ENGINEER MANUAL

EM 1110-3-132
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ENGINEERING AND DESIGN

RIGID PAVEMENTS FOR ROADS, STREETS, WALKS AND OPEN STORAGE AREAS

MOBILIZATION CONSTRUCTION

DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, D.C. 20314

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Mobilization Construction

1. Purpose. This manual provides guidance for the design of rigid pavements for roads, streets, walks and open storage areas at U.S. Army mobilization installations.

2. Applicability. This manual is applicable to all field operating activities having mobilization construction responsibilities.

3. Discussion. Criteria and standards presented herein apply to construction considered crucial to a mobilization effort. These requirements may be altered when necessary to satisfy special conditions on the basis of good engineering practice consistent with the nature of the construction. Design and construction of mobilization facilities must be completed within 180 days from the date notice to proceed is given with the projected life expectancy of five years. Hence, rapid construction of a facility should be reflected in its design. Time-consuming methods and procedures, normally preferred over quicker methods for better quality, should be de-emphasized. Lesser grade materials should be substituted for higher grade materials when the lesser grade materials would provide satisfactory service and when use of higher grade materials would extend construction time. Work items not immediately necessary for the adequate functioning of the facility should be deferred until such time as they can be completed without delaying the mobilization effort.

FOR THE COMMANDER:

PAUL F. KAVANAUGH
Colonel, Corps of Engineers
Chief of Staff

DEPARTMENT OF THE ARMY
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CHAPTER 1

GENERAL

1-1. Purpose and scope. This manual provides criteria for the design of rigid pavements for roads, streets, walks, and open storage areas at U. S. Army mobilization installations for the loadings and conditions set forth herein.

1-2. Basis of pavement design.

a. Design factor. The prime factor influencing the structural design of a pavement is the load-carrying capacity required. For rigid pavements, the slab thickness necessary to provide the desired load-carrying capacity is a function of five principal variables: (a) vehicle wheel load or axle load, (b) configuration of the vehicle wheels or tracks, (c) volume of traffic during the design life of the pavement, (d) modulus of rupture (flexural strength) of the concrete, and (e) modulus of subgrade reaction.

b. Pavement stresses. The rigid pavement design procedure presented herein is based on the critical tensile stresses produced within the slab by the vehicle loading. Maximum tensile stresses in the pavement occur when the vehicle wheels are tangent to a free or unsupported edge of the pavement. Stresses for the condition of the vehicle wheels tangent to a longitudinal or transverse joint are less severe due to the use of load-transfer devices in these joints to transfer a portion of the load to the adjacent slab. Other stresses which, due to their cyclic nature, will at times be additive to the vehicle load stresses include: (a) restraint stresses resulting from thermal expansion and contraction of the pavement and (b) warping stresses resulting from moisture and temperature gradients within the pavement.

c. Vehicle loadings. The criteria presented in this manual are applicable to rigid pavement design requirements for all Army vehicles. For determining pavement design requirements, all vehicles have been divided into three general classifications: (a) pneumatic-tired vehicles, (b) track-laying vehicles, and (c) forklift trucks (including both solid and pneumatic tires). By relating each vehicle, based on the wheel configuration and loading, to an equivalent number of operations of some arbitrary basic loading, pavement design requirements are established for any given type or volume of traffic. For the pavement design procedures presented in this manual, all vehicular traffic has been expressed in terms of an equivalent number of 18,000-pound single-axle load on dual wheels spaced 13-1/2 by 58-1/2 by 13-1/2 inches.

1-3. Frost conditions. When freezing temperatures penetrate a frost-susceptible subgrade or when frost may have a significant effect on pavements or pavement bases, the design procedures outlined in EM 1110-3-138 should be followed.

1-4. Soil stabilization. In some instances, unsuitable or adverse soils may be improved economically by stabilization with such materials as cement, fly ash, lime, or certain chemical additives whereby the characteristics of the composite material become suitable for subgrade purposes. When this is the case, the design procedures outlined in EM 1110-3-137 should be followed.

1-5. Concrete quality. The criteria contained in EM 1110-3-135 are applicable to the design of rigid pavements for facilities covered by this manual. Particular attention must be given to providing a nonslippery surface. Concrete flexural strength will be determined in accordance with ASTM C 78.

1-6. Walks. Portland cement walks may be provided where pedestrian traffic justifies this type of construction. Normally, the design thickness for walks will be 4 inches. Where it is necessary and desirable to continue the walk across driveways, private entrances, etc., provided for vehicle crossings, the thickness of the walk should be increased to provide sufficient strength to support the vehicular loads to which such portions of the walks will be subjected. Concrete walks should be grooved transversely into rectangular areas at 3- to 5-foot intervals to create planes of weakness for control of contraction cracking. The depth of such grooves should be a minimum of one-fourth the thickness of the slab. Expansion joints consisting of approved preformed bituminous filler or wood, approximately 1/2-inch thick, should be installed to surround or to separate all structures or features which project through or against the sidewalk slab. Expansion joints of a similar type should be installed at regularly spaced intervals transversely across the sidewalk slab. The spacing for such joints should be not less than 30 feet nor more than 50 feet.

CHAPTER 2

SUBGRADE

2-1. Preliminary investigations. The subgrade provides a foundation for supporting the pavement and base course. As a result, much of the required pavement thickness and the performance obtained from the pavement during its design life will depend on the strength and uniformity of the subgrade. It is desirable a thorough investigation of the subgrade be made so that the design and construction will insure uniformity of support for the pavement slab and realization of the maximum strength potential for the particular subgrade soil type.

a. Site investigations. Insofar as time will allow, investigations of subgrade conditions at the site of proposed construction should be performed to determine the engineering characteristics of the subgrade soils, and the extent of any peculiarities of the proposed site which might affect pavement behavior. Such investigations should determine the general suitability of the subgrade soils based on: (a) classification of the soil, (b) moisture-density relation, (c) degree to which the soil can be compacted, (d) expansion characteristics, (e) susceptibility to pumping, and (f) susceptibility to detrimental frost action. In order to give consideration to factors that may affect the performance of the pavement, a review of the service history of existing pavements on similar subgrades in the locality of the proposed site should be made. The engineer is cautioned that such factors as ground water, surface infiltration, soil capillarity, topography, rainfall, and drainage conditions also may affect the future support rendered by the subgrade.

b. Soil conditions. A general picture of the subgrade conditions to assist in determining the representative soils should be developed. Field reconnaissance should be made to study landforms and soil conditions in ditches and cuts. Full use also should be made of existing agricultural soil maps and geological maps in ascertaining subgrade conditions. Advice from contractors actively involved in the subject area should be solicited.

(1) Additional subsurface explorations should be made in those areas where the initial investigation indicates unusual or potentially troublesome subgrade conditions. Subsurface explorations should be carried to a minimum depth of 3 feet below the design grade.

(2) In-place moisture content should be determined to ascertain the presence of soft layers in the subsoil. Both natural and subsurface drainage of the subgrade soils must also be considered.

c. Borrow areas. Material in borrow areas should be visually inspected to insure that objectionable materials are not present.

2-2. Soil classification and tests. All soils should be classified in accordance with the Unified Soil Classification System as given in MIL-STD-619.

2-3. Compaction. Compaction improves the stability of the subgrade soils and provides a more uniform foundation for the pavement slab or base course. The CE-55 soil compaction test is used to determine the compaction characteristics of the subgrade soils and is given in MIL-STD-621. This is abbreviated as a percent of maximum density. Density measurements could also be made by the following procedure:

- Materials representing the soils at the project site are taken to a laboratory where moisture-density relationships are ascertained (ASTM D 1557). From these relationships, the material's maximum density, occurring at optimal water content, is determined. These relationships establish the bases to which field measurements are compared.

- Field in-place density tests are made at critical locations at the construction site. These tests can be the sand-cone test (ASTM D 1556), the balloon test (ASTM D 2167), or the nuclear test (ASTM D 2922). In-place density test values are then divided by the maximum obtainable and multiplied by 100 to obtain the percent maximum density.

a. Cut sections. With the exception of those areas in which the soil exhibits expansive characteristics or those areas composed of cohesionless sand or sandy gravel subgrades, the entire subgrade area should be scarified, moistened, if necessary, to approximately optimum moisture content, and compacted to a minimum of 90 percent of maximum density. If the densities of the natural subgrade materials are equal to or greater than 90 percent of the above-mentioned maximum value, no rolling is necessary other than that required to provide a smooth surface. In the case of cohesionless sands or sandy gravels, these materials should be compacted to a minimum of 95 percent of maximum density. For all subgrade soil types, it is required that the subgrade under the pavement slab or base course be compacted to a depth of 6 inches.

b. Fill sections. With the exception of fills composed of soils exhibiting expansive characteristics or those composed of cohesionless sands or sandy gravels, all fills should be compacted to a minimum of 90 percent of maximum density. In the case of fills composed of cohesionless sands or sandy gravels, the entire depth of the fill should be compacted to a minimum of 95 percent of maximum density.

2-4. Treatment of unsuitable materials. Materials unsuitable for pavement subgrades are:

- organic soils - top soil, loam, peat, bog, etc.

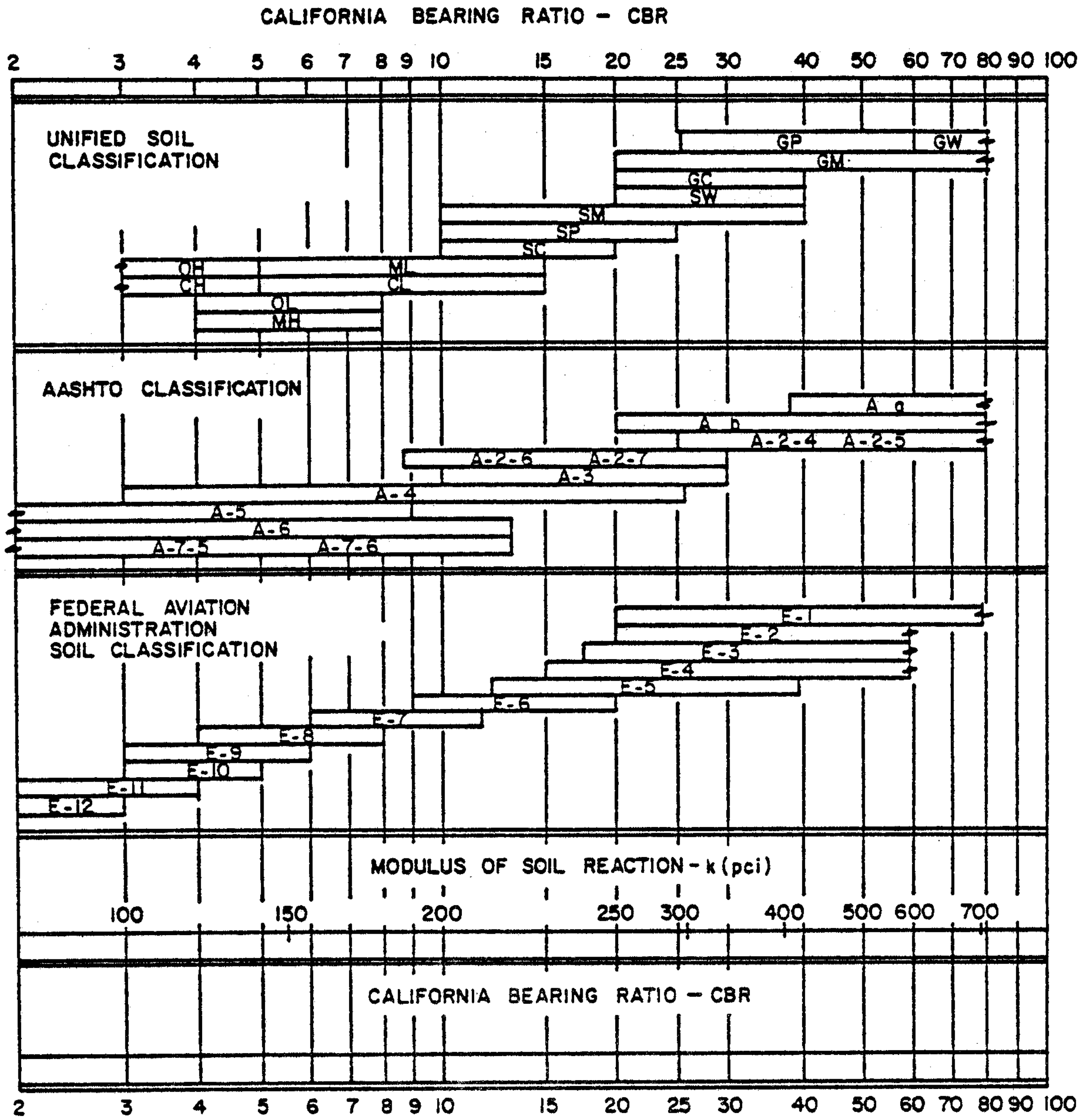
- excessively shrinking or expanding soils upon drying or moisture absorption.

- excessively wet soils such as quicksand or mud.

- soils which show a marked decrease in stability when scarified, worked, or rolled.

Such soils should be removed and replaced, or covered with soils which are suitable. The depth to which such adverse soils should be removed or covered depends on the soil type, drainage conditions, and depth of freezing temperature penetration and should be determined by the engineer on the basis of judgment and previous experience, with due consideration of the traffic to be served and the time element involved.

2-5. Determination of modulus of subgrade reaction. For the design of rigid pavements, the modulus of subgrade reaction, k, is used for design purposes. It usually is determined by the field plate-bearing test. However, when time will not allow for this testing, the subgrade modulus value can be determined from figure 2-1.



PCA Soil Primer (EB007.068), With Permission of the Portland Cement Association, Skokie, IL.

FIGURE 2-1. APPROXIMATE INTERRELATIONSHIPS OF SOIL CLASSIFICATION AND BEARING VALUES

CHAPTER 3

BASE COURSES

3-1. General requirements. Base courses may be required under rigid pavements for the purpose of: (a) providing additional structural strength, (b) providing a more uniform bearing surface for the pavement, (c) replacing soft, highly compressible or expansive soils, (d) providing protection for the subgrade against detrimental frost action, (e) providing drainage, and (f) providing a suitable surface for the operation of construction equipment during adverse weather conditions. Base courses, where required, will be a minimum of 4 inches in thickness over all subgrades. The designer is cautioned against the use of fine-grained material for leveling courses or choking open-graded base courses since this may create a pumping condition. Positive drainage should be provided for all base courses to insure against water being trapped directly beneath the pavement and saturation of these layers, thus inviting the pumping condition that the base course is intended to prevent. The use of base course for subsurface drainage is discussed further in EM 1110-3-136.

3-2. Compaction. Where base courses are used, the base-course material should be compacted with the same procedures as recommended for subgrades in paragraph 2-3. High densities are desirable to reduce future consolidation to a minimum.

3-3. Materials. If conditions indicate that a base course is desirable, an investigation should be made to determine the source, quantity, and characteristics of the available materials. The base course may consist of natural materials, processed materials, or stabilized materials. The material selected should be the one that best accomplishes the intended purpose of the base course. In general, the base-course material should be a well-graded, high-stability material. In this connection, all base courses to be placed beneath concrete pavements for Army roads and streets should conform to the following requirements:

Percent passing No. 10 sieve:	Not more than 85
Percent passing No. 200 sieve:	Not more than 15

CHAPTER 4

VEHICULAR TRAFFIC

4-1. Effect on pavement design. In order to determine the pavement thickness required for an adequate design, it is necessary that the designer obtain traffic data which will include: (a) the types of vehicles to be served (passenger cars, light trucks, heavy trucks, tanks, etc.), (b) the distribution of the vehicles by type, (c) vehicle loadings, including the maximum single-axle and tandem-axle loadings for pneumatic-tired vehicles and the gross weight of the heaviest track-laying vehicle expected, and (d) the average daily volume (ADV) of traffic which, in turn, determines the total volume of traffic anticipated during the design life of the pavement.

4-2. Traffic evaluation.

a. Pneumatic-tired vehicles. To aid in evaluating vehicular traffic for the purpose of pavement design, pneumatic-tired vehicles have been divided into three groups, as follows:

- Group 1. Passenger cars, panel trucks, and pickup trucks.
- Group 2. Two-axle trucks.
- Group 3. Three-, four-, and five-axle trucks.

Pneumatic-tired vehicular traffic has been classified into four general categories based on the distribution of vehicles from each of the three groups listed above. These traffic categories are defined as follows:

Category I - Traffic composed primarily of passenger cars, panel and pickup trucks (Group 1 vehicles), and containing not more than 1 percent two-axle trucks (Group 2 vehicles).

Category II - Traffic composed primarily of passenger cars, panel and pickup trucks (Group 1 vehicles), but containing as much as 10 percent two-axle trucks (Group 2 vehicles). No trucks having three or more axles (Group 3 vehicles) are permitted in this category.

Category III - Traffic containing as much as 15 percent trucks, but with not more than 1 percent of the total traffic composed of trucks having three or more axles (Group 3 vehicles).

Category IV - Traffic containing as much as 25 percent trucks, but with not more than 10 percent of the total traffic composed of trucks having three or more axles (Group 3 vehicles).

b. Track-laying vehicles and forklift trucks. Track-laying vehicles having gross weights not exceeding 15,000 pounds and forklift trucks having gross weights not exceeding 6,000 pounds may be treated as two-axle trucks (Group 2 vehicles) and substituted for trucks of this type in the traffic categories defined above on a one-for-one basis. Track-laying vehicles having gross weights exceeding 15,000 pounds but not exceeding 40,000 pounds and forklift trucks having gross weights exceeding 6,000 pounds but not exceeding 10,000 pounds may be treated as Group 3 vehicles and substituted for trucks having three or more axles in the appropriate traffic categories on a one-for-one basis. Traffic composed of track-laying vehicles exceeding 40,000 pounds and forklift trucks exceeding 10,000-pound gross weight has been divided into the following three categories.

	Maximum Vehicle Gross Weight, pounds	
Category	Track-laying vehicles	Forklift truck
V	60,000	15,000
VI	90,000	20,000
VII	120,000	35,000

CHAPTER 5

NONREINFORCED RIGID PAVEMENTS

5-1. Application. In general, all rigid pavements for roads, streets, and open storage areas at Army installations will be nonreinforced except for those conditions listed under paragraph 6-1, or unless otherwise required.

5-2. Design procedure.

a. Pneumatic-tired vehicles. For convenience in determining design requirements, the entire range of vehicle loadings and traffic intensities anticipated during the design life of pavements for the various classifications of Army roads and streets has been expressed as an equivalent number of coverages of an 18,000-pound single-axle loading. To further simplify the design procedure, the range of equivalent coverages of the basic loading thus determined has been designated by a numerical scale defined as the rigid-pavement design index. This index extends from one through ten with an increase in numerical value indicative of an increase in pavement design requirements. Values for the design index to be used during a mobilization situation are presented in table 5-1. Thus to arrive at the applicable design index, the designer needs only to determine the volume of traffic and the appropriate traffic category based on the distribution of traffic by vehicle type. Once the design index has been determined from table 5-1, the required thickness of nonreinforced pavement is then obtained from the design chart presented in figure 5-1. This design chart is a graphical representation of the interrelation of flexural strength, modulus of subgrade reaction, pavement thickness, and coverages of the basic 18,000-pound single-axle loading. The design chart is entered using the 28-day flexural strength of the concrete determined in accordance with paragraph 1-5. A horizontal projection is then made to the right to the design value for the modulus of subgrade reaction, k. A vertical projection is then made to the appropriate design-index line. A second horizontal projection to the right is then made to intersect the scale of pavement thickness. When the thickness from the design curve indicates a fractional value, it will be rounded upward to the nearest full inch thickness. All nonreinforced rigid pavements will be uniform in cross-sectional thickness. The minimum thickness of concrete for any Army road or street will be 6 inches.

b. Track-laying vehicles. Provision is made herein whereby the designer may determine pavement design requirements for track-laying vehicles in combination with traffic by pneumatic-tired vehicles, or for traffic by track-laying vehicles only. In most cases of traffic combining pneumatic-tired vehicles with track-laying vehicles having gross weights in excess of 40,000 pounds, the determination of the appropriate traffic category will be governed by the track-laying

Table 5-1. Rigid Pavement Design

Traffic Category	Rigid Pavement Design Index for Road or Street Classification B	D-E
I	1	1
II	1	1
III	3	2
IV	4	3
V (60-kip track-laying vehicles, 15-kip forklift trucks):		
500/day	6	6
200/day	5	5
100/day	5	5
40/day	5	4
10/day	4	4
4/day	4	4
1/day	4	3
VI (90-kip track-laying vehicles, 20-kip forklift trucks):		
200/day	8	8
100/day	7	7
40/day	6	6
10/day	5	5
4/day	5	5
1/day	4	4
1/week	4	3
VII (120-kip track-laying vehicles, 35-kip forklift trucks):		
100/day	9	9
40/day	8	8
10/day	7	7
4/day	6	6
1/day	5	5
1/week	4	4

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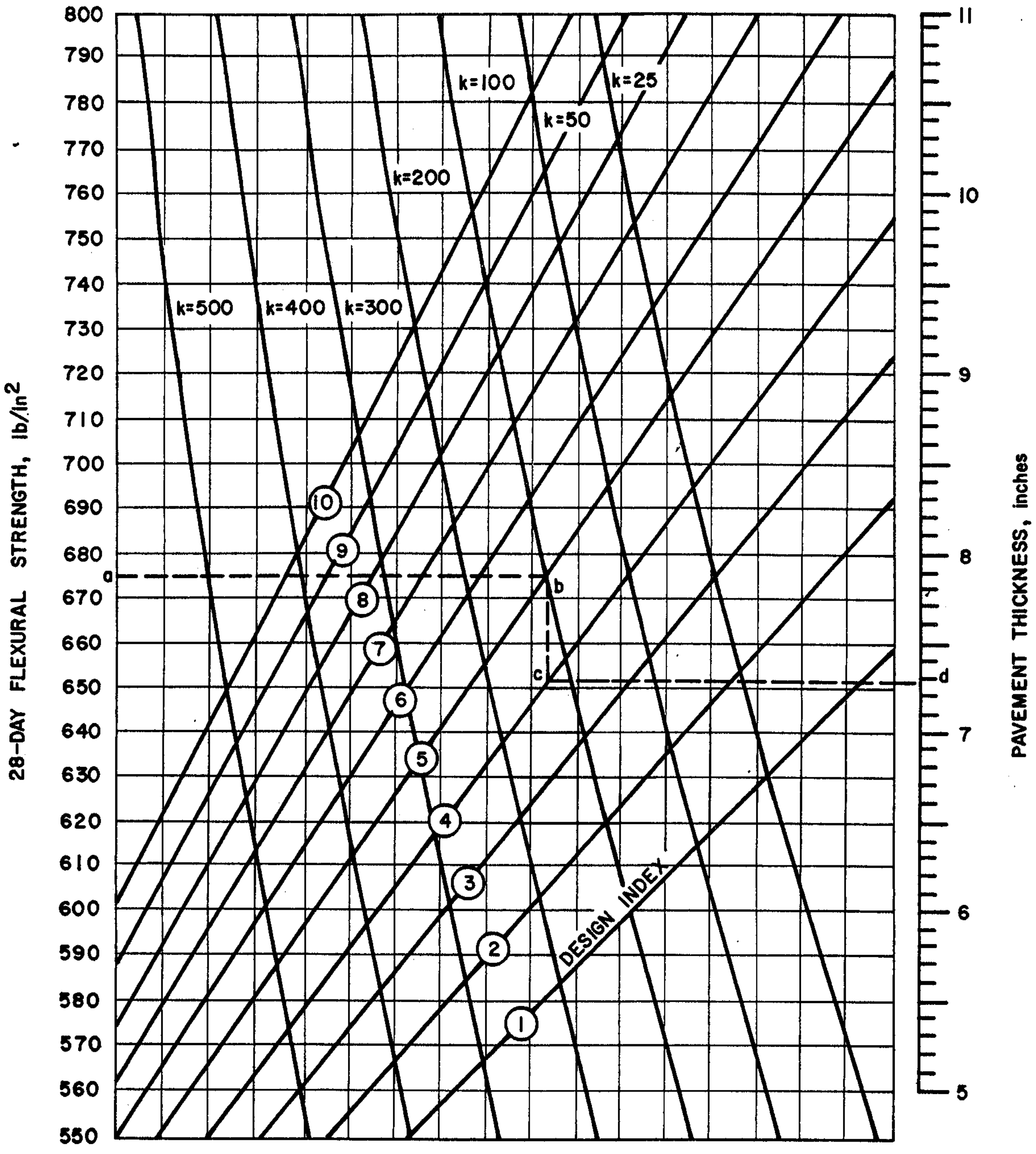

NOTE: Minimum allowable thickness of nonreinforced rigid pavement is 6 inches.

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FIGURE 5-1. DESIGN CURVES FOR CONCRETE PAVEMENTS, ROADS, STREETS, AND OPEN STORAGE AREAS vehicle component of the traffic. In table 5-1, the traffic for Categories V, VI, and VII has been divided further into various levels of frequency. If the track-laying vehicle traffic is composed of vehicles from more than a single traffic category, it will be necessary for the designer to determine the anticipated frequency of traffic in each category in order to determine the appropriate design index. For example, 40 vehicles per day of Category VI traffic requires a greater pavement design index than does one vehicle per day of Category VII traffic. Thus, the designer cannot rely on maximum gross weight alone to determine rigid pavement design requirements for track-laying vehicles. Once the design index has been determined from table 5-1, the required thickness of nonreinforced rigid pavement is obtained from figure 5-1 as described previously.

c. Design examples. Appendix A contains several examples of nonreinforced rigid pavement design involving various traffic volumes and types of vehicles.

5-3. Design procedures for stabilized foundations.

a. Soil stabilization or modification. Soils that have been treated with additives such as cement, lime, fly ash, or bitumen are considered to be either stabilized or modified. A stabilized soil is one that shows improvement in load-carrying capability and durability characteristics. A modified soil is one that shows improvement in its construction characteristics but which does not show an increase in the strength of the soil sufficiently to qualify as a stabilized soil. The principal benefits of soil modification or stabilization include: reduction of rigid pavement thickness requirements when applicable, a stable all-weather construction platform, reduction of swell potential, reduction of the susceptibility to pumping, and reduction of the susceptibility to strength loss due to moisture.

b. Requirements. The design of the stabilized or modified layers will be in accordance with EM 1110-3-137. To qualify as a stabilized layer, the stabilized material must meet the unconfined compressive strength and durability requirements in EM 1110-3-137; otherwise, the layer is considered to be modified.

c. Thickness design. The thickness requirements for a rigid pavement on a modified soil foundation will be designed as if the layer is unbound using the k value measured on top of the modified soil layer. For stabilized soil layers, the treated layer will be considered to be a low-strength base pavement and the thickness determined using the following modified partially bonded rigid overlay pavement design equation:

$$h_o = \sqrt[1.4]{h_d^{1.4} - (0.0063 \sqrt[3]{E_f}\, h_s)^{1.4}}$$

where:

h_o = thickness of rigid pavement overlay required over the stabilized layer, inches
h_d = thickness of rigid pavement from design chart (fig 5-1) based on k value of unbound material, inches
E_f = flexural modulus of elasticity.
h_s = thickness of stabilized layer, inches

5-4. Design details. Typical details for the design and construction of nonreinforced, rigid pavements for Army roads and streets are shown on Standard Mobilization Drawing No. XEC-007.

CHAPTER 6

REINFORCED RIGID PAVEMENTS

6-1. Application. Under certain conditions, concrete pavement slabs may be reinforced with welded wire fabric or deformed bar mats arranged in a square or rectangular grid. The advantages in using steel reinforcement include: (a) a reduction in the required slab thickness usually is permissible; (b) wider spacing between the transverse contraction joints may be used; (c) the width of crack opening is controlled, with the result that load transmission is maintained at a high level at these points and objectionable material is prevented from infiltrating the cracks; and (d) differential settlement due to nonuniform support and/or frost heave is reduced materially. Guidance relative to the use of reinforced pavement is discussed in the following subparagraphs.

a. Subgrade conditions. Reinforcement may be used to control cracking in rigid pavements founded on subgrades where differential vertical movement is a definite potential (for example, foundations with definite or borderline frost susceptibility that cannot feasibly be made to conform to conventional frost design requirements as given in EM 1110-3-138).

b. Nonreinforced pavements. In otherwise nonreinforced rigid pavements, steel reinforcement should be used for the following conditions:

(1) Odd-shaped slabs. Odd-shaped slabs should be reinforced using a minimum of 0.06 percent of steel in directions normal to each other over the entire area of the slab. An odd-shaped slab is considered to be one in which the longer dimension exceeds the shorter dimension by more than 25 percent or a slab which essentially is neither square nor rectangular.

(2) Mismatched joints. A partial reinforcement of slab is required where the joint patterns of abutting pavements or adjacent paving lanes do not match, and when the pavements are not positively separated by an expansion or slip-type joint. The pavement slab directly opposite the mismatched joint should be reinforced with a minimum of 0.06 percent of steel in directions normal to each other for a distance of 3 feet back from the juncture, and for the full width or length of the slab in a direction normal to the mismatched joint. Mismatched joints normally will occur at intersections or pavements or between pavement and fillet areas.

6-2. Design procedure.

a. Thickness design on unbound base or subbase. The design procedure for reinforced rigid pavements presented herein utilizes the principle of allowing a reduction in the required thickness of nonreinforced rigid pavement due to the presence of the steel reinforcing. Essentially, the design method consists of determining the percentage of steel required, the thickness of the reinforced rigid pavement, and the maximum allowable length of the slabs. A graphic solution for the design of reinforced rigid pavements is presented in figure 6-1. Since the thickness of a reinforced rigid pavement is a function of the percentage of steel reinforcing, the designer may: (a) determine the required percentage of steel for a predetermined thickness of pavement, or (b) determine the required thickness of pavement for a predetermined percentage of steel. In either case, it is necessary first to determine the required thickness of nonreinforced rigid pavement in accordance with the method outlined previously in paragraph 5-2 for nonreinforced pavements. The exact thickness (to the nearest 0.1 inch) of nonreinforced pavement, h_d, is used to enter the nomograph in figure 6-1. A straight line is then drawn from the value of h_d to the value selected for either the thickness of reinforced rigid pavement, h_r, or the percentage of reinforcing steel, S. It should be noted that the percentage or reinforcing steel, S, indicated by figure 6-1, is the percentage to be used in the longitudinal direction only. For normal designs, the percentage of nonreinforcing steel used in the transverse direction will be one-half of that to be used in the longitudinal direction. Examples of reinforced rigid pavement design are given in appendix A. Once the pavement thickness and percentage of reinforcing steel have been determined, the maximum allowable slab length, L, is obtained from the intersection of the straight line and the scale of L. A provision also is made in figure 6-1 for adjusting L on the basis of the yield strength, f_s, of the reinforcing steel. Difficulties may be encountered in sealing joints between very long slabs because of large volumetric changes caused by temperature changes.

b. Thickness design on stabilized base or subgrade. To determine the thickness requirements for reinforced concrete pavement on a stabilized foundation, it is first necessary to determine the thickness of nonreinforced concrete pavement required for the design conditions. This thickness of nonreinforced concrete pavement is determined according to procedures set forth in paragraph 5-3. Figure 6-1 is then entered with the exact thickness of nonreinforced concrete pavement and the thickness of reinforced pavement and the percent steel determined as discussed in paragraph 6-2.a. above.

6-3. Limitations. The design criteria for reinforced rigid pavement for Army roads and streets are subject to the following limitations:

a. No reduction in the required thickness of nonreinforced rigid pavement should be allowed for percentages of steel less than 0.06 percent.

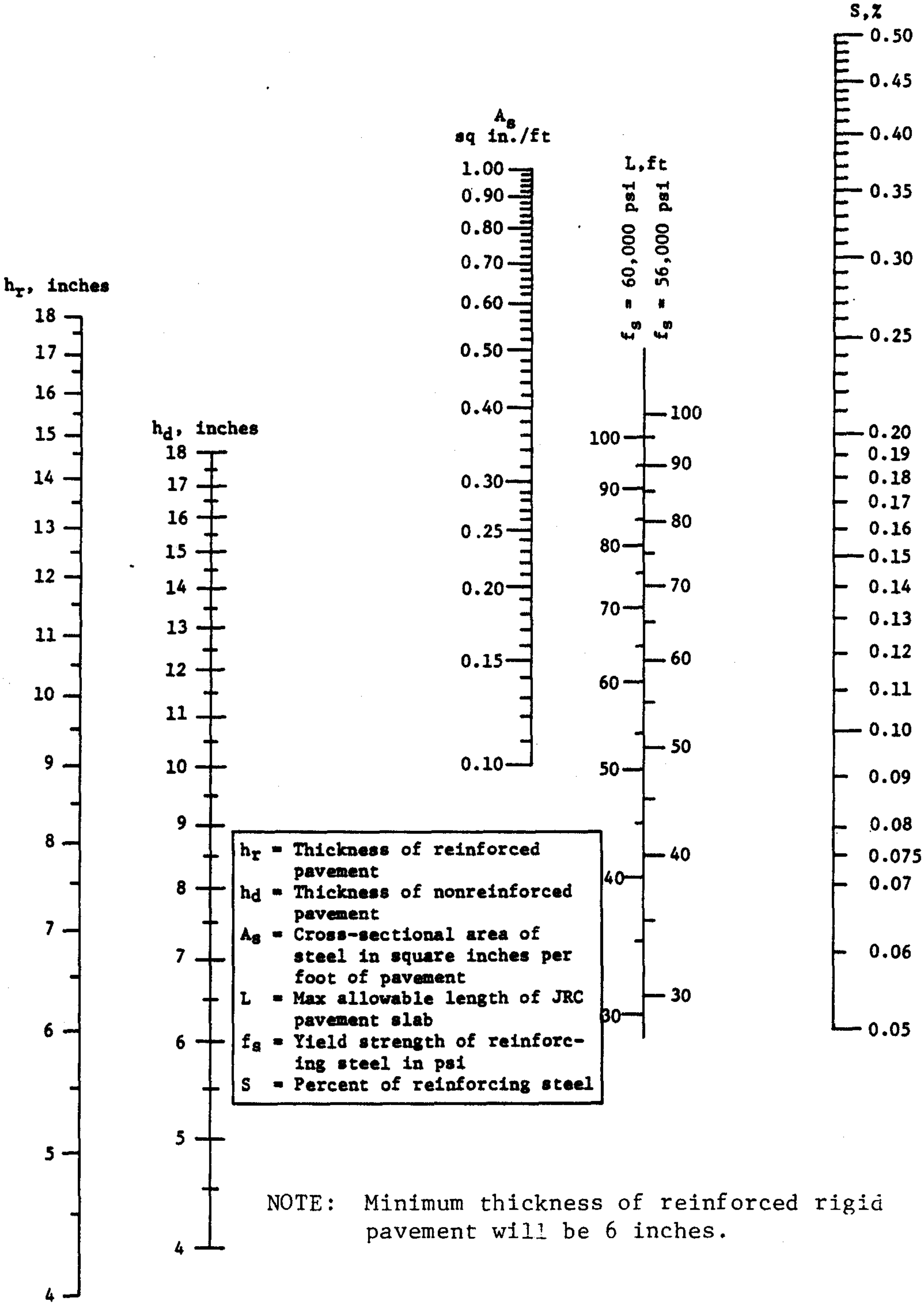

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FIGURE 6-1. REINFORCED RIGID PAVEMENT DESIGN

b. No further reduction in the required thickness of nonreinforced rigid pavement should be allowed over that indicated in figure 6-1 for 0.50 percent steel, regardless of the percentage of steel used.

c. The maximum length, L, of reinforced rigid pavement slabs should not exceed 75 feet regardless of the percentage of steel, yield strength of the steel, or thickness of the pavement.

d. The minimum thickness of reinforced rigid pavements should be 6 inches.

6-4. Reinforcing steel.

a. Type. The reinforcing steel for rigid pavements may be either deformed bars or welded wire fabric.

b. Placement. The following criteria regarding the maximum spacing of reinforcement should be observed: (1) for welded wire fabric, the maximum spacing of the longitudinal wires and transverse wires should not exceed 6 inches and 12 inches, respectively; and (2) for bar mats, the maximum spacing of the longitudinal bars and the transverse bars should not exceed 15 inches and 30 inches, respectively.

6-5. Design details. Typical details for the design and construction of reinforced rigid pavements for Army roads and streets are shown on Standard Mobilization Drawing No. XEC-007.

CHAPTER 7

PAVEMENT JOINTS

7-1. Joint types and usages. Joints are required in rigid pavements to permit expansion and contraction of concrete due to temperature and moisture changes, to relieve warping and curling stresses which result from temperature and moisture gradients within the slab, to minimize uncontrolled cracking caused by frost action, and as a construction expedient to separate the areas of concrete placed at different times. There are three general types of joints used in rigid pavements: (a) contraction, (b) construction, and (c) expansion. Guidance relative to the requirements for these joints is given in the following subparagraphs.

a. Contraction joints. Contraction joints are provided to control contraction cracking from temperature changes and from the initial shrinkage of the concrete. The minimum depth of the groove for contraction joints generally should be one-sixth of the pavement thickness, but not less than the maximum nominal size of the aggregate used. However, where this depth has been found to be insufficient to produce the desired cracking at the groove, the depth of the groove should be increased to one-fourth of the pavement thickness. The size of the groove should conform to the dimensions shown on Standard Mobilization Drawing No. XEC-006.

(1) For transverse contraction joints in nonreinforced rigid pavements, sufficient load transfer can be developed from the aggregate interlock along the fractured face of the joint so that no other provision for load transfer is required in Classes D and E pavements. For reinforced rigid pavements, the longer slab lengths will result in larger openings at the transverse contraction joints and for all such pavements the transverse contraction joints should be doweled. Dowels are also required for Class B nonreinforced pavements.

(2) Longitudinal contraction joints are required along the centerline of nonreinforced rigid pavement lanes having a width equal to or greater than the maximum spacing indicated in paragraph 7-3, for transverse contraction joints for various pavement thicknesses. Where such longitudinal joints are required, tie bars should be used to prevent cumulative opening of the joint and excessive separation of the adjacent lanes. The tie bars should be No. 5 deformed steel bars, 30 inches in length. Spacing of the tie bars should be 30 inches, center to center.

(3) For reinforced rigid pavements where two traffic lanes are placed as a single paving lane, a longitudinal dummy groove joint should be provided at the centerline of the paving lane to control cracking during concrete placement. In these joints, the reinforcing steel is carried through the joint, and tie bars are not required.

(4) Longitudinal contraction joints at the centerline of reinforced rigid pavements are required only when the width of the pavement exceeds the allowable length of slab, L, for the percentage of steel reinforcement being used. When such joints are required, the steel reinforcement should be broken at the joint, and tie bars similar to those described above should be used.

b. Construction joints. Construction joints are provided to separate the areas of concrete placed at different times, and may be either longitudinal or transverse, as required.

(1) The spacing of longitudinal construction joints will depend largely on the paving equipment. With most present-day equipment, paving lanes 24 feet or more in width are possible and may be used. Determination of the width of paving lane to be used, that is, whether a 24-foot-wide road or street should be paved in a single lane or in two 12-foot-wide lanes, is left to the judgment of the designer.

(2) When a longitudinal construction joint is used at the center of two-lane pavements, a keyed joint with tie bars similar to those required for longitudinal contraction joints, or threaded split 5/8-inch tie bolt, should be used. When a longitudinal construction joint is used at the center of pavements having four or more paving lanes, a doweled joint should be used.

(3) Transverse construction joints should be installed at the end of each day's paving operation, and at other points within a paving lane where the placing of concrete is discontinued a sufficient length of time for the concrete to start to set. All transverse construction joints in nonreinforced rigid pavements should be of the doweled type, and should be located in place of other regularly spaced transverse joints. When paving is resumed, the regular transverse joint construction should be used, beginning with the first regularly scheduled transverse joint. When a transverse construction joint is required within a slab in a reinforced rigid pavement, the reinforcing steel should be carried through the joint and tie bars added.

c. Expansion joints. Expansion joints are provided for the relief of forces resulting from thermal expansion of the pavement, and to permit unrestrained differential horizontal movement of adjoining pavements and/or structures. There are two types of expansion joints, doweled and thickened-edge, both of which should be provided with a nonextruding type filler metal. Usually a preformed filler 3/4-inch thick will be adequate. The expansion joint should be so designed as to provide a complete and uniform separation between the rigid pavements or between the rigid pavement and the structure concerned.

(1) Doweled expansion joints should be used for all transverse expansion joints within rigid pavements except at the intersections of rigid pavements with structures or with other rigid pavements. The

designer is cautioned that expansion joints within rigid pavements are difficult to construct and maintain, and often contribute to pavement failures. For these reasons, their use should be kept to the absolute minimum necessary to prevent excessive stresses or distortion in the pavement. Internal expansion joints should be omitted in all rigid pavements 8 inches or more in thickness, and also in pavements less than 8 inches thick when the concrete is placed during warm weather.

(2) At the intersection of two rigid pavements it is necessary to provide for some differential horizontal movement in joints of this type to prevent the expansion of one pavement from distorting the other pavement. In such cases, the transverse expansion joints should be designed as thickened-edge, slip-type joints. Similarly, the thickened-edge, slip-type expansion joint normally will be the most suitable for use where expansion joints are installed to surround or to separate from the pavement any structure that projects through, into, or against the pavement. Typical examples include the approaches to buildings or around drainage inlets.

(3) Should it be necessary to construct a longitudinal expansion joint within a rigid pavement, again a thickened-edge, slip-type expansion joint should be used. Expansion joints are not required between new and existing rigid pavements when the existing pavement is being widened or extended with paving lanes parallel to the longitudinal axis of the existing pavement.

7-2. Joint design. Typical details for the design of expansion, contraction, and construction joints are shown on Standard Mobilization Drawing No. XEC-006 for nonreinforced and reinforced rigid pavements.

a. Doweled joints. The primary function of dowels in rigid pavements is that of a load-transfer device. As such, the dowels effect a reduction in the critical edge stress that is directly proportional to the degree of load transfer achieved at the joint. A secondary function of the dowels is to maintain the vertical alinement of adjacent slabs, thereby preventing faulting at the joint. Dowels should be required for the following types of joints: (a) transverse contraction joints in Class B nonreinforced rigid pavements, (b) transverse contraction joints in all reinforced rigid pavements, (c) transverse construction joints in all nonreinforced rigid pavements, (d) center longitudinal construction joints in rigid pavements four or more lanes in width, and (e) transverse expansion joints in all rigid pavements. Dowel diameter, length, and spacing should be in accordance with the criteria presented in table 7-1. Where dowels larger than 1-inch diameter are required, extra-strength pipe may be used as an alternate for solid bars. When extra-strength steel pipe is used for dowels, however, the pipe should be filled with a stiff mixture of either sand-asphalt or cement mortar, or plugged at the ends of the pipe. If the ends of the pipe are plugged, the plug should fit inside the pipe and be cut off flush with the end of the pipe so that there will be no protruding material to bond with the concrete and prevent free movement of the pavement. Normally, dowels should be located at the middepth of the pavement slab. However, a tolerance of one-half of the dowel diameter, above or below the middepth of the slab, may be allowed in locating the dowels in contraction or construction joints where the allowance of such a tolerance will expedite construction. For doweled expansion joints, the dowels should be placed at the middepth of the slab with no tolerance allowed in positioning the dowels. All dowels should be straight, smooth, and free from burrs at the ends. One-half of each dowel should be painted and oiled or greased thoroughly to prevent bonding with the concrete. Dowels used at expansion joints should be capped at one end to permit unrestrained movement of the dowels when the expansion joints close.

Table 7-1. Doweled Joint Design Requirements

Pavement Thickness (inches)	Less than 8	8 to 11	12 to 15
Dowel Diameter and Type	3/4-inch bar	1-inch bar	1-1/4-inch bar
Maximum Dowel Spacing (inches):			
Expansion Joints	9	10	12
Contraction Joints			
Reinforced Pavement	11	12	14
Nonreinforced Pavement	18	20	24
Construction Joints	12	13	15
Minimum Dowel Length (inches)	15	16	18

b. Keyed joints. As with dowels, keyed joints are constructed to provide load transfer at the joint. The structural adequacy of keyed construction joints in rigid pavements, however, can be impaired seriously by such factors as: (a) small changes in the dimensions of the key, and (b) positioning the key other than at the middepth of the slab. Exceeding the design values for the key dimensions produces an oversize key which can result in failure of either the top or bottom edge of the female side of the joint. Similarly, construction of an undersize key can result in shearing off the key. Keyed joints should not be used in rigid pavements 8 inches or less in thickness except where tie bars are used. Details of the required dimensions for keyed joints are shown on Standard Mobilization Drawing No. XEC-006. It should be noted that the vertical and horizontal dimensions of the key are expressed as a function of the slab thickness. Consequently, the correct dimensions for the key must be determined for each thickness of pavement. For all thicknesses of pavement where keyed joints may be used, however, the center of the key should be located at the middepth of the slab.

c. Thickened-edge joints. Thickened-edge type joints may be used for all types of expansion joints with the exception of transverse expansion joints within rigid pavements. When thickened-edge joints are used, the amount of increased thickness at the edge should be approximately one-fourth of the design thickness of the main portion of the pavement. The thickening should start at a distance of not less than 3 feet from the joint and taper uniformly to the full required thickness at the joint.

7-3. Joint spacing. For improved pavement performance and lower maintenance costs, it is desirable to keep the number of joints to a minimum by using the maximum joint spacings that will satisfactorily control cracking. Under certain conditions where temperature changes are moderate and high humidity prevails, joint spacings greater than those indicated herein may be satisfactory.

a. Nonreinforced pavements. Transverse contraction joints should be constructed across each paving lane, at intervals not less than 12-1/2 feet nor more than 25 feet. The joint pattern should be made uniform throughout any major paved area. Each joint should be straight and continuous from edge to edge of the paving lane, and extend across all paving lanes for the full width of the paved area. The staggering of joints in adjacent paving lanes should not be permitted. The maximum spacing of transverse joints that will effectively control contraction cracking will vary appreciably depending on pavement thickness, climatic conditions, effective subgrade restraint, coefficients of thermal expansion of the concrete, and other characteristics of the aggregate, cement, etc. The joint spacings shown in the following tabulation have given satisfactory control of contraction cracking in most instances and should be used as a guide subject to modification based on available information regarding local conditions. Experience has shown that under traffic, oblong slabs tend to crack into smaller slabs of nearly equal dimensions. This is particularly true for thin pavements. Therefore, it is desirable to keep the ratio of slab length to width as near unity as practicable. In no case should the slab length exceed the width by more than 25 percent.

Pavement Thickness, inches	Spacing of Contraction Joints, feet
Less than 9	12.5 to 15
9 to 11	15 to 20
More than 11	20 to 25

b. Reinforced pavements. Transverse contraction joints in reinforced rigid pavements should be constructed across each paving lane, perpendicular to the pavement centerline, and at intervals of not less than 25 feet nor more than 75 feet. Allowable slab widths or lengths can be determined directly from figure 6-1 for yield strengths of either 56,000 or 60,000 lb/in^2. Each joint should be straight and continuous from edge to edge of the paving lane and should extend across all paving lanes for the full width of the paved area.

7-4. Joint sealing. All joints in rigid pavements should be sealed with a sealing compound to prevent infiltration of surface water and solid materials into the joint openings. In areas of heavy spillage of diesel fuel or lubricants, a jet-fuel-resistant sealant will be used. In some climates, joint sealing may not be required. Local sources of information, such as state highway departments, should be investigated.

CHAPTER 8

OPEN STORAGE AREAS

8-1. Parking areas. Rigid pavement for parking areas may be provided at U. S. Army installations where vehicular traffic or local conditions justify this type of construction. Normally, parking areas are provided to accommodate passenger cars and other light vehicles and should be designed for Category I traffic. Pavement jointing details should be determined in accordance with criteria for roads and streets as given previously in this manual.

8-2. Motor pools or motor storage areas. Rigid pavements for service and storage areas at motor pools or motor storage areas may be provided at U. S. Army installations where vehicular traffic and/or local conditions justify this type of construction.

a. Administration vehicles. Rigid pavements at motor pools or motor storage areas designated to accommodate administrative vehicles should be designed for Category I traffic. The floor-slab thickness in vehicular-maintenance buildings will be determined using a rigid pavement design index of 1. Joints will be sealed with a material resistant to spilled fuels and lubricants.

b. General purpose motor pools or motor storage areas. General purpose motor pools or motor storage areas should be designed to accommodate all pneumatic-tired vehicles having gross weights (empty) not exceeding 30,000 pounds, and track-laying vehicles having gross weights not exceeding 25,000 pounds. Where track-laying vehicles must be included, rigid pavements should be used to prevent damage to the surface of the pavement during the turning of these vehicles. Rigid-pavement thickness requirements should be designed for Category III traffic. The floor-slab thickness in vehicular-maintenance buildings will be determined using a rigid-pavement design index of 3. Joints will be sealed with a material resistant to spilled fuels and lubricants.

c. Special purpose motor pools or motor storage areas. Special purpose motor pools or motor storage areas should be designed to accommodate any pneumatic-tired vehicle regardless of gross weight or axle load, and special engineer and ordnance equipment including dozers, graders, cranes, tank retrievers, tanks, etc. Where track-laying vehicles must be included, rigid pavements should be used to prevent damage to the surface of the pavement during the turning of these vehicles. Rigid-pavement thickness requirements for use by pneumatic-tired vehicles of unlimited weight only should be designed for Category V traffic. Rigid-pavement thickness requirements for track-laying vehicles having gross weights in excess of 40,000 pounds should be in accordance with criteria given previously in chapter 4. The floor-slab thickness in vehicular-maintenance buidings will be determined by using a rigid-pavement design index of 5. Joints will be sealed with a material resistant to spilled fuels and lubricants.

8-3. Open storage of supplies and materials. In areas to be used for the open storage of supplies and materials, rigid pavements normally should be considered only for the driveways and traffic aisles to accommodate the operating equipment to handle the supplies, materials, and equipment. However, rigid pavements should be provided in all traffic areas where forklift trucks, small-wheeled tractors, and small-wheeled trailers are used for the intertransfer of crated materials, supplies, and equipment. Rigid-pavement design thickness requirements should be based on the traffic category appropriate for the maximum gross weights of the forklift truck vehicles in accordance with criteria given in chapter 4. Where rigid pavements are to be provided for truck-mounted cranes, pavement thickness requirements should be based on Category V traffic. For crawler-mounted cranes, pavement thickness requirements should be based on the appropriate maximum gross weights to be encountered. Other pavement requirements and jointing details should be in accordance with criteria for roads and streets as given previously in this manual.

CHAPTER 9

OVERLAY PAVEMENTS

9-1. General. Normally, overlays of existing pavements are used for two reasons: (a) to increase the load-carrying capacity of an existing pavement, or (b) to correct a defective surface condition on the existing pavement. Of these reasons, the first requires a structural design procedure for determining the thickness of overlay, whereas the second requires only a thickness of overlay sufficient to correct the surface condition, and no increase in load-carrying capacity is considered. The design method for overlays included herein is to determine the thickness required to increase load-carrying capacity.

9-2. Definitions and symbols for overlay pavement design. The following terms and symbols apply to the design of overlay pavements and are defined for the purpose of clarity.

a. Definitions.

(1) Rigid base pavement - Existing pavement to be overlaid and is composed of portland cement concrete.

(2) Flexible base pavement - Existing pavement to be overlaid and is composed of bituminous concrete, base, and subbase courses.

(3) Composite pavement - Existing pavement to be overlaid and is composed of an all-bituminous or flexible overlay on a rigid base pavement.

(4) Overlay pavement - A rigid or nonrigid pavement constructed on an existing base pavement to increase load-carrying capacity.

(5) Rigid overlay - An overlay pavement and is composed of portland cement concrete.

(6) Nonrigid overlay - An overlay pavement and is composed of all-bituminous concrete or a combination of bituminous concrete, base, and subbase courses.

(7) All-bituminous overlay - A nonrigid overlay composed of bituminous concrete for the full depth.

(8) Flexible overlay - A nonrigid overlay composed of bituminous concrete surface and granular base and subbase courses.

b. Symbols. The following symbols are used.

(1) k Modulus of subgrade reaction, lb/in^3.

(2) CBR California bearing ratio.

(3) R Concrete flexural strength, lb/in^2.

(4) h Existing rigid pavement thickness, inches.

(5) h_o Rigid overlay thickness, inches.

(6) t Nonrigid overlay thickness, inches.

(7) C Coefficient depending upon structural condition of rigid base pavement.

(8) h_d Exact thickness of rigid pavement that would be required if placed directly on the foundation. h_d is determined from figure 5-1 using the modulus of subgrade reaction, k. For rigid overlays, the flexural strength, R, will be the 28-day strength of the overlay. For nonrigid overlays, the flexural strength to be used for the determination of h_d will be that of the rigid base pavement.

(9) t_d Exact thickness of flexible pavement that would be required if placed directly on the subgrade. The thickness is determined from design procedures presented in EM 1110-3-131.

9-3. Preparation of existing pavement. Inspections of the existing pavement should be made to locate all areas of distress in the existing pavement and to determine the cause of the distress. Areas showing extensive and progressive cracking and/or foundation failures should be removed and repaired prior to the overlay. This is especially true of areas where excessive pumping, bleeding of water at joints or cracks, excessive settlement in foundation, subgrade rutting, slides, etc., have occurred. If voids are detected beneath the base pavement, they should be filled by grouting prior to the overlay. The surface of the existing pavement should be conditioned for the various types of overlay as follows:

a. Rigid overlay. The surface of the existing base pavement should be cleaned of all foreign matter, spalled concrete, extruded joint seal, bituminous patches, and other materials that would prevent the overlay from bonding to the base pavement.

b. Flexible overlay. No special conditioning of the existing surface is required other than the removal of debris and loose aggregate and/or concrete.

c. All-bituminous overlay. The surface of the existing pavement will be cleaned of all foreign matter, fat spots in existing bituminous patches, spalled concrete, and extruded joint seal. When the joints, cracks, or spalled areas in the existing pavement are wide enough, a hot sand-asphalt mixture should be used to fill them to the grade of the existing pavement. Wedge courses of bituminous concrete should be used to bring the existing pavement to proper grade when necessary. Prior to placement of the all-bituminous overlay, a tack coat should be applied to the existing pavement surface.

9-4. Rigid overlay of rigid base pavements. The criteria contained in paragraph 1-5 are applicable to the design of rigid overlays. The placement of forms and the determination of thickness for the rigid overlay should be as follows:

a. Placing forms. If it is necessary to drill holes in the existing rigid pavement to provide anchorage for the overlay pavement forms, the size of the holes and the number drilled should be the minimum that will adequately accomplish the purpose. The holes should not be located close to joints or cracks where they might induce spalling, and they should be spaced or staggered so as to minimize additional cracking.

b. Determination of overlay thickness. The thickness of rigid pavement overlay necessary to increase the load-carrying ability of an existing rigid base pavement should be determined by one of the following equations:

$$h_o = \sqrt[1.4]{h_d^{1.4} - Ch^{1.4}} \qquad \text{(eq 9-1)}$$

Equation 9-1 is for the condition of partial bond developing between the rigid overlay and rigid base pavement. It should be used to determine the overlay thickness when no bond-breaking medium is used, such as a tack coat, sand-asphalt patch, or leveling course, etc.

$$h_o = \sqrt{h_d^2 - Ch^2} \qquad \text{(eq 9-2)}$$

Equation 9-2 is for the condition of no bond developing between the rigid overlay and rigid base pavement. It should be used to determine the overlay thickness when a sand-asphalt leveling course, bituminous patch, or tack coat, etc., is used on the surface of the existing base pavement. The coefficient C is determined by the structural condition of the rigid base pavement. Its numerical value should be established as follows, based upon a visual inspection of the existing pavement.

C = 1.00 when the slabs are in good condition, with little or no structural cracking.

C = 0.75 when the slabs show initial cracking due to loading, but little or no multiple cracking.

C = 0.50 when a larger number of slabs show multiple cracking, but the majority of slabs are intact or contain only single cracks.

C = 0.35 when the majority of slabs show multiple cracking.

In both of the equations, h_d is the exact thickness, to the nearest tenth of an inch, of monolithic rigid pavement that would be required for the design traffic conditions, and is determined from figure 5-1. The design thickness of all overlay slabs should be in multiples of 1 full inch. Whenever the calculations show a fractional inch thickness greater than one-quarter, the next full inch thickness should be used. The minimum rigid overlay pavement thickness should be 6 inches unless it is reinforced or bonded to the rigid base pavement, as described in the following paragraphs.

c. Joints. Unless a bond-breaking medium is used between the rigid overlay and rigid base pavement, or the rigid overlay is reinforced, joints should be provided in the overlay which coincide with all joints in the base pavement. However, it is not necessary that the joints in the overlay be of the same type as those in the existing base pavement. When an appreciable thickness of bond-breaking medium is used, 1/4 inch or more, the matching of joints in the overlay and base pavement is not necessary but is advisable.

9-5. Reinforced rigid overlay of rigid base pavements. Reinforced rigid overlays of existing rigid pavements should be used only when they prove to be more economical, when it is necessary to reduce the thickness of the overlay to meet grade requirements, or for other reasons where it is impractical or impossible to provide the required strengthening by means of a nonreinforced rigid overlay. The thickness of nonreinforced rigid overlay should be determined in accordance with paragraph 9-4, and the percentage of steel and thickness reduction should be determined in accordance with chapter 6 of this manual. When reinforced rigid overlays are used, the minimum thickness of overlay should be 4 inches. It is not necessary to provide joints in the reinforced rigid overlay which coincide with all joints in the base pavement; however, when a joint is required in the overlay, it should coincide with a joint in the base pavement.

9-6. Rigid overlays of flexible base and composite base pavements.

a. Flexible base pavements. A rigid overlay of an existing flexible pavement should be designed in the same manner as a rigid pavement on grade, in accordance with chapter 5. A modulus of subgrade reaction, k, should be determined by a plate-bearing test made on the surface of the existing flexible pavement. If not practicable to determine k from a plate-bearing test, conservative value may be estimated from figure 2-1 by comparing the existing flexible pavement with a well-packed gravel or consolidated clay. The following limitations, however, should apply:

- In no case should a k value greater than 500 lb/in^3 be used.

- The plate-bearing test to determine the k value should be performed on the flexible pavement at a time when the temperature of the bituminous concrete is of the same order as the ambient temperature of the hottest period of the year in the locality of the proposed construction.

b. Composite base pavements. Two conditions of composite pavement can be encountered when considering a rigid overlay. When the composite pavement is composed of a rigid base pavement with less than 4 inches of all-bituminous overlay, the required thickness of rigid overlay should be determined using the no-bond overlay equation 9-2. If the composite pavement is composed of a rigid base pavement with 4 inches or more of either all-bituminous or flexible overlay, the required thickness of rigid overlay should be determined in accordance with paragraph 9-6.a.

9-7. Nonrigid overlay of rigid base pavements.

a. Design procedure. The design procedure presented herein determines the thickness of nonrigid-type overlay necessary to increase the load-carrying capacity of existing rigid pavement. This method is limited to the design of the two types of nonrigid overlay defined in paragraph 9-2. The selection of the type of nonrigid overlay to be used for a given condition is dependent only on the required thickness of the overlay. Normally, the flexible overlay should be used when the required thickness of overlay is sufficient to incorporate a minimum 4-inch compacted layer of high-quality base-course material plus the required thickness of bituminous concrete surface courses. For lesser thicknesses of nonrigid overlay, the all-bituminous overlay should be used. The method of design is referenced to the deficiency in thickness of the existing rigid base pavement and assumes that a controlled degree of cracking will take place in the rigid base pavement during the design life of the pavement.

b. Determination of overlay thickness. The thickness of nonrigid overlay (all-bituminous or flexible) required to increase the load carrying capacity of an existing rigid base pavement to a designated level should be determined by the following equation:

$$t = 2.5(Fh_d - Ch)$$

where h_d is the exact thickness (to the nearest 1/10 inch) determined from figure 5-1 using the flexural strength of the existing rigid base pavement, the measured or estimated subgrade modulus, k, and the appropriate rigid-pavement design index. The factor F will be: .1 for a design index = 1; .7 for a design index = 2; .9 for a design index =

3; and .95 for design indices 4 through 10. The C factor is a coefficient depending on the structural condition of the existing rigid base pavement. Numerical values of C are determined as follows:

C = 1.00 when rigid base pavement slabs contain only nominal initial cracking.

C = 0.75 when the rigid base pavement slabs contain multiple cracks and numerous corner breaks.

The overlay thickness, t, used in design should be determined to the nearest 1 inch.

c. All-bituminous overlay. The all-bituminous overlay is required only when the combined thickness of a minimum 4-inch compacted base course and the required thickness of bituminous surface course exceeds the design thickness, t. There is no limitation, other than the economics of construction, on the maximum thickness of all-bituminous overlay that can be used. The bituminous concrete overlay should be designed in accordance with the requirements of EM 1110-3-131. A tack coat is required between the rigid base pavement and the all-bituminous overlay. A minimum thickness of 2 inches will be required for an all-bituminous overlay designed to increase the structural capacity of a base pavement. No limitation is placed on the minimum thickness of an all-bituminous overlay when used as a maintenance measure to improve pavement surface smoothness.

d. Flexible overlay. A flexible overlay (bituminous surface course and granular base course) may be used when the design thickness, t, is large enough to permit the use of a 4-inch compacted base course plus the required thickness of bituminous surface course. The required thickness of bituminous surface course and the design of the surface course should be in accordance with EM 1110-3-131. The base-course material should be a crushed aggregate material exhibiting a CBR of 100 for the full depth. The gradation and compaction requirements of the base course should be determined from EM 1110-3-131.

9-8. Overlays in frost regions. Whenever the subgrade is susceptible to differential heaving or weakening during the frost-melt period, the overlay design should meet the requirements for frost action as given in EM 1110-3-138. When it is determined that distress in an existing pavement has been caused by differential heaving due to frost action, an overlay may not correct the condition unless the combined thickness of the pavement is sufficient to prevent substantial frost penetration into the underlying frost-susceptible material.

APPENDIX A

DESIGN EXAMPLES

A-1. Example of a nonreinforced rigid pavement design. Let it be required to design a nonreinforced rigid pavement for a road in a rural area on rolling terrain, to carry the following traffic:

Average daily volume	3,500 vehicles per lane
Trucks, 2-axle	150 per lane per day
Trucks, 3 or more axles	50 per lane per day

In accordance with EM 1110-3-130 and based on the definitions of traffic categories given previously, this traffic would be evaluated as requiring a Class C road designed for Category IV traffic. However for mobilization work, Class C translates to a Class B pavement. From table 5-1, the rigid pavement design index for a B-IV pavement is 4. Assuming a 28-day flexural strength for the concrete of 675 lb/in^2 and a modulus of subgrade reaction of 100 lb/in^3, the required pavement thickness as indicated by figure 5-1 is approximately 7.3 inches. Since the fractional thickness is greater than 1/4 inch, the design thickness would be 8 inches. To illustrate the design procedure when traffic includes track-laying vehicles, assume that in addition to the pneumatic-tired traffic used in the previous example, the designer must provide for an average of 60 tanks per lane per day and that the gross weight of each tank is 50,000 pounds. The 50,000-pound gross weight would be classified as Category V traffic since it exceeds the maximum of 40,000 pounds permitted for track-laying vehicles in Category IV. Inasmuch as the tank traffic exceeds 40 per day, the rigid pavement design index would be based on the next higher traffic volume given in table 5-1, which is 100 per day. Thus from table 5-1, the design index for a Class B street would be 5. Assuming the same 28-day flexural strength and modulus of subgrade reaction as in the previous example, the required pavement thickness as indicated by figure 5-1 is approximately 7.9 inches and would require a design thickness of 8 inches. To illustrate the procedure for combining both forklift trucks and track-laying vehicles with pneumatic-tired vehicles, let it be required to design a rigid pavement on rolling terrain for the following traffic:

Average daily volume	750 vehicles per lane
Trucks, 2-axle	100 per lane per day
Trucks, 3 or more axles	40 per lane per day
Track-laying vehicles, 50,000 pounds	50 per lane per day
Track-laying vehicles, 80,000 pounds	20 per lane per day
Forklift trucks, 25,000 pounds	2 per lane per day

In accordance with EM 1110-3-130, this traffic on rolling terrain would be evaluated as requiring a Class D road or Class E street. From table 5-1, the 50-kip, track-laying vehicles are classified as Category V traffic. For a frequency of 50 of these vehicles per lane per day, the rigid pavement design index would be 5. The 80-kip, track-laying vehicles are classified as Category VI traffic. For a frequency of 20 of these vehicles per lane per day, the rigid pavement design index would be 6. The 25-kip, forklift trucks are classified as Category VII traffic. For a frequency of two of these vehicles per lane per week, the design index would be 5. Thus it can be seen that the 80-kip, track-laying vehicle traffic is the governing factor as it requires the highest design index. Assuming the same 28-day flexural strength and modulus of subgrade reaction as in the previous design examples, the required pavement thickness from figure 5-1 is 9.0 inches.

A-2. Example of a reinforced rigid pavement design. Let it be required to design a reinforced rigid pavement for the same set of conditions used in example A-1. Using the value of h_d of 7.5 inches, the percentage of longitudinal reinforcing steel S required to reduce the pavement thickness to 7 inches obtained from figure 6-1 as 0.07 percent. Similarly, the percentage of longitudinal reinforcing steel required to reduce the pavement thickness to 6 inches is 0.21 percent. The percentage of transverse reinforcing steel would be either 0.035 for a design thickness of 7 inches or 0.11 for a design thickness of 6 inches. The choice of which percentage of steel reinforcement to use should be based on economic considerations as well as on foundation and climatic conditions peculiar to the project area. If the yield strength of the steel is assumed to be 60,000 lb/in^2, the maximum allowable spacing of the transverse contraction joints would be 38 feet for 0.07 percent longitudinal steel, and 76 feet would be indicated as the maximum spacing for 0.21 percent longitudinal steel. In the latter case, the maximum permissible spacing of 75 feet would be used.

APPENDIX B

REFERENCES

Government Publications.

Military Standards.

MIL-STD-619B	Unified Soil Classification System for Roads, Airfields, Embankments, and Foundations.
MIL-STD-621A & Notices 1, 2	Test Method for Pavement Subgrade, Subbase, and Base-Course Materials.

Department of the Army Publications.

EM-1110-3-130	Geometrics for Roads, Streets, Walks, and Open Storage Areas.
EM-1110-3-131	Flexible Pavements for Roads, Streets, Walks, and Open Storage Areas.
EM-1110-3-135	Standard Practice for Concrete Pavements.
EM-1110-3-136	Drainage and Erosion Control.
EM-1110-3-137	Soil Stabilization for Pavements.
EM-1110-3-138	Pavement Criteria for Seasonal Frost Conditions.

Nongovernment Publications.

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

C 78-75	Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading).
D 1556-64 (R 1974)	Density of Soil In Place by the Sand-Cone Method.
D 1557-78	Moisture-Density Relations of Soils and Soil-Aggregate Mixtures (Using 10-lb. (4.5-kg) Rammer and 18 in. (457-mm) Drop).

D 2167-66 (R 1977)	Density of Soil in Place by the Rubber-Balloon Method.
D 2922-81	Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth).