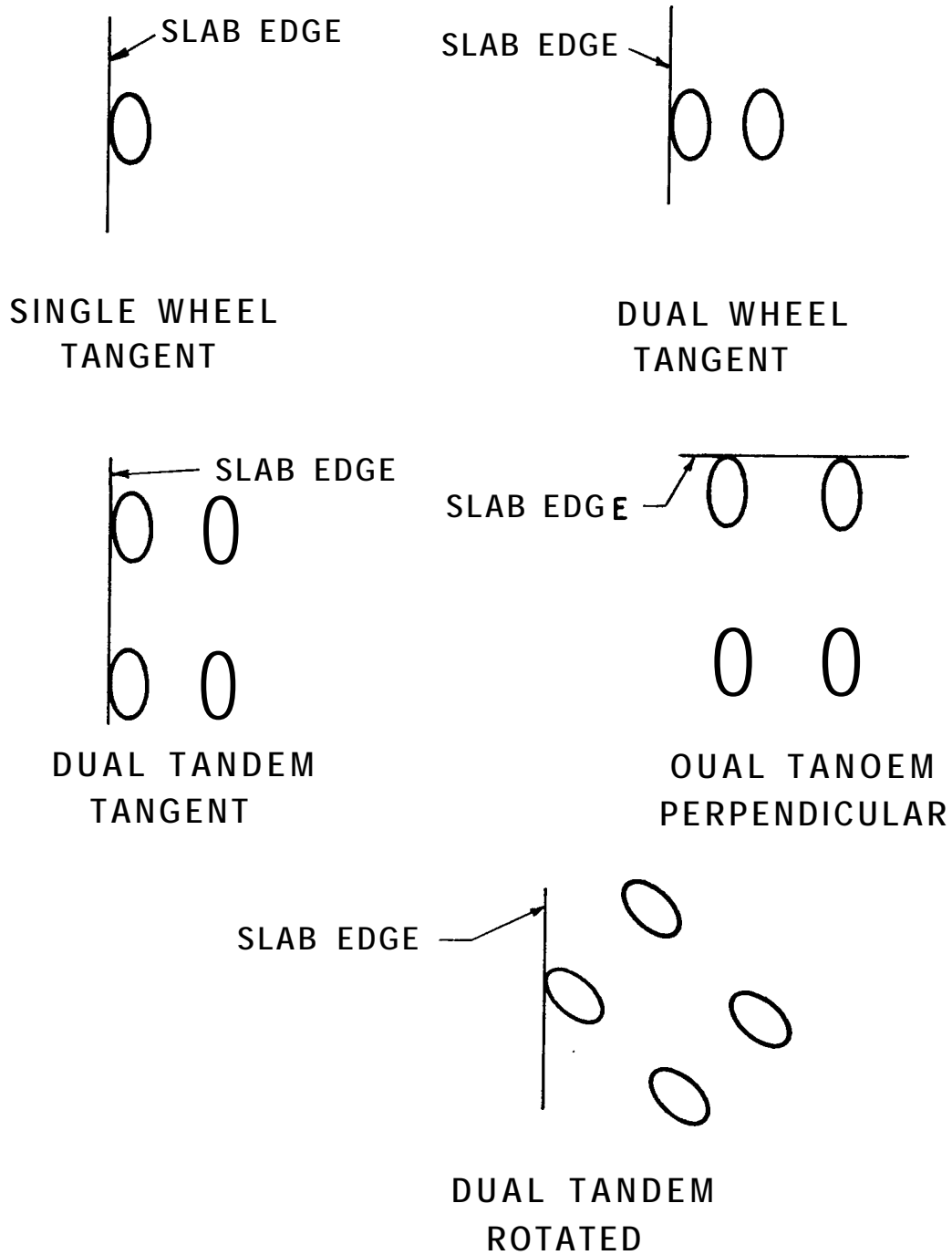


FIGURE 1. ASSEMBLY POSITIONS FOR RIGID PAVEMENT ANALYSIS

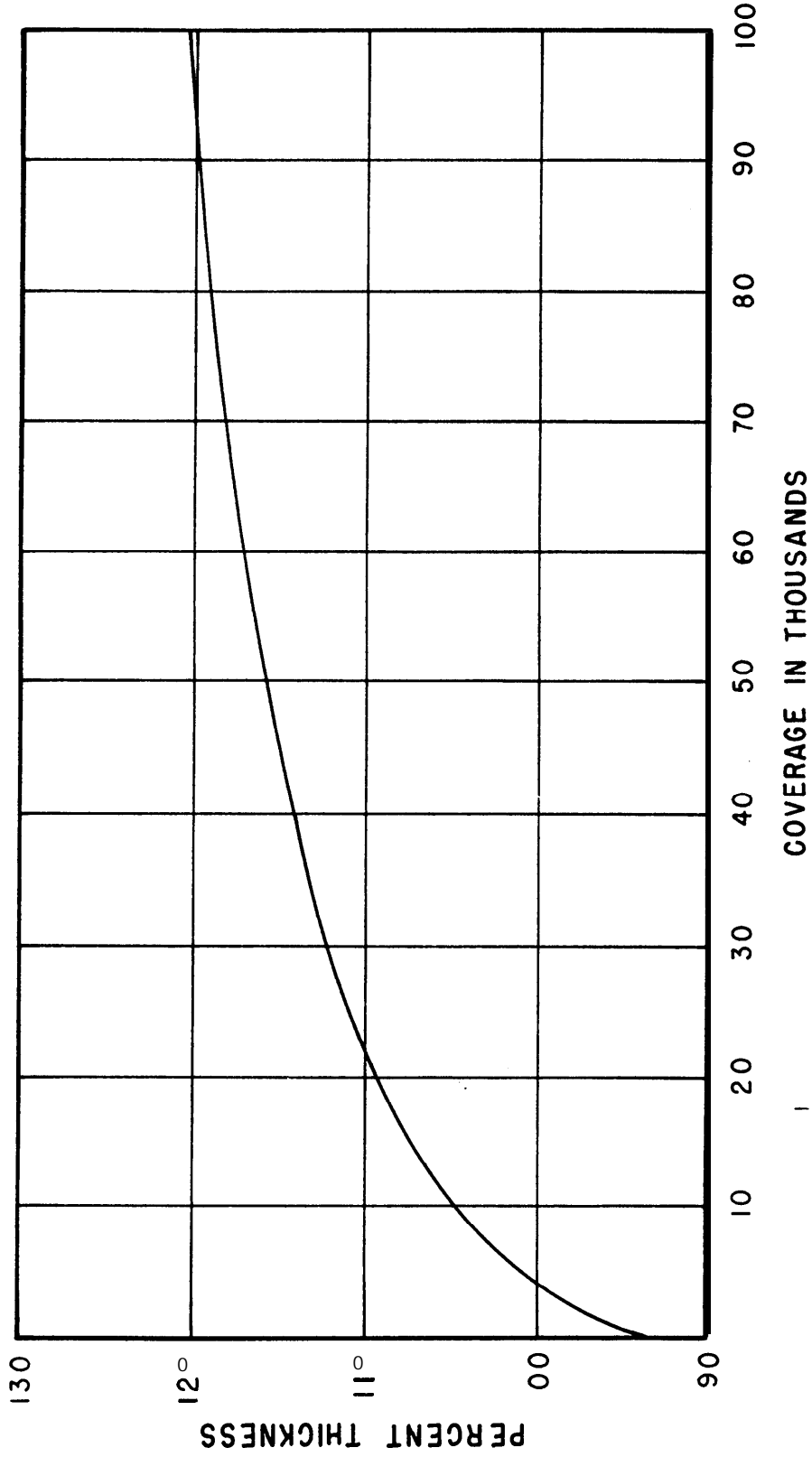


FIGURE 2. PERCENT THICKNESS VS. COVERAGES

3. **FLEXIBLE PAVEMENTS.** The design curves for flexible pavements in Chapter 3 of this circular are based on the CBR method of design. The CBR is the ratio of the load required to produce a specified penetration of a standard piston into the material in question to the load required to produce the same penetration in a standard well-graded, crushed limestone. Pavement thicknesses necessary to protect various CBR values from shear failure have been developed through test track studies and observations of in-service pavements. These thicknesses have been developed for single wheel loadings. Assemblies other than single wheel are designed by computing the equivalent single wheel load for the assembly based on deflection. Once the equivalent single wheel is established, the pavement section thickness can be determined from the relationships discussed above.

a. **Load Repetitions.** Load repetitions are indicated on the design curves in terms of annual departures. The annual departures are assumed to occur over a 20-year life. In the development of the design curves, departures are converted to coverages. For flexible pavements, coverage is a measure of the number of maximum stress applications that occur on the surface of the pavement due to the applied traffic. One coverage occurs when all points on the pavement surface within the traffic lane have been subjected to one application of maximum stress, assuming the stress is equal under the full tire print. Each pass (departure) of an aircraft can be converted to coverages using a single pass-to-coverage ratio which is developed assuming a normal distribution and applying standard statistical techniques. The pass-to-coverages ratios used in developing the flexible pavement design curves in Chapter 3 are given in Table 5. Annual departures are converted to coverages by multiplying by 20 and dividing that product by the pass-to-coverage ratios given in Table 5. Figure 3 shows the relationship between load repetition factor and coverages. The pavement section thickness determined in accordance with paragraph a. above is multiplied by the appropriate load repetition factor, Figure 3, to give the final pavement thickness required for various traffic levels.

TABLE 5.
PASS-TO-COVERAGE
RATIOS FOR FLEXIBLE
PAVEMENTS

Design Curve	Pass-to- Converge Ratio
Single Wheel	5.18
Dual Wheel	3.48
Dual Tandem	1.84
A-300 Model B2	1.76
A-300 Model B4	1.73
B-747	1.85
B-757	1.94
B-767	1.95
c-130	2.07
DC 10-10	1.82
DC 10-30	1.69
L-101 1	1.81

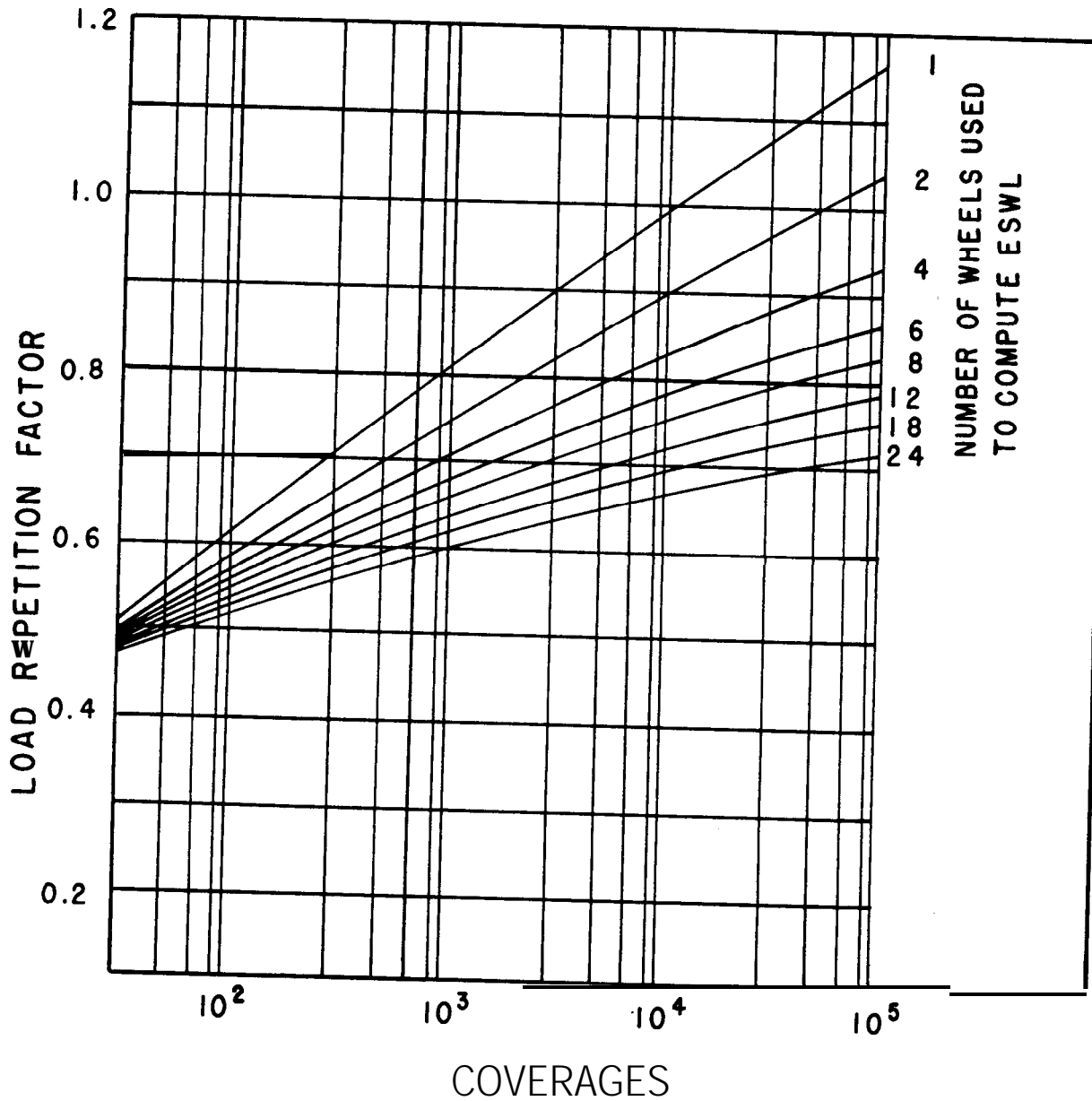


FIGURE 3. LOAD REPETITION FACTOR VS. COVERAGES

APPENDIX 3. DESIGN OF STRUCTURES FOR HEAVY AIRCRAFT

1. **BACKGROUND.** Airport structures such as culverts and bridges are usually designed to last for the foreseeable future of the airport. Information concerning the landing gear arrangement of future heavy aircraft is speculative. It may be assumed with sufficient confidence that strengthening of pavements to accommodate future aircraft can be performed without undue problems. Strengthening of structures, however, may prove to be extremely difficult, costly, and time-consuming. Point loadings on some structures may be increased; while on overpasses, the entire aircraft weight may be imposed on a deck span, pier, or footing.

2. RECOMMENDED DESIGN PARAMETERS.

a. **Structural Considerations.** For many structures the design is highly dependent upon the aircraft gear configuration. Our assessment indicates that three basic configurations, shown in Figure 1, will, if all are considered in the design of the bridge components, provide sufficient support for any aircraft which may be forthcoming. These consist of two areas enclosing eight wheels each, or 16 wheels per aircraft comprising the main gear. Nose gears, as such, are not considered, except as they occur in the static load. The "area" dimensions are 6 to 8 feet by 20 feet (2-3 m by 6 m) each supporting half of the aircraft gross weight. Wheel prints are uniformly spaced within their respective areas.

b. **Foundation Design.** Foundation design will vary with soil type and depth. No departure from accepted methodology is anticipated; except that for shallow structures, such as inlets and culverts, the concentrated loads may require heavier and wider spread footings than those presently provided by the structural standards in current use. For buried structures, such as culverts, the following guidance from AASHTO is recommended.

(1) When the depth of fill is less than 2 feet the wheel loads shall be treated as concentrated loads.

(2) When the depth of fill is 2 feet or more, wheel loads shall be considered as uniformly distributed over a square with sides equal to $1\frac{3}{4}$ times the depth of the fill. When such areas from several concentrations overlap, the total load shall be uniformly distributed over the area defined by the outside limits of the individual areas, but the total width of distribution shall not exceed the total width of the supporting slab.

c. **Loads.** It should be noted that all loads discussed herein are to be considered as dead load plus live loads. The design of structures subject to direct wheel loads should also anticipate braking loads as high as 0.7 G (for no-slip brakes).

d. **Direct Loading.** Decks and covers subject to direct heavy aircraft loadings such as manhole covers, inlet grates, utility tunnel roofs, bridges, etc., should be designed for the following loadings:

(1) Manhole covers for 100,000 lb. (45 000 kg) wheel loads with 250 psi (1.72 MPa) tire pressure.

(2) For spans of 2 feet (0.6 m) or less in the least direction, a uniform live load of 250 psi (1.72 Mpa).

(3) For spans of 2 feet (0.6 m) or greater in the least direction, the design shall be based on the number of wheels which will fit the span. Wheel loads of 50,000 to 75,000 pounds (22 700 to 34 000 kg) should be considered.

(4) Special consideration shall be given to structures that will be required to support both in-line and diagonal traffic lanes, such as diagonal **taxiways** or apron taxi routes. If structures require expansion joints, load transfer may not be possible.

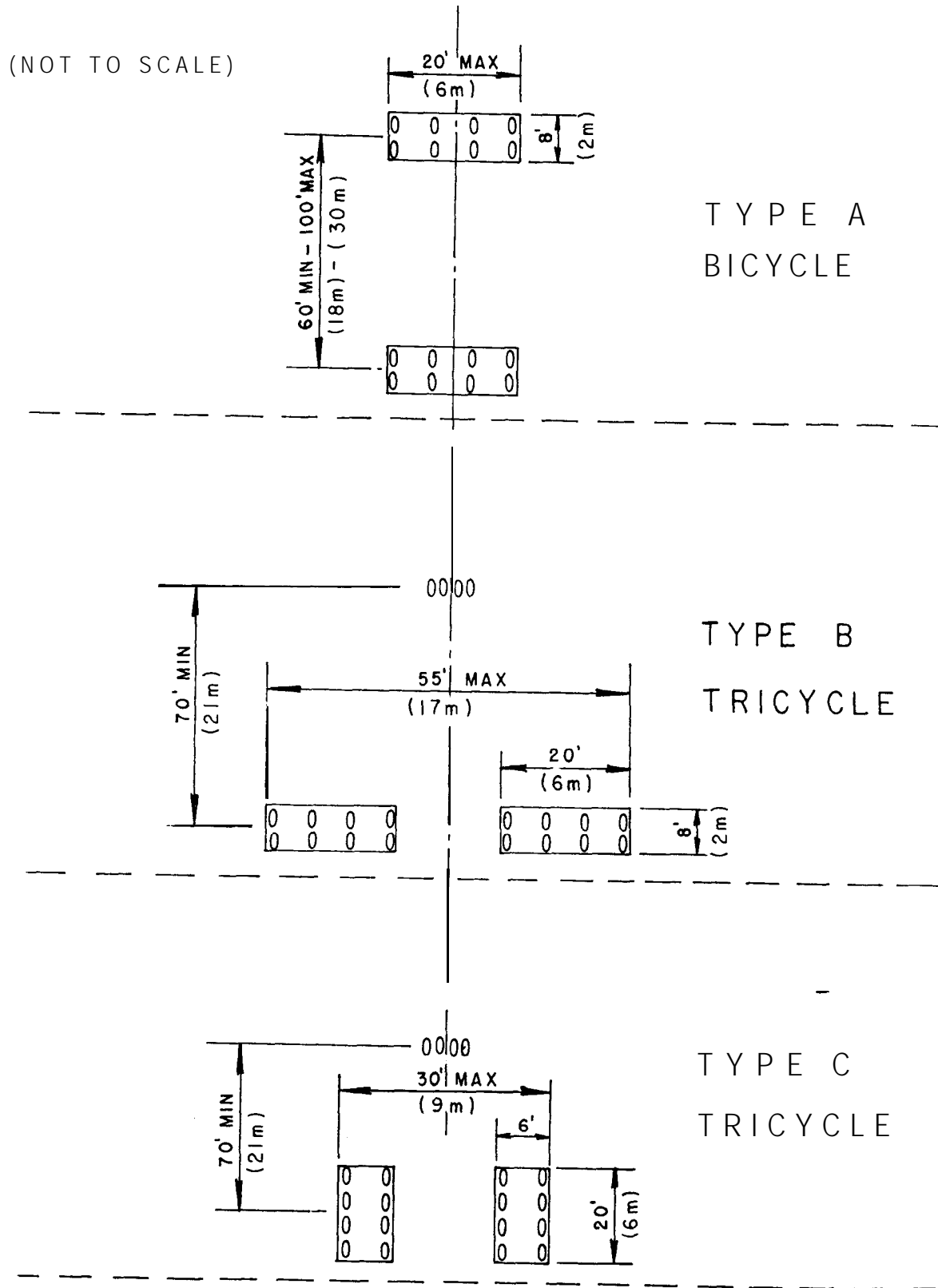


FIGURE 1. TYPICAL GEAR CONFIGURATIONS FOR DESIGN OF STRUCTURES

APPENDIX 4. RELATED READING MATERIAL

1. The latest issuance of the following free publications may be obtained from the Department of Transportation, Utilization and Storage Section, M-443.2, Washington, D.C. 20590. Advisory Circular 00-2, updated triennially, contains the listing of all current issuances of these circulars and changes thereto.
 - a. AC 00-2, Federal Register, Advisory Circular Checklist and Status of Federal Aviation Regulations.
 - b. AC 150/5320-12, Measurement, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces.
 - c. AC 150/533 5-5, Standardized Method of Reporting Airport Pavement Strength
 - d. AC 150/5370-1 1, Use of Nondestructive Testing Devices in the Evaluation of Airport Pavements.
 - e. AC 150/5380-6, Guidelines and Procedures for Maintenance of **Airport** Pavements,
 - f. AC 1520/5300-9, Predesign, Prebid, and Preconstruction Conferences for **Airport** Grant Projects.
2. The following advisory circulars which can be found in AC 00-2 may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Use the Superintendent of Documents stock number when ordering, along with the AC number and title. Send a check or money order in the amount listed for each document. No. c.o.d. orders are accepted.
 - a. AC 150/5300-13, Airport Design.
 - b. AC 150/5320-5, Airport Drainage.
 - c. AC 150/5370-10, Standards for Specifying Construction of Airports.
3. Copies of the following reports may be obtained from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.
 - a. FAA-RD-73-169, Review of Soil Classification Systems Applicable to Airport Pavement Design, May 1974, by Yoder; AD-783-190.
 - b. FAA-RD-74-30, Design of Civil Airfield Pavement for Seasonal Frost and Permafrost Conditions, October 1974, by Berg; ADA-006-284.
 - c. FAA-RD-74-36, Field Survey and Analysis of Aircraft Distribution on **Airport** Pavements, February 1975, by Ho Sang; ADA-01 1-488.
 - d. FAA-RD-76-66, Design and Construction of Airport Pavements on Expansive Soils, January 1976, by **McKeen**; ADA-28-094.
 - e. FAA-RD-73-198-1, Design and Construction and Behavior Under Traffic of Pavement Test Sections, June 1974, by Burns, Rone, Brabston, Ulery; AD-785-024.
 - f. FAA-RD-74-33, III, Design Manual for Continuously Reinforced Concrete Pavements, May 1974, by Treybig, McCullough, Hudson; AD-780-5 12.
 - g. FAA-RD-75-1 IO-II, Methodology for Determining, Isolating and Correcting Runway Roughness, June 1977, by **Seeman**, Nielsen; **ADA-44-378**.

- h. FAA-RD-73-198-111, Design and Construction of MESL, December 1974 by **Hammitt**; AD-005-893.
 - i. FAA-RD-76-179, **Structural** Design of Pavements for Light Aircraft December 1976, by Ladd, Parker, Percira; ADA-04 1-300.
 - j. FAA-RD-74-39, Pavement Response to Aircraft Dynamic Loads, Volume II - Presentation and Analysis of Data, by Ledbetter; ADA-22-806.
 - k. FAA-RD-81-78, Economic Analysis of **Airport** Pavement Rehabilitation Alternatives, October 1981, by Epps and **Wootan**.
- 4. Copies of ASTM standards may be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19 103.
- 5. Copies of AASHTO standards may be obtained from the American Association of State Highway and Transportation Officials, 3 14 National Press Building, Washington, D.C. 20004.
- 6. Copies of the following publications may be obtained from: Commander, U.S. Army, A.G. Publication Center, 1655 **Woodson** Road, St. Louis, Missouri 63 114.
 - a. **TM5-824-2**, Flexible Airfield Pavements, Department of the Army Technical Manual, **February** 1969.
 - b. **TM5-824-3**, Rigid Pavements for Airfields other than Army, Departments of the Army and the Air Force, Technical Manual, December 1970.
 - c. **TM5-818-2**, Pavement Design for Frost Conditions, Department of the Army, Technical Manual, July 1965.
- 7. Copies of MS-1 1, Full Depth Asphalt Pavements for Air Carrier Airports, **January** 1973, IS-154, Full Depth Asphalt Pavements for General Aviation, January 1973, and **MS-10**, Soils Manual, Fourth Edition (**1986**), may be obtained from the Asphalt Institute, Asphalt Institute Building, College Park, Maryland 20740.
- 8. Copies of Engineering Bulletin, Design of Concrete Airport Pavement, by Robert G. Packard can be obtained from the Portland Cement Association, Old Orchard Road, Skokie, Illinois 60076.
- 9. Copies of Special Technical Publication M-5, The Estimation of Concrete **Flexural** strength from Other Types of Strength Tests, by W. Charles Greer can be obtained from Director of Publications, Law Engineering Testing Company, Corporate Office, 1140 Hammond Drive, Atlanta, GA 30328.
- 10. Copies of FHWA-HI-90-001, Geotextile Design and Construction Guidelines, October 1989, obtained from the Department of Transportation, Federal Highway Administration, Turner **Fairbank** Highway Research Center, 6300 Georgetown Pike, McLean, Virginia, 22101-229.

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