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UNIFIED FACILITIES CRITERIA (UFC)

PAVEMENT DESIGN FOR ROADS, STREETS, AND OPEN STORAGE AREAS, ELASTIC LAYERED METHODS

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UNIFIED FACILITIES CRITERIA (UFC)

PAVEMENT DESIGN FOR ROADS, STREETS, AND OPEN STORAGE AREAS, ELASTIC LAYERED METHODS

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes TM 5-822-13, dated 24 October 1994. The format of this UFC does not conform to UFC 1-300-01; however, the format will be adjusted to conform at the next revision. The body of this UFC is the previous TM 5-822-13, dated 24 October 1994.

FOREWORD

\1\
The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD(AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the more stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

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ARMY TM 5-822-13
AIR FORCE AFJMAN 32-1018

PAVEMENT DESIGN FOR ROADS, STREETS, AND OPEN STORAGE AREAS, ELASTIC LAYERED METHOD

DEPARTMENTS OF THE ARMY AND THE AIR FORCE
OCTOBER 1994

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AND THE AIR FORCE
WASHINGTON, DC, *24 October 1994*

PAVEMENT DESIGN FOR ROADS, STREETS, AND OPEN STORAGE AREAS, ELASTIC LAYERED METHOD

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CHAPTER 1

GENERAL

1-1. Purpose.

This manual provides an elastic layered method for the thickness design of pavements for roads, streets, walks, and open storage areas at US Army and Air Force installations for the loadings and conditions set forth herein.

1-2. Scope.

The elastic layered procedure is used to determine thickness requirements of flexible and rigid pavement structures subject to vehicular traffic loads. This manual treats the thickness design of concrete pavements (both plain and reinforced), conventional flexible pavements, bituminous concrete pavements, and flexible pavements with stabilized layers. Other aspects of design, such as the preliminary investigation, mix design, material requirements, joints, overlays, reinforced concrete pavements, and the requirements for compaction and frost considerations are described in TM 5-822-5/AFM 88-7, Chap. 3.

1-3. References.

Appendix A contains a list of references used in this manual.

1-4. Computer Program.

A user-friendly road design computer program LEDROAD designed to be run on IBM or IBM-compatible personal computer has been prepared and is attached in appendix D. Stresses and strains are calculated with the JULEA computer program within LEDROAD. Any questions concerning the program should be directed to:

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ATTN: CEMRD-ED-TT
12565 West Center Road
Omaha, Nebraska 68144-3869
Telephone: (402) 221-7496

or

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CHAPTER 2

BASIS OF PAVEMENT DESIGN

2-1. Design Principles.

a. Concrete pavements. The basic principle for the elastic layered design procedure is to limit the tensile stresses in the portland cement concrete (PCC) to levels that are sufficiently below the flexural strength of the concrete such that failure occurs only after the pavement has sustained a number of load repetitions. The tensile stress is modeled by the use of Burmister's solution for elastic multilayered continua. The computed tensile stress divided into the concrete strength is the design parameter and is referred to as the design factor. This parameter has been related to pavement performance through a study of test section data. Use of a cumulative damage concept determines the required concrete thickness. Correlations among theory, small-scale model studies, and full-scale accelerated traffic tests have shown that maximum tensile stresses in the pavement occur when the vehicle wheels are placed at a free or unsupported edge of the pavement. Only interior stresses are computed using the elastic layered method while edge stresses can be computed with the Westergaard solution. The former is always less than the latter; the difference depends upon the load configuration and pavement geometry and properties. Stresses for the condition of the vehicle wheels placed at a longitudinal or transverse joint are less severe because of the use of load-transfer devices or aggregate interlock in these joints to transfer a portion of the load to the adjacent slab. In military roads and streets, dowel bars are generally installed in the transverse joints and tie bars in the longitudinal joints. Since traffic loads travel near the pavement (free) edges and free edge stresses govern the pavement design thickness, interior stresses computed with JULEA does not simulate the edge stress condition. Thus the computed stress will be multiplied by a factor of 1.33.

b. Flexible pavements. The basic principle for the design procedure is to select a pavement thickness required to limit the vertical strains in the subgrade and the horizontal strains at the bottom of the bituminous concrete induced by design vehicular traffic loads at select traffic levels. The purpose is to prevent shear failure in the subgrade and cracking in the bituminous surface course. Use of a cumulative damage concept permits the rational handling of variations in the bituminous concrete properties and subgrade strength caused by cyclic climatic conditions. The strains used for entering the criteria are computed by the use of Burmister's solution for multilayered elastic continua. The solution of Burmister's equations for most pavement systems will require the use of computer programs and the characterization of the pavement materials by the modulus of elasticity and Poisson's ratio.

2-2. Design Variables.

The prime factor influencing the structural design of a pavement is the load-carrying capacity required. The pavement thickness necessary to provide the desired load-carrying capacity is a function of the following.

a. Principal variables.

(1) Vehicle wheel load or axle load.

(2) Configuration of vehicle wheels or tracks.

(3) Volume of traffic during the design life of pavement.

b. Additional rigid pavement variables.

(1) Modulus of rupture (flexural strength) of the concrete.

(2) Elastic moduli and Poisson's ratios of concrete, base course, and subgrade soils.

c. Additional flexible pavement variables.

(1) Elastic moduli of each layer of the pavement structure and the subgrade soils.

(2) Poisson's ratios of each layer of the pavement structure and the subgrade soils.

2-3. Pavement Response Model.

The pavement system is assumed to be a multilayered continuum with each layer being elastic and homogeneous. Each layer is to extend to infinity in the horizontal direction and have, except for the bottom layer, a finite thickness. The applied loads to the pavement are considered as static, circular, and uniform over the contact area. The program chosen for the analysis is JULEA computer code. The program provides different degrees of bond between interfaces. With the program the performance criteria for rigid pavements are developed with the assumptions that the interface between the PCC slab and the supporting subgrade is considered smooth with no bond, i.e., there is no frictional resistance at the interface. All other interfaces are considered to be completely bonded. With these codes the performance criteria for flexible pavements are developed with the assumptions that the interfaces between each layer of the flexible pavement are considered completely bonded, i.e., complete frictional resistance at interfaces.

2-4. Frost Considerations.

For the design and construction of pavements placed on subgrade or base course materials subject to seasonal frost action, the criteria and procedures given in TM 5-822-5/AFM 88-7, Chap. 3, are applicable.

CHAPTER 3
VEHICULAR TRAFFIC

3-1. Effect on Pavement Design.

Pavement thickness is determined from anticipated traffic data which include types, distribution, and loadings of vehicles. Types include cars, light and heavy trucks, tanks, and forklifts. Distribution covers the average daily volume of each type of vehicle which, in turn, determines the total volume of traffic anticipated during the design life of the pavement. Vehicle loadings include maximum single-and tandem-axle pneumatic-tire loads and gross weight of the heaviest tracked vehicle. For most pavements, the magnitude of the axle load is of greater importance than the gross weight of pneumatic-tired vehicles. Thus, for the case of pneumatic-tired vehicles having equal axle loads, the increased severity of loading imposed by conventional four-or five-axle trucks as compared with that imposed by two- or three-axle trucks is largely a fatigue effect resulting from an increased number of load repetitions per vehicle operation. For forklift trucks where the loading is concentrated largely on a single axle, the severity of the loading is a function of the gross weight of the vehicle and the frequency of loading. For tracked vehicles where the loading is evenly divided between the two tracks and nearly evenly divided among the bogies, the severity of the track loading is a function of the gross weight of the vehicle, number of bogies, and the frequency of loading. In pavement design, one operation of a single axle is one stress application for both flexible and rigid pavements, but one operation of a tandem axle is one stress repetition in a rigid pavement and is more than one stress repetition in a flexible pavement. For instance, for one operation of a tandem-axle dual-wheel load, it is one stress repetition in a rigid pavement and two stress repetitions in a flexible pavement. Relations between load repetition and required pavement thickness developed from accelerated traffic tests of full-scale pavements have shown that, for any given vehicle, increasing the gross weight by as little as 10 percent can be equivalent to increasing the volume of traffic by as much as 300 to 400 percent. On this basis, the magnitude of the vehicle loading must be considered as a more significant factor in the design of pavements than the number of load repetitions.

3.2 Vehicle Representative Configurations.

For determining pavement design requirements, vehicles have been divided into three general groups. They are pneumatic-tired vehicles (cars, trucks, buses, etc.) tracked vehicles, and forklift trucks (including both solid and pneumatic tires). Each group has been divided into representative load configurations, and table 3-1 shows data for these representative configurations.

3-3. Traffic Evaluation.

Procedures for the evaluation of future traffic and determination of a design index are contained in TM 5-822-2/AFM 88-7, Chap. 5.

*Table 3-1. Representative Configuration Data. **

Confirmration	Load Range kips	Tire or Grouser Contact Area sq in.	Average Tire Width** In.	Average Wheel Spacing† in.
		Passenger Cars. Trucks. Buses. etc.		
Pneumatic tires				
Single axle, single wheels	0-5	39	7.5	62.0
	5-10	42-46	9.5	72.0
Single axle, dual wheels	0-10	46-50	9.0	70.0†
	10-20	46-50	9.6	72.0
	20-30	46-50	10.5	72.0†
Tandem axle, single wheels††	0-10	50	7.5	72.0
	10-15	50	10.0	76.0
Tandem axle, dual wheels††	10-15	50	7.5	67.5
	15-20	50	11.0	72.0†
	20-50	50	12.0	72.0
		Forklift Truck		
Pneumatic tires				
Single axle, dual wheels	10-35	--	7.5	72.0
Solid rubber tires				
Single axle, single wheels	0-5	19-42	5.0	28.0
	5-10	19-42	6.0	28.0
	10-20	19-42	7.0	28.0
		Tracked Vehicles		
Solid rubber grousers (cleat)	0-20	28	15.0	64.0
	20-35	28	16.0	83.0
	35-50	--	16.0	99.0
	50-70	54	19.0	100.0
	70-120	54	23.0	110.0

*Based on characteristics of military vehicles.
**Width of track for tracked vehicles.
†Distance between center lines of single wheels or tracks; distance between center lines of dual wheels.
††Wheel spacings are 13-l/2 x 58-l/2 x 13-l/2. Tandem-axle spacing is 48 inches.

CHAPTER 4

ELASTIC MODULI OF PAVEMENT MATERIALS

4-1. Climatic Factors.

In the design system, two climatic factors, temperature and moisture, are considered to influence the structural behavior of the pavement. Temperature influences the stiffness and fatigue of bituminous material and is the major factor in frost penetration. Moisture conditions influence the stiffness and strength of the base course, subbase course, and subgrade. Temperature does not influence the stiffness and fatigue of the PCC, but temperature differential in the concrete can cause the slab to warp and break easily. In concrete pavements, moisture differential can also cause the slab to warp but the effect is relatively minor.

a. Design pavement temperature. Pavement is generally designed for two different failure modes. One is for the shear failure in the subgrade and the other is for the fatigue cracking in the surface layers. The design procedure requires the determination of one design pavement temperature for consideration of vertical compressive strain at the top of the subgrade and horizontal tensile strain at the bottom of cement- or lime-stabilized layers and a different design pavement temperature for consideration of the fatigue damage of the bituminous concrete surface. In either case, a design air temperature is used to determine (figure 4-1) the design (mean) pavement temperature. Temperature data for computing the design air temperatures are available from the National Oceanic and Atmospheric Administration (NOAA) “Local Climatological Data Annual Summary with Comparative Data.” With respect to subgrade strain and fatigue of cement- and lime-stabilized base or subbase courses, the design air temperature is the average of two temperatures: (1) the average daily mean temperature and (2) the average daily maximum temperature during the traffic period. The traffic period is normally 1 month. For consideration of the fatigue damage of bituminous materials, the design air temperature is the average daily mean temperature. Thus, for each traffic period, two design air temperatures are determined. For design purposes, it is best to use the long-term averages such as the 30-year averages given in the annual summary. As an example, the determination of the design pavement temperatures for lo-inch bituminous pavement can be demonstrated by considering the climatological data for Jackson, Mississippi as tabulated below. For the month of August, the average daily mean temperature is 81.5 degrees F., and the average daily maximum is 92.5 degrees F.; therefore, the design air temperature for consideration of the subgrade strain is 87 degrees F., and the design pavement temperature determined from figure 4-1 would be approximately 100 degrees F. For consideration of bituminous fatigue, the design air temperature for August in Jackson, Mississippi is 81.5 degrees F., resulting in a design pavement temperature of approximately 92 degrees F. (from fig 4-1). These design pavement temperatures are determined for each of the traffic periods.

	Temperature, degrees F.	
Month	Average Daily Maximum	Average Daily Mean
January	58.4	47.1
February	61.7	49.8
March	68.7	56.1
April	78.2	65.7
May	85.0	72.7
June	91.0	79.4
July	92.7	81.7
August	92.5	81.5
September	88.0	76.0
October	80.1	65.8
November	68.5	55.3
December	60.5	48.9

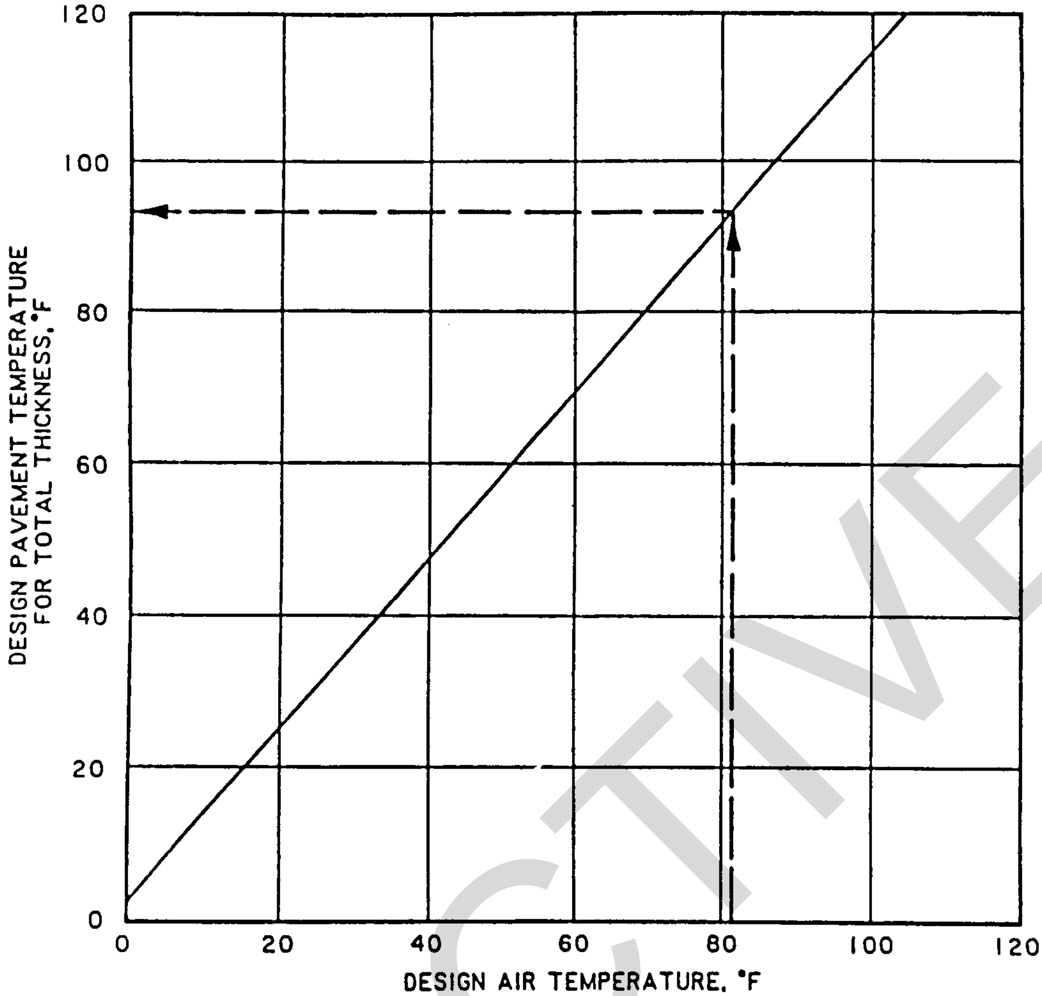

Figure 4-1. Relationship Between Design (Mean) Pavement Temperature and Design Air Temperature.

b. Thaw periods. The effects of temperature on subgrade materials are considered only with regard to frost penetration. The basic requirements for frost protection are given in TM 5-822-5/AFM 88-7, Chap. 3.

c. Subgrade moisture content for material characterization. Pavement design is usually predicated on a subgrade which is assumed to be near-saturation. The design may be based on subgrade with lower moisture content if available field measurements indicate that the subgrade will not reach saturation. These measurements must reflect the period of the year when the water table is at its highest level, and such designs must be approached with caution.

4-2. Material characterization.

Characterization of the pavement materials requires the quantification of the material stiffness as defined by the resilient modulus of elasticity and Poisson's ratio and, for selected pavement components, a fatigue strength as defined by a failure criterion. The use of layered elastic design procedures does not negate the material requirements set forth in TM 5-822-5/AFM 88-7, Chap. 3.

a. Modulus of elasticity.

(1) *Bituminous mixtures.* The term "bituminous mixtures" refers to a compacted mixture of bitumen and aggregate designed in accordance with standard practice. The modulus for these materials is determined by use of the repetitive triaxial tests. The procedure for preparation of the sample is given in TM-5-825-2-1/AFM 88-6, Chap. 2, Section A with the procedure for the conduct of the repetitive triaxial test given in chapter 9 of the same manual.

(a) The stiffness of the bituminous mixtures will be greatly affected by both the rate of loading and temperature. For roads and streets design, a loading rate of 2 to 4 hertz is recommended. Specimens should be tested at temperatures of 40, 70 and 100 degrees F. so that a modulus-temperature relationship can be established. If temperature data indicate greater extremes than 40 and 100 degrees F., tests should be conducted at

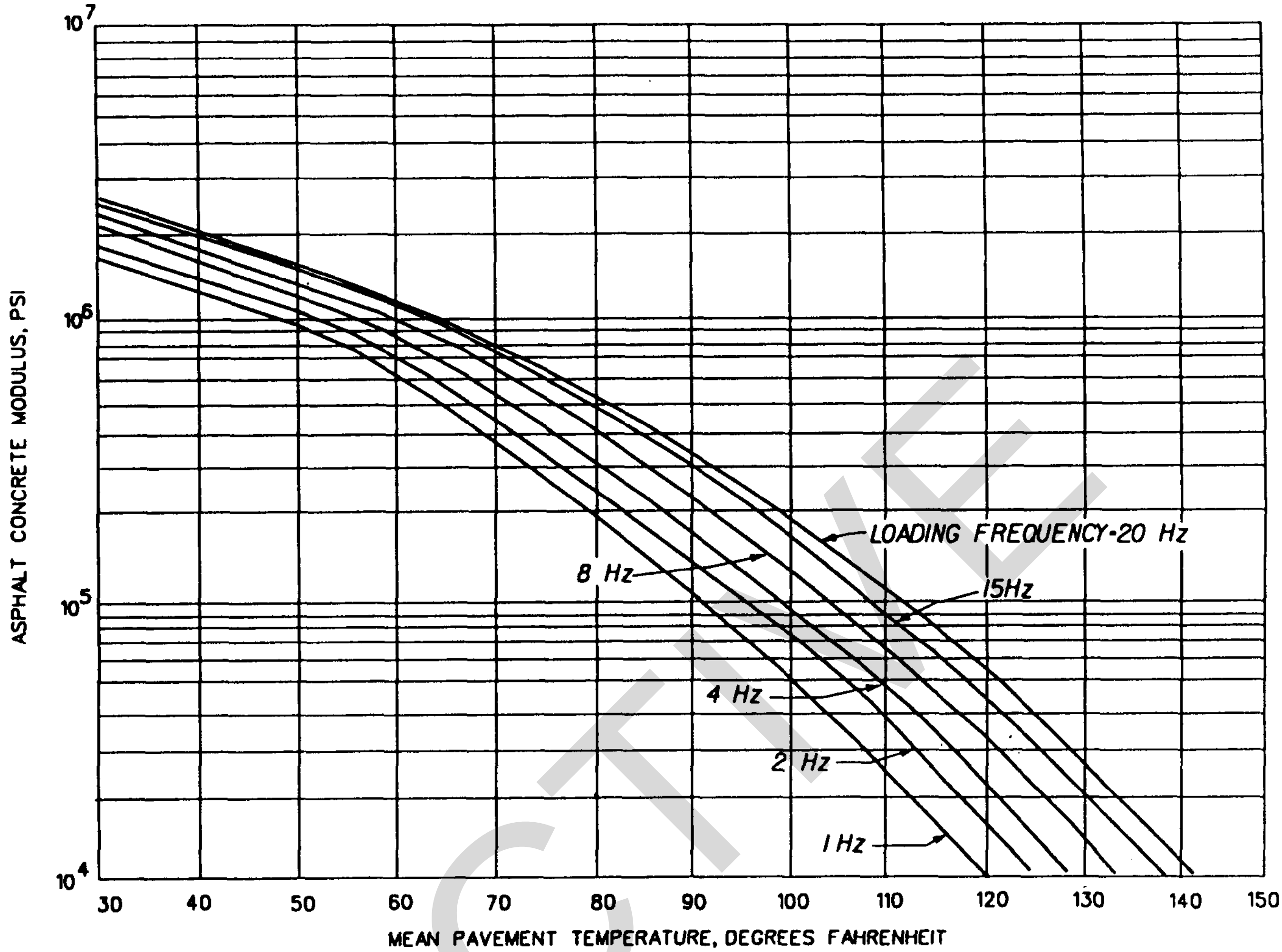

Figure 4-2. Prediction of Asphalt Concrete Modulus for Bituminous Layers.

these extreme ranges, if possible. The modulus value to be used for each strain computation would be the value applicable for the specific pavement temperature determined from the climatic data.

(b) An indirect method of obtaining an estimated modulus value for bituminous concrete is presented in detail in TM 5-825-2-1/AFM 88-6, Chap. 2, Section A. Use of this method requires that the ring-and-ball softening point and the penetration of the bitumen as well as the volume concentration of the aggregate and percent air voids of the compacted mixture be determined. The modulus of bituminous concrete may also be estimated from the design pavement temperature using figure 4-2.

(2) Portland cement concrete (PCC). The modulus of elasticity and flexural strength of PCC will be determined from static flexural beam tests in accordance with ASTM C 78. When test results are not available, a modulus value of 4,000,000 psi may be assumed for the concrete. Proportioning of the concrete mix and control of the concrete for pavement construction will be in accordance with TM 5-822-7/AFM 88-6, Chap. 8.

(3) Unbound *granular base and subbase course materials.* The terms "unbound granular base course material" and "unbound granular subbase course material" as used herein refer to materials meeting grading requirements and other requirements for base and subbase for roads and streets, respectively. These materials are characterized by use of a chart in which the modulus is a function of the underlying layer and the layer thickness. The chart and the procedure for use of the chart are given in appendix B. The modulus values of unbound granular bases may also be determined from cyclic triaxial tests on prepared samples. The recommended test procedure is outlined in TM 5-825-3-1/AFM 88-6, Chap. 3, Section A. The base course under a rigid pavement can be unbound granular or a chemically stabilized material. Design using stabilized materials is described in the next section.

(4) Stabilized material. The term "stabilized material" as used herein refers to soil treated with such agents as bitumen, portland cement, slaked or hydrated lime, and flyash or a combination of such agents to obtain a substantial increase in the strength of the material over the material's untreated natural strength.

Stabilization with portland cement, lime, flyash, or other agent that causes a chemical cementation to occur shall be referred to as chemical stabilization. Chemically treated soils having unconfined compressive strengths greater than the minimum strength are considered to be stabilized materials and should be tested in accordance with the methods specified for stabilized materials. Chemically treated soils having unconfined compressive strengths less than the minimum strength are considered to be modified soils. Most likely this will result in using the maximum allowable subgrade modulus. Bituminous-stabilized materials should be characterized in the same manner as bituminous concrete. Stabilized materials other than bituminous stabilized should be characterized using cracked section criteria, which is explained later in conjunction with figure 4-3.

(a) Stabilized materials for the base and subbase must meet the strength and durability requirement of TM 5-822-14/AFJMAN 32-1018. The basic strength requirements are presented in table 4-1.

Table 4-1. Minimum Unconfined ***Compressive Strengths for Cement, Lime, and Combined Lime-Cement Flyash Stabilized Soils.***

Stabilized Soil Layer	Minimum Unconfined Compressive Strength,* pounds per square inch	
	Concrete Pavement	Flexible Pavement
Base Course	500	750
Subbase course, select material, or subgrade	200	250

*Unconfined compressive strength determined at 7 days for cement stabilization and 28 days for lime or lime-cement-flyash stabilization.

(b) Lime-stabilized materials will continue to gain strength with time; therefore, if sufficient evidence is available that indicates a lime-stabilized material will acquire adequate strength prior to traffic, then the 28-day strength requirement may be waived.

(c) For concrete pavements having a stabilized base or subbase, the determination of elastic modulus values becomes more complicated than for the pavement with unbound granular base. Two cases in particular should be considered. In the first case, where the stabilized layer is considered to be continuous with cracking due only to curing and temperature, the elastic modulus values may be determined from flexural beam tests. In the second case, the stabilized layer is considered cracked because of load. Once the cracks have developed extensively in the stabilized base, the layer would behave as a granular material but with a higher modulus value. The cracked stabilized base course is represented by a reduced resilient modulus value, which is determined from the relationship between resilient modulus and unconfined compressive strength shown in figure 4-3. This relationship may be used for concrete pavement design for roads and streets.

(d) The general, material, and compaction requirements of base courses under a pavement are described in TM 5-822-5/AFM 88-7, Chap. 3.

(5) Subgrade soils. The term "subgrade" as used herein refers to the natural, processed, or fill soil foundation not meeting the requirements for a base or subbase on which a pavement structure is placed. The modulus of the subgrade is determined through the use of the repetitive triaxial test. The procedure is described in TM 5-825-2-1/AFM 88-6, Chap. 2, Section A. For most subgrade soils, the modulus is greatly affected by changes in moisture content and state of stress. As a result of normal moisture migration, water table fluctuation, and other factors, the moisture content of the subgrade soil can increase and approach saturation with only a slight change in density. Since the strength and stiffness of fine-grained materials are particularly affected by such an increase in moisture content, these soils should be tested in the near-saturation state.

(a) Procedures for specimen preparation, testing, and interpretation of test results for cohesive and granular subgrades are presented in TM 5-825-2-1/AFM 88-6, Chap. 2, Section A. For the layered elastic theory of flexible pavement design, the maximum allowable modulus for a subgrade soil should be restricted to 30,000 pounds per square inch (psi).

(b) In areas where the subgrade is to be subjected to freeze-thaw cycles, the subgrade modulus must be determined during the thaw-weakened state. Testing soils subject to freeze-thaw requires specialized test apparatus and procedures. The Cold Regions Research and Engineering Laboratories (CRREL) can assist in characterizing subgrade soils subjected to freeze-thaw.

(c) For some design situations, estimating the resilient modulus of the subgrade (M,) based on available information may be necessary when conducting the repetitive load triaxial tests. An estimate of the resilient modulus can be made from the relationship of $M_R = 1500 \bullet CBR$, where CBR is the California Bearing Ratio. This relationship provides a method for checking the reasonableness of the laboratory results. The relationship shown in figure 4-4 may be used to estimate the elastic modulus from the modulus of

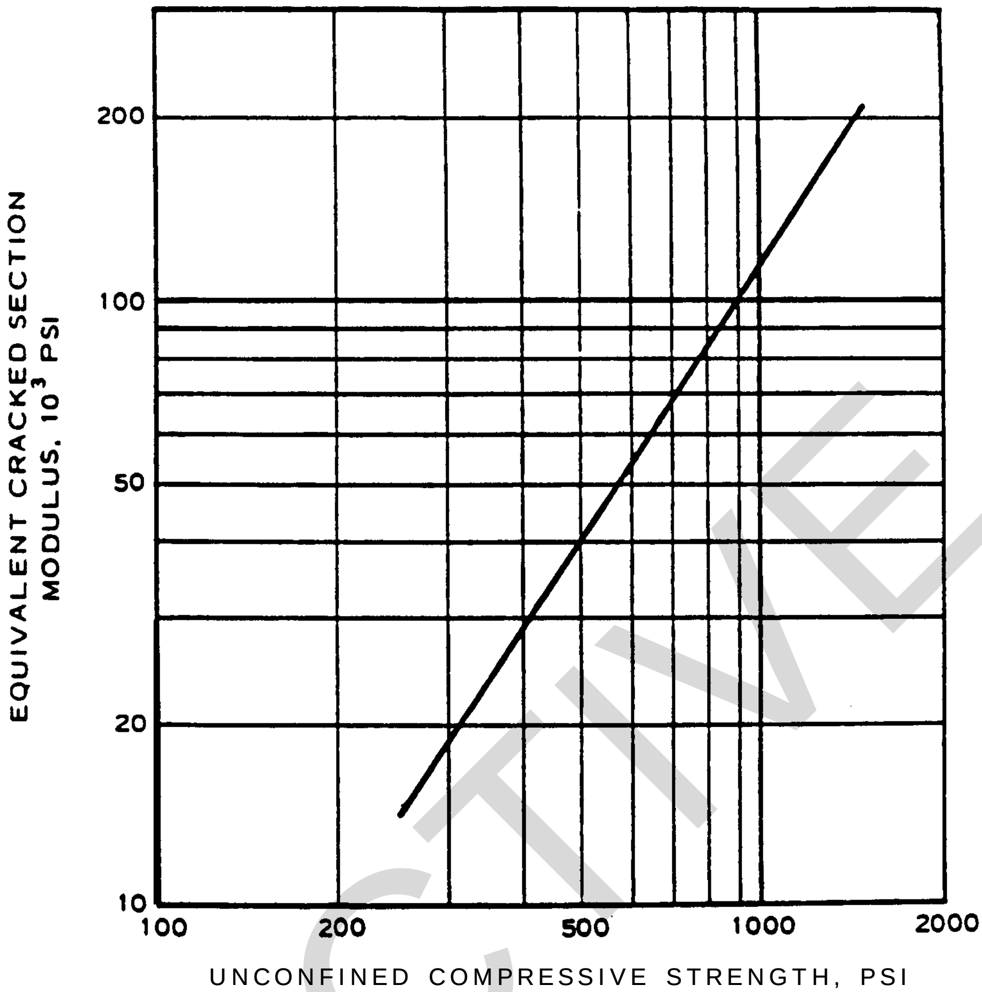

Figure 4-3. Relationship Between Equivalent Cracked Section Modulus and Unconfined Compressive Strength.

soil reaction k. It is to be noted that the relationship shown in figure 4-4 is established based on limited data. The modulus of soil reaction k can be determined using the plate-bearing test in the field or from table 4-2 when field test results are not available.

*Table 4-2. Modulus of Soil Reaction.**

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

Notes:

1. Values of k shown are typical for materials having dry densities equal to 90 to 95 percent of the maximum. For materials having dry densities less than 90 percent of the maximum, except that a k of 25 pci will be the minimum used for design.
2. Values shown may be increased slightly if density is greater than 95 percent of the maximum except that a k of 500 pci will be the maximum used for design.
3. Frost-melting-period k values are given in TM 5-822-5/AFM 88-7, Chap. 3.

*Typical values k in pci for rigid pavement design.

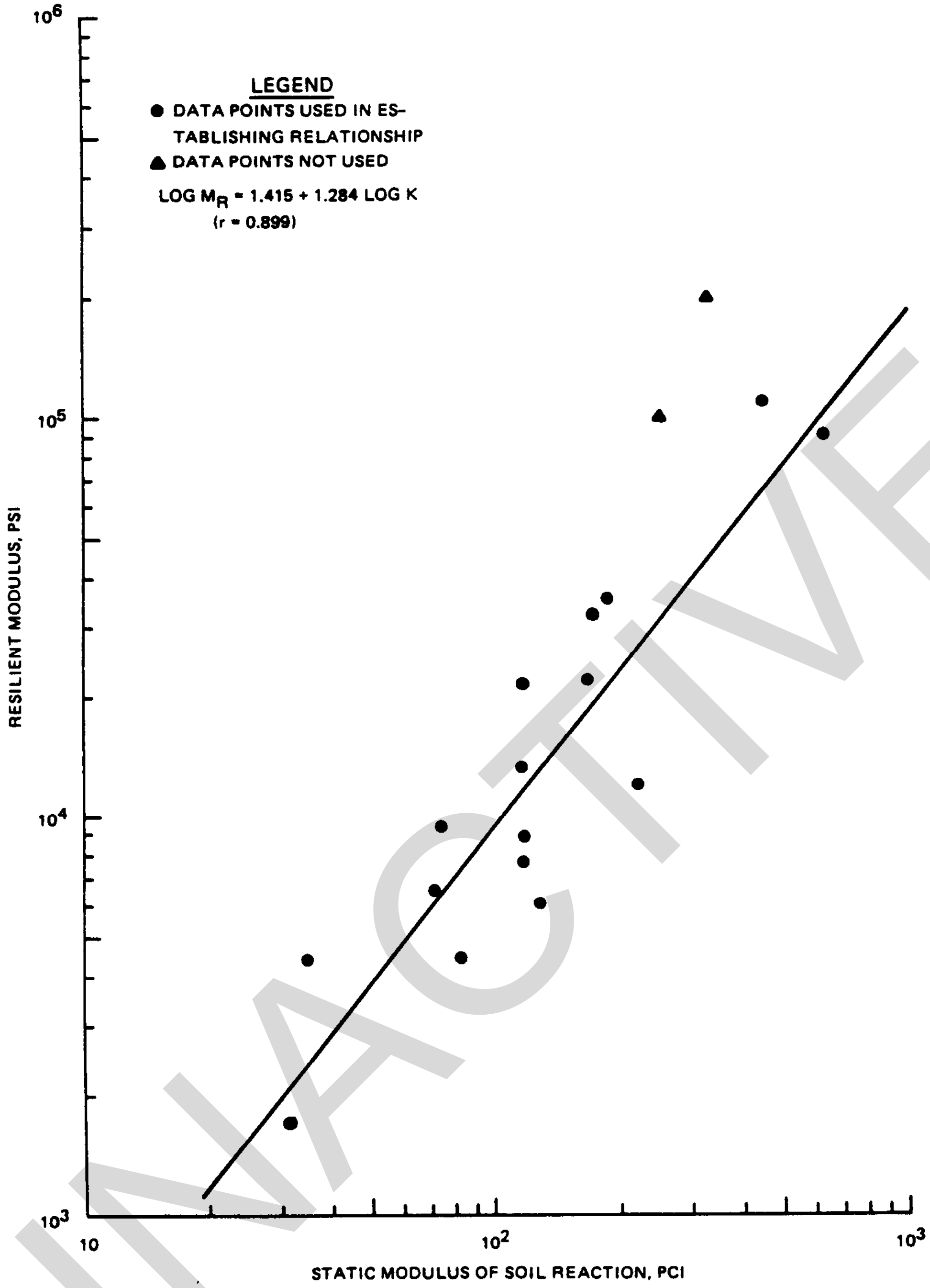

Figure 4-4. Correlcation Between Resilient Modulus of Elasticity and Static Modulus of Soil Reaction.

b. Poisson's ratio. Poisson's ratio is difficult to determine and has relatively minor influence on the design compared to other parameters. Therefore, commonly recognized values of Poisson's ratio are used. These values are as follows:

Pavement Material	Poisson's Ratio v
Portland cement concrete	0.15 ˜ 0.20
Bituminous concrete	0.5 for E < 500,000 psi
	0.3 for E > 500,000 psi
Unbound granular base or subbase course	0.3 ˜ 0.35
Chemically stabilized base or subbase course	0.2
Subgrade	
Cohesive subgrade	0.4
Cohesionless subgrade	0.3

4-3 Nondestructive Testing Procedure.

When computer programs are used to compute the stresses and strains in a pavement, the input needed is the elastic moduli of the pavement layers. The modulus values may be determined using the nondestructive testing (NDT) procedure presented in TM 5-826-5/AFP 88-24, Chap. 5. The NDT procedure used in this manual is the falling weight deflectometer (FWD). With the FWD the deflection basins of the pavement can be measured. Based on the measured deflection basins, the elastic modulus of the pavement material in each layer can be backcalculated by a computer program WESDEF available at US Army Engineer Waterways Experiment Station (WES) (TM 5-826-5/AFP 88-24, Chap. 5).

CHAPTER 5
DESIGN CRITERIA

5-1. Damage Factor.

The damage factor is defined as DF = n/N where n is the number of effective stress or strain repetitions and N is the number of allowable stress or strain repetitions. The cumulative damage factor is the sum of the damage factors for all vehicles. The value of n is determined from the number of vehicle operations, and the value of N is determined from the computed stress or strain and the appropriate criteria. The pavement thickness is determined when the cumulative damage factor equals one.

5-2. Vehicle Operations.

When vehicle operations (passes) are given, an operation-per-coverage ratio is needed for the particular design vehicle to convert operations to coverages. The operation-per-coverage ratios for the representative configurations are shown in tables 5-1 and 5-2 for rigid and flexible pavements, respectively. In LEDROAD computer program, the operations-per-coverage ratio is computed based on the standard deviations listed in the tables. The computations are based on the assumption that the wheels wander in a normal distribution across the traffic lane. The operations-per-coverage ratio computed in LEDROAD will be different from those listed in the tables and consequently the values computed using LEDROAD may be slightly different from those presented in this manual.

5-3. Concrete Pavement.

The limiting stress (fatigue) criteria are the basis for the design of concrete pavements. The thickness of the portland cement concrete slab is selected so that the maximum tensile stress at the bottom of the slab does not exceed the preselected value. The criteria are presented as a relationship between design factor and allowable coverages by the equation:

$$N = 10^{x} \qquad \text{(eq 5-1)}$$

where

N = allowable coverages

$$X = \frac{(R/\sigma - A)}{B}$$

A = 0.2967 + 0.002267 (SCI)

B = 0.3881 + 0.000039 (SCI)

R = flexural strength, psi

σ 1.33 times the maximum tensile stress at bottom of the slab computed with elastic layered method

SCI = Structural condition index. SCI = 80 for the first-crack condition, and SCI = 50 for the shattered slab condition

5-4. Flexible Pavement.

Basically, there are two criteria for determining the allowable stress (or strain) repetitions N. The first is the allowable number of operations as a function of the vertical strain at the top of the subgrade. The second is the allowable number of operations as a function of the horizontal strain at the bottom of the asphalt layer. There is no strain criteria for unbound base. In developing the procedure, it was assumed that unbound base and subbase that meet CE guide specification for quality will perform satisfactorily.

a. Asphalt strain criteria.

(1) The primary means recommended for determining the limiting horizontal tensile strain for bituminous concrete is the use of the repetitive load flexural beam test on laboratory-prepared specimens. Procedures for the test are presented in detail in appendix C. Several tests are run at different stress levels and different sample temperatures such that the number of load repetitions to fracture can be represented as a function of

Table 5-1. Operations Per Coverage Ratio, Flexible Pavements.

Configuration	(1) Load Range kips	(2) Contact Width* in.	(3) Wander** in.	(4) Standard Deviation† in.	(5) Operations per Coverage
			Passenger Cars. Trucks. Buses. etc.		
Pneumatic tires					
single axle,	0-5	5.63	64.37	21.46	9.59
single wheels	5-10	7.14	52.86	17.62	6.25
Single axle,	0-10	6.75	44.25	14.75	2.95
dual wheels	10-20	7.20	41.20	13.73	2.64
	20-30	7.77	39.60	13.20	2.37
Tandem axle,	0-10	5.63	54.37	18.13	4.05
single wheels	10-15	7.50	48.50	16.16	2.73
Tandem axle,	10-15	5.63	49.38	16.46	1.93
dual wheels	15-20	8.25	38.75	12.92	1.23
	20-50	9.00	37.00	12.34	1.03
			Forklift Trucks		
Pneumatic tires Single axle, dual wheels	10-35	5.63	44.88	14.93	3.52
Solid rubber tires					
Single axle,	0-5	5.00	51.00	17.00	8.36
single tires	5-10	6.00	50.00	16.67	7.00
	10-20	7.00	49.00	16.34	5.90
			Tracked Vehicles		
Solid rubber					
grousers	0-20	11.22	56.75	18.92	1.43
	20-35	12.00	37.00	12.34	0.89
	35-50	12.00	21.00	7.00	0.55
	50-70	14.25	17.75	5.92	0.43
	70-120	17.25	4.75	1.58	0.33

Note: Traffic lane width (P_w) - 11 ft (except for solid-rubber-tired fork-lift trucks; P_w - 7 ft), T_w - average tire width from table 3-1. Spacing between dual wheels(s) - 2 in., W_s - average wheel spacing from table 3-1.

*Contact width (C_w - 0.75 T_w (except for solid-rubber-tired forklift truck where C_w - T_w.

**Wander (B_w) for single wheels or track - P_w - (W_s + C_w); for dual wheels, B_w - P_w - (W, + 1.75 T_w + S).

†Standard deviation (a) - B_w/3.

temperature and initial stress. The initial stress is converted to initial strain in order to yield criteria based on the tensile strain of the bituminous concrete.

(2) An alternate method for determining values of limiting tensile strain for bituminous concrete is the use of the provisional laboratory fatigue data employed by Heukelom and Klomp (1964). These data are presented in appendix C in the form of a relationship between stress, strain, load repetitions, and elastic moduli of bituminous concrete. The data may be approximated by the following equation

$$\text{Allowable coverage} = 10^{x} \qquad \text{(eq 5-2)}$$

where

$X = 5 \log S_A + 2.665 \log_{10} (E/14.22) + 0.392$

S_A = tensile strain of asphalt (in./in.)

E = elastic modulus of the bituminous concrete (psi)

The equation used to determine the allowable tensile strain at the bottom of the asphalt layer is:

$$\text{Allowable strain } \epsilon_{AC} = 10^{-A} \qquad \text{(eq 5-3)}$$

Table 5-2. Operations ***Per*** Coverage ***Ratio, Rigid Pavements.***

Configuration	(1) Load Range kips	(2) Contact Width* in.	(3) Wander*+ in.	(4) Standard Deviation† in.	(5) Operations per Coverage
		Passenger Cars. Trucks. Buses. etc.			
Pneumatic tires					
single axle,	0-5	5.63	64.37	21.46	9.59
single wheels	5-10	7.14	52.86	17.62	6.29
Single axle,	0-10	6.75	44.25	14.75	2.95
dual wheels	10-15	7.20	41.20	13.73	2.64
	20-30	7.77	39.60	13.20	2.37
Tandem axle,	0-10	5.63	54.37	18.13	8.1
single wheels	10-15	7.50	48.50	16.16	5.46
Tandem axle,	10-15	5.63	49.38	16.46	3.86
dual wheels	15-20	8.25	38.75	12.92	2.46
	20-50	9.00	37.00	12.34	2.06
		Forklift Trucks			
Pneumatic tires					
Single axle,					
dual wheels	10-35	5.63	44.88	14.93	3.52
Solid rubber tires					
Single axle.	0-5	5.00	51.00	17.00	8.36
single tires	5-10	6.00	50.00	16.67	7.00
	10-20	7.00	49.00	16.34	5.90
		Tracked Vehicles††			
Solid rubber					
grousers	0-20	11.22	56.75	18.92	8.58(1.43)
	20-35	12.00	37.00	12.34	5.36(0.89)
	35-50	12.00	21.00	7.00	4.38(0.55)
	50-70	14.25	17.75	5.92	2.59(0.43)
	70-120	17.25	4.75	1.58	2.0 (0.33)

Note: Traffic lane width (P_w) - 11 ft (except for solid rubber-tired forklift trucks; P_w - 7 ft), T_w - average tire width from table 3-1. Spacing between dual wheels(s) - 2 in., W_s - average wheel spacing from table 3-1.

*Contact width (C_w - 0.75 T_w (except for solid rubber-tired forklift truck where C_w - T_w).

**Wander (B_w) for single wheels or track - P_w - (W_s + C_w; for dual wheels, B_w - P_w - (W_s + 1.75 T_w + S).

†Standard deviation (a) - B_w/3.

††The values shown in the parentheses are for conservative type of design.

where

$$A = \frac{N + 2.665 \log_{10} (E/14.22) + 0.392}{5}$$

N = $\log_{10}$(coverage)

E = elastic modulus of the bituminous concrete (psi)

b. Subgrade strain *criteria.* Failure criteria (fig 5-1) for roads and streets are approximated by the equation

$$\text{Allowable strain } \epsilon_{SUB\ G} = 10^{-A} \qquad \text{(eq 5-4)}$$

where

A = 0.1408 $\log_{10}$ (coverage) + 2.408

Equation 5-5 can also be written as

$$\text{Allowable coverage} = 10^{-A} \qquad \text{(eq 5-5)}$$

where

A = (2.408 + $\log_{10}$ (ϵ_{SUBG}))/0.1408

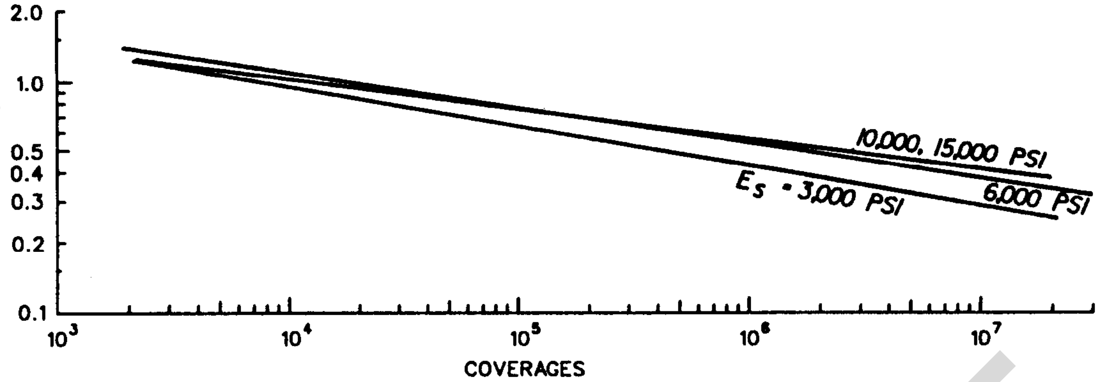

Figure 5-1. Subgrade Strain Criteria for Roads and Streets.

CHAPTER 6

FLEXIBLE PAVEMENT DESIGN

6-1. Design Requirements.

Flexible pavement designs will provide the following:

a. Adequate thickness above the subgrade and above each layer together with adequate quality of the select material, subbase, and base courses to prevent detrimental shear deformation under traffic and, when frost conditions are a factor, to control or reduce to acceptable limits effects of frost heave or permafrost degradation.

b. Sufficient compaction of the subgrade and of each layer to prevent objectionable settlement under traffic.

c. Adequate drainage of base course to provide for drainage of base course during spring thaw.

d. A stable, weather-resistant, wear-resistant, waterproof, nonslippery pavement.

6-2. Determination of Pavement Thickness.

a. Bituminous concrete. When the computed thickness of the bituminous concrete is a fractional value, it will be rounded to the nearest full or half inch thickness. Values falling midway between the full and half inch values will be rounded upward.

b. Conventional flexible pavements.

(1) *General.* Conventional flexible pavements for roads, streets, and open storage areas consist of relatively thick aggregate layers with a thin (3- to 5-inch) wearing course of bituminous concrete. In this type of pavement, the bituminous concrete layer is a minor structural element of the pavement, and thus, the temperature effects on the stiffness properties of the bituminous concrete may be neglected. Also, it must be assumed that if the minimum thickness of bituminous concrete is used as specified in TM 5-822-5/AFM 88-7, Chap. 3, then fatigue cracking will not be considered. Thus, for a conventional pavement, the design problem is one of determining the thickness of pavement required to protect the subgrade from shear deformation. The steps for determining the required thickness for nonfrost areas are:

(a) Since summer temperature condition is considered most severe for subgrade shear failure, i.e., largest subgrade vertical strain under load, a modulus value of 200,000 psi (considered to be small for bituminous concrete) is used for the bituminous concrete.

(b) The traffic data determine the design loadings and coverages.

(c) An initial pavement section is determined using the minimum thickness requirements from TM 5-822-5/AFM 88-7, Chap. 3 or by estimation. The resilient modulus of the base and of the subbase is determined from figure B-l and the initial thickness.

(d) The vertical strain at the top of the subgrade is computed using JULEA for each axle load being considered in the design.

(e) The number of allowable coverages for each computed strain is determined from the subgrade strain criteria using equation 5-5.

(f) The value of n/N is computed for each axle load and summed to obtain the cumulative damage.

(g) The initial thicknesses are adjusted to make the value of the cumulative damage approach 1. This may be accomplished by first making the computations for three or four thicknesses and developing a plot of thickness versus damage. From this plot the thickness that gives a damage of 1 may be selected.

(2) *Frost conditions.* Where frost conditions exist and the design thickness is less than the thickness required for complete frost protection, the design must be based on weakened subgrade condition. In some cases, it may be possible to replace part of the subgrade with material not affected by cycles of freeze-thaw but which will not meet the specifications for a base or subbase. In this case, the material must be treated as a subgrade and characterized by the procedures given for subgrade characterization. For information on designing for frost conditions, see TM 5-822-5/AFM 88-7, Chap. 3.

c. All-bituminous concrete pavements. The all-bituminous concrete pavement differs from the conventional flexible pavement in that the bituminous concrete is sufficiently thick (greater than 5 inches) to contribute significantly to the strength of the pavement. In this case, the variation in the stiffness of the bituminous concrete caused by yearly climatic variations must be taken into account by dividing the traffic into increments during which variation of the resilient modulus of the bituminous concrete is at a minimum. One procedure is to determine the resilient modulus of the bituminous concrete for each month, then group the months when the bituminous concrete has a similar resilient moduli. Since the bituminous concrete is a major structural element, the failure of this element due to fatigue cracking must be checked.

d. Pavements with a chemically stabilized base course. For a pavement having a chemically stabilized base course and an aggregate subbase course, damage must be accumulated for subgrade strain and for horizontal tensile strain at the bottom of the asphalt surface layer. Normally in this type of pavement, the base course resilient modulus is sufficiently high (≥ 100,000 psi) to prevent fatigue cracking of the bituminous concrete surface course (where the bituminous concrete surface course has a thickness equal to or greater than the minimum required for the base course given in TM 5-825-2), and thus, this mode of failure is only a minor consideration. For most cases, a very conservative approach can be taken in checking for this mode of failure; i.e., all the traffic can be grouped into the most critical time period and the computed bituminous concrete strain compared with the allowable strain. If the conservative approach indicates that the surface course is unsatisfactory, then the damage should be accumulated for different traffic periods. For the pavement having a stabilized base or subbase, the stabilized layer is considered cracked for the purpose of design. The cracked stabilized base course is represented by a reduced resilient modulus value, which is determined from the relationship between resilient modulus and unconfined compressive strength shown in figure 4-3. When the cracked base concept is used, the subgrade criteria generally control the design. The section obtained should not differ greatly from the section obtained by use of the equivalency factors presented in TM 5-822-5/AFM 88-7, Chap. 3.

6-3. Design Example for a Conventional Flexible Pavement.

Design a conventional flexible pavement to support the following traffic:

Passenger car	2,000 operations per day
3-axle trucks	200 operations per day

As stated in TM 5-822-8/AFM 88-7, Chap. 3, this traffic results in a design index of 6 and the required pavement thickness is determined to be 22 inches for a subgrade CBR of 4.

a. Assume each axle of the passenger car carries 1,500 pounds and the front axle of the truck (single-axle, single wheel) carries 9,000 pounds and the rear axle of the truck (dual-axle, dual wheels) carries 32,000 pounds. The total number of operations and their corresponding coverages (n_1) for each axle load are tabulated in table 6-1. The design using the layered elastic method is discussed in the following paragraph.

b. Three pavement thicknesses (16, 20, and 24 inches) are assumed for the design. The bituminous concrete surface and base layers are 4 and 6 inches, respectively. The subgrade strains are computed for each thickness under each axle load using the layered elastic method. The modulus values of the base and subbase layers are determined from the chart in figure B-l of appendix B. The strains calculated using JULEA are tabulated in table 6-1. Based on the strain values, the allowable coverages (N_i) are determined from figure 5-1. The corresponding damage for each thickness under each axle load is computed as n_i/N_i and is tabulated in the last column of table 6-1. The total damage for each thickness is the sum of the damage of each axle load. A plot of the damage against the thickness indicates that the required thickness is 22 inches for a damage of one, which is the same thickness derived using the design index method in TM 5-822-5/AFM 88-7, Chap. 3. The subbase is therefore 12.0 inches. Table 6-1 shows that the damage caused by the passenger cars is so small that their inclusion in the damage computation could actually be neglected.

6-4. Design Example for an All-Bituminous Concrete (ABC) Pavement.

Design an ABC pavement for the same condition shown in previous example. For computation of the fatigue damage and subgrade damage, monthly temperature variations are considered; the corresponding variations of bituminous concrete modulus are shown in tables 6-2 and 6-3, respectively. Three pavement thicknesses of 8, 10, and 12 inches are used for damage computation. Normally for ABC design the subgrade damage will be the controlling criteria and thus the thickness for satisfying the subgrade criteria is first determined. The design is carried out in the following steps:

a. Subgrade failure.

(1) The subgrade strains are computed for each thickness under each axle load for each month using JULEA computer program. The bituminous concrete moduli for each month are shown in the last column of table 6-3. Because the effect of passenger cars on damage computation was proven to be negligible in the previous example, damage computation for passenger cars was not done.

(2) The allowable coverages N_i for each pavement are computed from the failure criteria shown in figure 5-1.

(3) The damage increments for each month are computed. The strains, allowable coverages, and the cumulative damage for the 32-kip tandem-axle, dual-wheels loads are tabulated in table 6-4. Cumulative damage for the 9-kip load is negligible. It is seen that nearly all the subgrade damage in the flexible pavement is done during the warmer months, i.e., May, June, July, August, and September.

(4) Similar computations are made for 9-kip single-axle, single-wheel loads. A plot of the cumulative damage for both 32-kip and 9-kip loads and pavement thickness indicates that for a damage of one, the required ABC thickness is 10.05 inches. For design purpose lo-inches are used.

Table 6-1. Strain Values and Damage for Trail Thicknesses.

Axle	Axle Type	Axle Load lb	Operations	Operations* per Coverage	Coverages n_i	Subgrade Vertical Strains+ 10^{-3} in./in. Pavement Thicknesses, in. 16†	20††	24‡	Allowable Coverage N_i ** Pavement Thicknesses, in. 16	20	24	Damage $D_i = n_i/N_i$ Pavement Thicknesses 16	20	24
1	Single-axle Single wheel	1,500	36,500,000‡‡	9.59	3,806,040	-0.09	-0.06	-0.03	Too Large	--	--	0.0	0.0	0.0
2	Single-axle Single wheel	9,000	1,825,000§	6.29	290,143	-0.85	-0.37	-0.19	867,000	12,850,000	Too Large	0.33	0.02	0.0
10	Tandem-axle Dual wheels	32,000	1,825,000§	1.03	1,771,844	-0.77	-0.56	-0.32	100,000	860,200	30,000,000	17.72	2.06	0.06
											Total damage	18.05	2.08	0.06

+The computations are made with the following conditions:

a. Tire contact pressure = 70 psi.

b. The moduli and Poisson's ratios for the AC surface and the subgrade are 200,000 psi, 0.4, 6,000 psi, 0.4, respectively. The Poisson's ratio of base and subbase is 0.35.

c. The layers are assumed to be fully bonded to each other.

d. The moduli of the base and subbase layers are determined based on the subgrade modulus.

Base	6 in.	E = 30,250 psi	6 in.	E = 40,452 psi	6 in.	E = 51,739 psi
Subbase	6 in.	E = 12,000 psi	10 in.	E = 18,175 psi E = 11,393 psi	14 in.	E = 26,380 psi E = 19,173 psi E = 11,813 psi

e. Interface conditions between each layer are fully bonded.

*From table 5-1.

**From figure 5-1 based on computed subgrade strain.

†The pavement consists of 4 inches of bituminous concrete, 6 inches of base course, and 6 inches of subbase.

††The pavement consists of 4 inches of bituminous concrete, 6 inches of base course, and 10 inches of subbase.

‡The pavement consists of 4 inches of bituminous concrete, 6 inches of base course, and 14 inches of subbase.

‡‡36,500,000 = 2 axles × 2,000 operations per day × 365 days × 25 years.

§1,825,000 = 1 × 200 × 365 × 25.

Table 6-2. Bituminous Concrete Moduli for Each Month for ABC Pavement Design Based on Bituminous Concrete Strain.

Month	Average† Daily Mean Air Temperature degrees F.	Design†† Pavement Temperature degrees F.	Dynamic††† Modulus $\|E^*\|$ 10^3 psi
Jan	47.5	54	1,600
Feb	50.7	57	1,400
Mar	58.0	64	1,060
Apr	66.1	72	700
May	73.3	80	460
Jun	80.5	88	280
Jul	83.1	91	230
Aug	82.7	91	230
Sep	77.3	85	340
Oct	67.2	73	670
Nov	56.2	61	1,200
Dec	49.3	56	1,500

†For fatigue damage of bituminous materials, the design air temperature is the average daily mean temperature.
††Obtained from figure 4-1.
†††Obtained from laboratory tests or other sources.

b. Fatigue failure in the bituminous concrete. To check if the lo-inch thick ABC pavement would fail by fatigue cracking, the cumulative damage in the bituminous concrete layer is computed for each month. The monthly modulus values of the bituminous concrete used in computations are from table 6-2. The results of the analysis indicate that the fatigue damage factor, i.e., $\Sigma n_i/N_i$, is 0.36 which is considerably less than 1; thus a pavement thickness of lo-inches meets both the subgrade criteria and the asphalt fatigue criteria.

6-5. Design Details.

Typical details for the design and construction of shoulders, curbs, and gutters of flexible pavements for military roads and streets are contained in TM 5-822-5/AFM 88-7, Chap. 3.

Table 6-3. Bituminous Concrete Moduli for Each Month for ABC Pavement Design Based on Subgrade Strain.

Month	Average Daily Mean Air Temperature degrees F.	Average Daily Maximum Air Temperature degrees F.	Design Air† Temperature degrees F.	Design Pavement Temperature degrees F.	Dynamic Modulus |E*| 10^3 psi
Jan	47.5	56.4	52	57	1,600
Feb	50.7	60.1	55	62	1,150
Mar	58.0	68.0	63	70	790
Apr	66.1	76.0	71	77	540
May	73.3	83.2	78	86	320
Jun	80.5	90.4	85	95	180
Jul	83.1	92.9	88	97	160
Aug	82.1	92.8	88	97	160
Sep	77.3	87.4	82	91	230
Oct	67.2	78.1	73	82	400
Nov	56.2	66.4	61	69	830
Dec	49.3	58.3	54	61	1,200

†With respect to subgrade strain, the design air temperature is the average of the average daily mean temperature and the average daily maximum temperature.

Table 6-4. Strain Values and Damage for ABC Pavement, 32-kip Tandem-Axle, Dual-Wheels.

Month	Bituminous Modulus 10^3 psi	Subgrade Vertical Strain* 10^{-3} in./in. ABC Thickness, in.			Allowable Coverage, N_i ABC Thickness, in.			Damage $D_i = n_i^{**}/N_i$ ABC Thickness, in.			Cumulative Damages ABC Thickness, in.		
		8	10	14	8	10	14	8	10	14	8	10	14
Jan	1,400	-0.26	-0.20	-0.13	0.2×10^8	0.1×10^{10}	0.3×10^{11}	0.0	0.0	0.0	0.0	0.0	0.0
Feb	1,150	-0.29	-0.22	-0.15	0.1×10^8	0.7×10^8	--	0.01	0.0	0.0	0.01	0.0	0.0
Mar	790	-0.35	-0.27	-0.18	0.3×10^8	0.2×10^8	--	0.01	0.0	0.0	0.02	0.0	0.0
Apr	540	-0.43	-0.33	-0.22	0.6×10^7	0.4×10^8	0.7×10^8	0.03	0.0	0.0	0.05	0.0	0.0
May	320	-0.57	-0.43	-0.29	0.9×10^6	0.6×10^7	0.1×10^8	0.17	0.02	0.0	0.22	0.02	0.0
Jun	180	-0.80	-0.59	-0.39	0.8×10^5	0.7×10^6	0.1×10^8	1.89	0.22	0.01	2.11	0.24	0.01
Jul	160	-0.86	-0.63	-0.42	0.5×10^5	0.4×10^6	0.8×10^7	3.16	0.35	0.02	5.27	0.59	0.03
Aug	160	-0.86	-0.63	-0.42	0.5×10^5	0.4×10^6	0.8×10^7	3.16	0.35	0.02	8.43	0.94	0.05
Sep	230	-0.70	-0.52	-0.34	0.2×10^6	0.2×10^7	0.3×10^8	0.74	0.09	0.00	9.17	1.03	0.05
Oct	400	-0.51	-0.38	-0.26	0.2×10^7	0.2×10^8	0.2×10^8	0.08	0.01	0.0	9.25	1.04	0.05
Nov	830	-0.34	-0.26	-0.18	0.34×10^8	0.22×10^8	--	--	0.0	0.0	9.25	1.04	0.05
Dec	1,200	-0.28	-0.22	-0.14	0.14×10^8	0.14×10^8	0.75×10^8	--	0.0	0.0	9.25	1.04	0.05

*The computations are made with the following conditions:

a. The Poisson's ratios of the AC and the subgrade are both 0.4.

b. The interface condition between the AC layer and the subgrade is assumed to be fully bonded, as the subgrade vertical strain is much greater in the case.

c. Tire contact pressure = 70 psi.

**n_i is the total coverages for the 25 year design life divided into 12-month periods = 1,771,845/12 = 147,654, where 1,771,845 is obtained from table 6-2.

CHAPTER 7

CONCRETE PAVEMENTS

7-1. Application.

In general, all concrete pavements for roads, streets, and open storage areas on military installations will be plain concrete unless otherwise approved by Headquarters, Department of the Army (CEMP-ET), Washington, DC 20314-1000, or the appropriate Air Force Major Command. Roller-compacted concrete pavements (RCCP) are plain concrete pavements constructed using a zero-slump PCC mixture that is placed with an asphalt concrete paving machine and compacted with vibratory and rubber-tired rollers. Most of the engineering and material properties of RCCP are similar to those of conventional concrete. Pavements constructed using RCCP have been approved for use in parking and storage areas and for road and street classes where vehicle speed does not exceed 45 miles per hour.

7-2. Design Procedure.

The design of a concrete pavement for mixed vehicular loads and traffic levels is based on Minor's hypothesis. It involves selecting a thickness of the PCC slab in which the maximum tensile stress does not exceed a certain value. This tensile stress is calculated using the JULEA computer program, and the limiting stress criteria are based on equations 5-1 and 5-2. Since traffic loads travel near the pavement (free) edges, load transfer is not considered in the design for roads and streets but is considered for parking and storage areas.

a. Select several concrete slab thicknesses and compute the maximum tensile stresses under each design axle load using the layered elastic method. The concrete thickness required using the conventional design procedure may be used as a starting point. The computed maximum stresses should be multiplied by 1.33 for roads and streets.

b. Based on the computed stresses, determine the allowable coverages N_i using equation 5-1 for each thickness.

c. Compute the damage which is equal to the sum of the ratios of the design coverage n_i to the allowable coverage N_i, where i varies to account for each design axle load. For instance, if there are three different axle loads involved in the design, i varies from 1 to 3.

d. Select the thickness at a damage of 1.

e. Select the slab thickness for the damage value of 1 from the relationship between the damage and slab thickness.

f. The selection of an unbound granular base or a stabilized base under the concrete slab is a matter of engineering judgment depending on many factors such as cost, material availability, frost protection requirement, pumping, and subgrade swell potential. Subgrade soil may be stabilized to gain strength or modified to increase its workability and reduce swell potential.

g. All plain concrete pavements will be uniform in cross-sectional thickness. The minimum thickness of concrete will be 6 inches. The computed thickness will be rounded to the next full or half-inch thickness.

7-3. Design Procedures for Stabilized Foundations.

a. Soil stabilization or modification. Soils that have been treated with additives such as cement, lime, flyash, 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 sufficient to qualify as a stabilized soil. The principal benefits of soil modification or stabilization include a stable all-weather construction platform, a reduction of concrete pavement thickness requirements, and when applicable, a reduction of swell potential and susceptibility to pumping and strength loss due to moisture.

b. Requirements. The design of the stabilized or modified layers will follow TM 5-822-4/AFM 88-7, Chap. 4, and TM 5-822-5/AFM 88-7, Chap. 3. To qualify as a stabilized layer, the stabilized material must meet the unconfined compressive strength and durability requirements in TM 5-822-14/AFJMAN 32-1019; otherwise, the layer is considered to be modified.

c. Thickness design. The thickness requirements for a plain concrete 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 overlay pavement design equation:

$$h_o = \sqrt[1.4]{h_d^{1.4} - \left(\sqrt[3]{\frac{E_f}{E_c}}\, h_s\right)^{1.4}} \qquad \textbf{(eq 7-1)}$$

where

h_o = thickness of plain concrete pavement overlay required over the stabilized layer, inches
h_d = design thickness of equivalent single slab placed directly on foundation determined from layered elastic method
E_c = modulus of elasticity of concrete, usually taken as 4 x 10^6 psi
E_f = flexural modulus of elasticity of the stabilized soil. The modulus value for bituminous stabilized soils will be determined according to the procedures in appendix B of TM 5-822-5/AFM 88-7, Chap. 3. The modulus value for lime and cement stabilized soils will be determined using equations in appendix B of TM 5-822-5/AFM 88-7, Chap. 3
h_S = thickness of stabilized layer, inches

7-4. Reinforced Concrete Pavements.

Figure 7-1 is a design chart for determining the thickness of reinforced concrete pavement based on the thickness of the plain concrete pavement and the amount of steel to be used in the pavement. Figure 7-1 also shows the maximum allowable length of reinforced concrete slab.

7-5. Design Examples.

a. The input information needed for the design are as listed in paragraph 2-2. Based on the trial pavement sections, the critical stresses and strains are computed using the elastic layered computer codes. Damage from each vehicle group is summed and the design thickness is determined when the cumulative damage is equal to one.

b. In the computation, the following values are used.

(1) The interface between the concrete slab and the subgrade soil is assumed to be frictionless and the parameter equal to 10,000 is used in the computation.

(2) The moduli and Poisson's ratio of the PCC and the subgrade are 4,000,000 psi, 0.2, 10,000 psi, 0.4, respectively.

(3) The tire contact pressure is assumed to be 70 psi. In tracked vehicle, the track width is constant and the contact pressure varies with the gross load.

c. Example No. 1. This example is to show the procedures for determining the elastic modulus values of unbound granular base and subbase courses from figure B-l.

(1) Assume a concrete pavement having a base course thickness of 4 inches and a subbase course thickness of 8 inches over a subgrade having a modulus of 10,000 psi. Initially, the subgrade is assumed to be layer n + 1 and the subbase course to be layer n. Entering figure B-l with a modulus of layer n + 1 of 10,000 psi and using the 8-inch subbase course curve, the modulus of the subbase (layer n) is found to be 18,500 psi. In order to determine the modulus value of the base course, the subbase course is now assumed to be layer (n + 1). Entering figure B-l with a modulus of layer n + 1 of 18,500 psi and using the 4-inch base course curve, the modulus of the base course is found to be 36,000 psi.

(2) If, in this example, the design thickness of the subbase course had been 12 inches, it would have been necessary to divide this layer into two 6-inch-thick sublayers. Then, using the procedure above, the modulus values determined for the lower and upper sublayers of the subbase course and for the base course are 17,500, 25,500, and 44,000 psi, respectively.

d. Example No. 2.

(1) As an example of the application of the design procedures given for nonstabilized foundations, determine thickness requirements for a plain concrete road to carry the following traffic:

Passenger cars	2,000 per lane per day
Panel and pickup trucks	1,300 per lane per day
Trucks, 2-axle	150 per lane per day
Trucks, 3-axle	50 per lane per day

For each type of vehicle, the operations per coverage ratios are obtained from table 5-1 and used to convert operations to coverages according to axle configurations. The computed coverages for each axle type are tabulated in table 7-1.

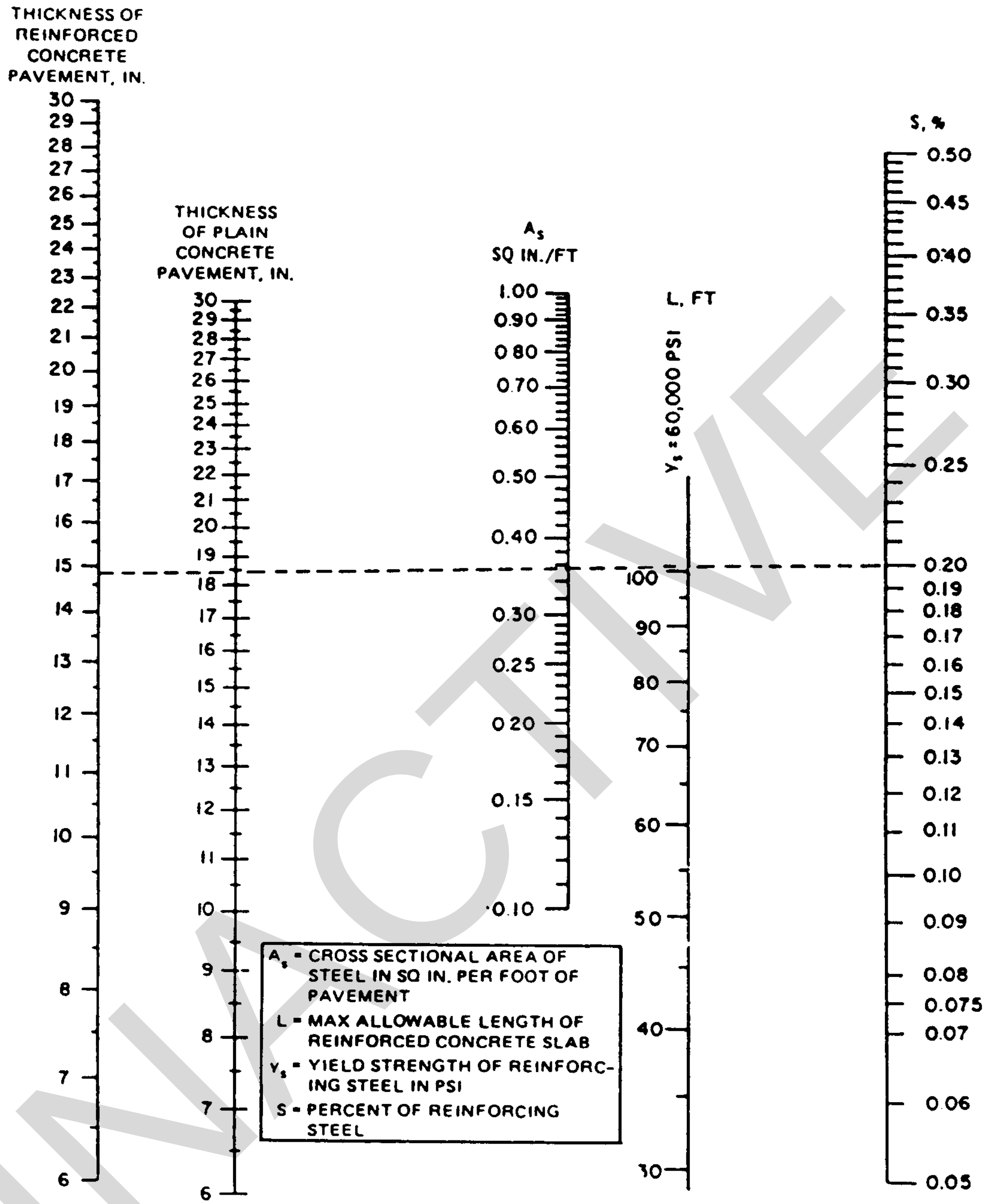

Figure 7-1. Reinforced Concrete Pavement Design.

(2) The required concrete thickness is first determined using the current design procedure presented in TM 5-822-5/AFM 88-7, Chap. 3 as a starting point. Assuming an E value of 10,000 psi for the subgrade soil, four concrete thicknesses were selected as shown in table 7-2, and the maximum stresses were computed using JULEA computer program for all the axle configurations. The stresses are tabulated in column 4 of table 7-2. Since load transfer is not considered in roads and streets for concrete pavements as wheel and track loads travel along the concrete slab edges, stresses computed with codes such as JULEA (interior stresses) do not simulate the edge stress condition and thus the computed stresses will be multiplied by a factor of 1.33. The modified stresses are shown in column 5 of the table. Assuming a 28-day flexural strength R for the concrete of 675 psi and a SCI of 80, the allowable coverages were computed using equation 5-l. The damage is computed as the ratio of design coverage n_i to the allowable coverage N_i, and is presented in column 8 of the table; the cumulative damage for design thicknesses of 6, 7, 8, and 10 inches is 58.6, 3.8, 0.2, and 0.0, respectively. A plot of these values indicates a required concrete thickness of 7.2 inches for a damage factor of one. This thickness value would be rounded off to 7.5 inches for design.

Table 7-1. Computed Design Coverages for Example 2.

Vehicle Type	Configuration	Load* kips	Operationa Per Lane, Per Day	Operations** Per Coverage	Coverage Per Lane, Per Day	Coverage† Per Lane, 25 Years
Passenger cars	Single axle, single wheels	1.5	2 x 2,000	9.59	417.1	3,806,037
Panel and pick-up truck	Single axle, single wheels	3.0	2 x 1,300	9.59	271.1	2,473,787
Truck 2-axle	Single axle, single wheels	9.0	150	6.25	24.0	219,000
	Single axle, dual wheels	18.0	150	2.64	56.8	518,300
Truck 3-axle	Single axle, single wheels	9.0	50	6.25	8.0	73,000
	Tandem axle, dual wheels	32.0	50	2.06	24.3	221,737

*Some loads are assumed values.
**Values are obtained from Table 5-1.
†Values are obtained by multiplying 25 x 365 to the value of coverages per lane per day.

Table 7-2. Compuations of Cumulative Damage for Example 2.

Axle Type (1)	Load kips (2)	Slab Thickness, in. (3)	Maximum Stress σ_{max} psi (4)	1.33* × σ_{max} psi (5)	Allowable** Coverage N_i (6)	Design Coverage n_i† (7)	Damage n_i/N_i (8)
Single-axle	1.5	6	35.6	47.35	Too large	3,806,037	0.0
single wheels	1.5	7	26.9	35.78	Too large	3,806,037	0.0
	1.5	8	21.2	28.20	Too large	3,806,037	0.0
	1.5	10	14.2	18.89	Too large	3,806,037	0.0
Single-axle	3.0	6	66.4	88.31	Too large	2,473,787	0.0
single wheels		7	51.5	68.50	Too large	2,473,787	0.0
		8	40.8	54.26	Too large	2,473,787	0.0
		10	27.7	36.84	Too large	2,473,787	0.0
Single-axle	9.0	6	169.0	224.77	2,845,700	21,900	0.01
single wheels		7	133.0	176.89	Too large	21,900	0.0
		8	108.0	143.64	Too large	21,900	0.0
		10	75.2	121.43	Too large	21,900	0.0
Single-axle	18.0	6	251.0	333.83	8,839	518,300	58.6
dual wheels		7	204.0	271.32	137,152	518,300	3.8
		8	170.0	226.10	2,564,720	518,300	0.2
		10	124.0	164.92	Too large	518,300	0.0
Tandem-axle	32.0	6	205.0	272.65	127,698	221,737	1.7
dual wheels		7	169.0	224.77	2,854,733	221,737	0.0
		8	144.0	191.52	Too large	221,737	0.0
		10	111.0	147.63	Too large	221,737	0.0

*1.33 is the factor to account for no-load transfer free edge stress conditions.
**Computed from equation 5-1.
†Values obtained from table 7-1.

e. Example No. 3.

(1) To illustrate the design procedure for tracked vehicles, it is assumed that a concrete pavement is to be designed for an average of 10 M1 tanks per lane per day. The Ml tank has the following characteristics:

Gross weight	120 kips
Track spacing (c to c)	112 inches
Track width	25 inches
Track contact width	18.75 inches (= 0.75 x 25)
Track length	180 inches
Number of bogies per track	7.0
Operations per coverage ratio	0.33 (from table 5-1)

(2) To use computer codes such as the JULEA computer program, the track load will be converted into eight uniformly distributed circular loads. Each circle has a diameter of 17.25 inches (the width of the track) and a load of 7,500 pounds. The distance between bogies is 20.4 inches center to center. The computed maximum stresses for several concrete thicknesses are tabulated in column 2 of table ‘7-3. The maximum stress in this case occurs under the center load. In other cases, the location of the maximum stress needs to be determined. This is done by computing stresses in many locations and selecting the maximum stress. Following the procedures in example 2, a plot of concrete thickness (column 1) against damage (column 6) shows that the design concrete thickness is 13.7 inches. This thickness value would be rounded off to 14.0 inches for design.

Table 7-3. Cumulative Damage Computed for M1 Tank.

Slab Thickness in. (1)	Maximum Stress σ_{max} (2)	1.33 x σ_{max} (3)	Allowable* Coverage N_i (4)	Design** Coverage n_i (5)	Damage n_i/N_i (6)
8	347	461.5	329	273,204	830
10	275	365.8	3,124	273,204	87
12	224	297.9	37,137	273,204	7.4
14	185	246.1	615,013	273,204	0.4

*SCI = 80, R = 625 psi.
**Design coverages for 25 years is 25 x 365 x 10/0.33 = 273,204.

f. Example No. 4. To illustrate the procedure for conventional traffic plus forklift trucks and tracked vehicles, design a concrete pavement road for the following traffic:

Passenger cars	300 per lane per day
Panel and pickup trucks	200 per lane per day
Trucks, 2-axle	100 per lane per day
Trucks, 3-axle	40 per lane per day
Track-laying vehicles, 120,000 pounds (Ml tank)	2 per lane per day
Forklift trucks, 25,000 pounds (Pneumatic tires)	20 per lane per day

Table 7-4 shows the design coverages for each wheel or track configuration, and table 7-5 shows the computed maximum stresses and damage. The cumulative damage for concrete thicknesses of 8, 10 and 12 inches is 34.2, 3.4 and 0.3, respectively. A plot of these values indicates a required concrete thickness of 11.2 inches for a damage of one. This thickness value would be rounded off to 11 inches for design.

7-6. Joints.

The design and construction of joints for plain and roller-compacted concrete, the design and installation of dowel bars, special provisions for slipform paving, and joint sealing are presented in TM 5-822-5/AFM 88-7, Chap. 3.

7-7. Design Details.

Typical details for the design and construction of plain concrete pavements are contained in TM 5-822-5/AFM 88-7, Chap. 3.

Table 7-4. Computed Design Coverages for Example 4.

Vehicle Type	Configuration	Loads* kips	Operations Per Lane, Per Day	Operations Per Coverage	Coverage Per Lane, Per Day	Coverage** Per Lane, 25 years
Passenger cars	Single-axle single wheels	1.5	2 x 300	9.59	63.0	574,875
Panel and pick-up truck	Single axle, single wheels	3.0	2 x 200	9.59	42.0	383,256
Truck **2-axle**	Single axle, single wheels	9.0	100	6.25	16.0	146,000
	Single axle, dual wheels	18.0	100	2.64	38.0	346,750
Truck **3-axle**	Single axle, single wheels	9.0	40	6.25	6.0	54,750
	Tandem axle, dual wheels	32.0	40	2.06	19.0	173,375
H-1 tank	Track	60.0	2	2.0	1.0	9,125
Forklift† truck	Single axle dual wheels	25.0	20	3.52	5.7	52,010

*Loads are assumed values.
**Coverages are obtained by multiplying 25 x 365 to coverages per lane per day.
†The forklift truck has single axle, dual wheels with wheel spacings of 11 inch by 52 inch by 11 inch. The tire contact area is 62.5 square inches.

Table 7-5. Computations of Cumulative Damage for Example 4.

Axle Type	Load kips	Slab Thickness in.	Maximum Stress σ_{max} psi	$1.33 \times \sigma_{max}$ psi	Allowable* Coverage N_i	Design** Coverage n_i	Damage n_i/N_i
Single axle single wheels	1.5	8	21.2	28.2	Too large	574,875	0.0
	1.5	10	14.2	18.9	Too large	574,875	0.0
	1.5	12	10.2	13.6	Too large	574,875	0.0
Single axle single wheels	3.0	8	40.8	54.3	Too large	383,250	0.0
		10	27.7	36.8	Too large	383,250	0.0
		12	20.1	26.7	Too large	383,250	0.0
Single axle single wheels	9.0	8	108.0	143.6	Too large	200,750†	0.0
		8	75.2	100.0	Too large	200,750	0.0
		12	55.6	74.0	Too large	200,750	0.0
Single axle dual wheels	18.0	8	168.0	223.4	3,171,527	346,750	0.11
		10	124.0	164.9	Too large	346,750	0.0
		12	95.3	126.7	Too large	346,750	0.0
Tandem axle dual wheels	32.0	8	144.0	191.5	61,348,000	173,375	0.0
		10	111.0	147.6	Too large	173,375	0.0
		12	89.6	119.1	Too large	173,375	0.0
M1 Tank	30.0 per track	8	353.0	469.5	284	9,125	32.2
		10	279.0	371.1	2,678	9,125	3.4
		12	227.0	301.9	31,122	9,125	0.3
Forklift truck	25.0	8	230.0	305.9	26,202	52,010	2.0
		10	169.0	224.8	2,845,729	52,010	0.0
		12	130.0	172.9	571,536,300	52,010	0.0

*SCI = 80, R = 675 psi.
**Values obtained from table 7-4.
†It is the sum of 146,000 and 54,750 from table 7-4.

CHAPTER 8

OVERLAY PAVEMENTS

8-1. General.

Normally, overlays of existing pavements are used to increase the load-carrying capacity of an existing pavement, or 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 in this chapter determines the thickness required to increase load-carrying capacity. These methods have been developed from a series of full-scale accelerated traffic tests on various types of overlays and is therefore empirical. These methods determine the required thickness of overlay that, when placed on the existing pavement, will be equivalent in performance to the required design thickness of a new plain concrete pavement placed on subgrade.

8-2. Definitions 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. Rigid base pavement. An existing rigid pavement on which an overlay is to be placed.

b. Flexible base pavement. Existing pavement to be overlaid is composed of bituminous concrete, base, and subbase courses.

c. Composite pavement. Existing pavement to be overlaid with rigid pavement is composed of an all-bituminous or flexible overlay on a rigid base pavement.

d. Overlay pavement. A pavement constructed on an existing base pavement to increase load-carrying capacity.

e. Rigid overlay. A rigid pavement used to strengthen an existing flexible or rigid pavement.

f. Flexible overlay. A flexible pavement (either all-bituminous or bituminous with base course> used to strengthen an existing rigid or flexible pavement.

8-3. Preparation of Existing Pavement.

Existing pavement is prepared according to procedures in TM 5-822-5/AFM 88-7, Chap. 3.

8-4. Rigid Overlay of Existing Rigid Pavement.

The concrete overlay thickness for roads and streets can be determined using overlay equations 8-1 to 8-3. The conditions for the use of the equations are described in TM 5-822-5/AFM 88-7, Chap. 3.

Fully bonded

$$h_o = h_d - h_E \qquad \text{(eq 8-1)}$$

Partially bonded

$$h_o = \sqrt[1.4]{h_d^{1.4} - C_r\left(\frac{h_d}{h_e} \times h_E\right)^{1.4}} \qquad \text{(eq 8-2)}$$

Nonbonded

$$h_o = \sqrt{h_d^{2} - C_r\left(\frac{h_d}{h_e} \times h_E\right)^{2}} \qquad \text{(eq 8-3)}$$

where

h_o = required thickness of concrete overlay, inches

h_E = thickness of existing concrete slab, or equivalent thickness of plain concrete pavement having the same load-carrying capacity as the existing pavement, inches

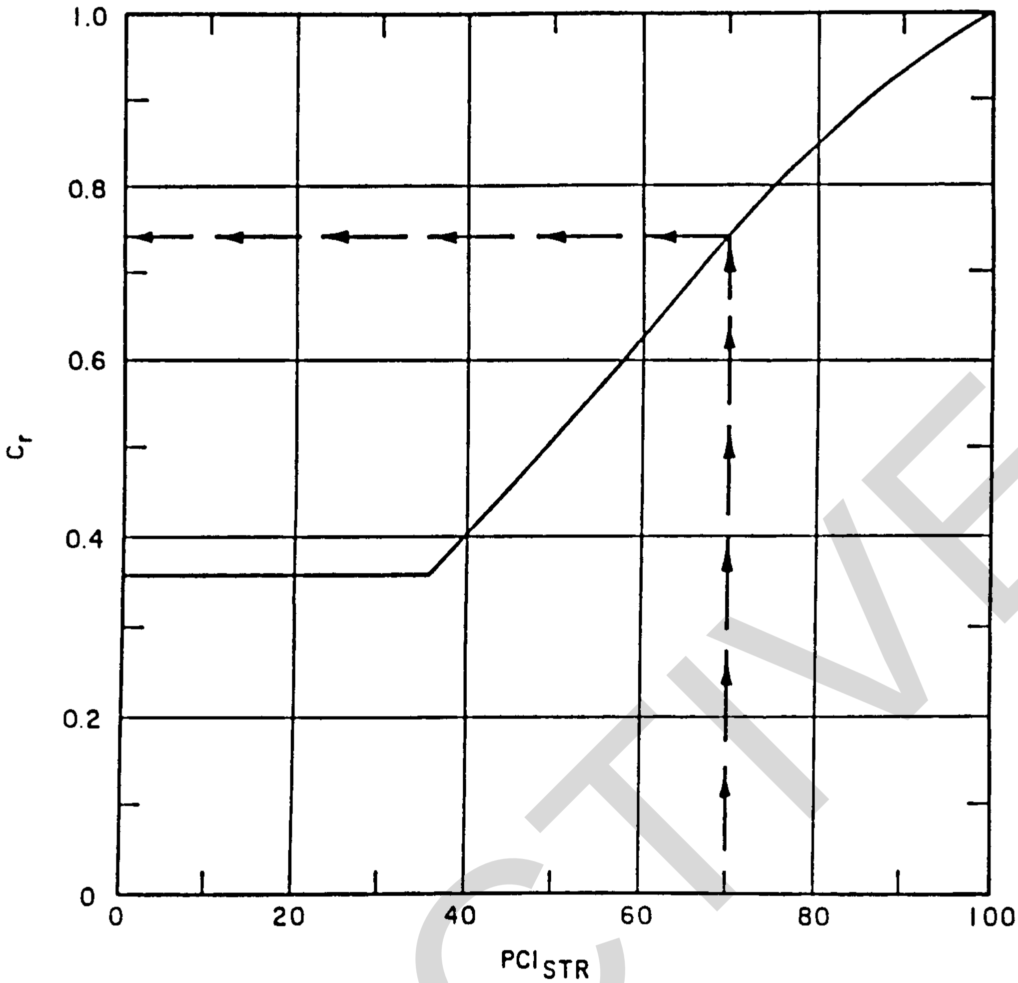

Figure 8-1. Chart for Determining C_r for Concrete Overlays.

h_d = required single slab thickness above existing subgrade determined using the elastic layered method with the design flexural strength of the overlay, inches

h_e = required single slab thickness above existing subgrade determined using the elastic layered method with the measured flexural strength of the existing rigid pavement, inches

C_r = condition factor for plain concrete pavement and reinforced concrete pavement

For plain concrete pavement, C_r is assigned according to the following conditions:

C_r = 1.00 - Pavements are in good condition with little or no structural cracking due to load.

C_r = 0.75 - Pavements exhibit initial cracking due to load but no progressive cracking or faulting of joints or cracks.

C_r = 0.35 - Pavements exhibit progressive cracking due to load accompanied by spalling, raveling, or faulting of cracks and joints.

For reinforced concrete pavement, C_r is assigned according to the following conditions:

C_r = 1.00 - Pavements are in good condition with little or no short-spaced transverse (1- to 2-foot) cracks, no longitudinal cracking, and little spalling or raveling along cracks.

C_r = 0.75 - Pavements exhibit short-spaced transverse cracking but little or no interconnecting longitudinal cracking due to load and only moderate spalling or raveling along cracks.

C_r = 0.35 - Pavements exhibit severe short-spaced transverse cracking and interconnecting longitudinal cracking due to load, severe spalling along cracks, and initial punchout type failures.

An estimate of condition factor C_r may also be made using the structural condition index (SCI) of the existing rigid pavement. The SCI is that part of the pavement condition index (PCI) related to structural distress types or deduct values. The relationship is shown in TM 5-623. If PCI condition survey data are available, C_r can be obtained from figure 8-1 using the structural PCI (PCI computed using only load related distresses).

8-5. Rigid Overlay of Flexible and Composite Base Pavements.

This type of design includes rigid overlay of either flexible or composite base pavements. The design procedure for these types of overlays are contained in TM 5-822-5/AFM 88-7, Chap. 3.

8-6. Flexible Overlay of Rigid Base Pavements.

The flexible overlay thickness for roads and streets can be determined using equation 8-4.

$$t_o = 3.0\ (Fh_d - C_b h_E) \qquad \text{(eq 8-4)}$$

where

t_o = required flexible overlay thickness, inches

F = a factor that projects the cracking expected to occur in the base pavement during the design life of the overlay

h_E, h_d = defined in equation 8-1 to 8-3

C_b = condition factor

Condition factors for existing plain concrete pavements are assigned based on the following conditions:

C_b = 1.00 - Pavements are in good condition with some cracking due to load but little or no progressive-type cracking.

C_b = 0.75 - Pavements exhibit progressive cracking due to load and spalling, raveling, and minor faulting at joints and cracks.

C_b = 0.50 - Pavements exhibit multiple cracking along with raveling, spalling, and faulting at joints and cracks.

Condition factors for existing reinforced concrete pavement are assigned based on the following conditions:

C_b = 1.00 - Pavements are in good condition but exhibit some closely spaced load-induced transverse cracking, initial interconnecting longitudinal cracks, and moderate spalling or raveling of joints and cracks.

C_b = 0.75 - Pavements in trafficked areas exhibit numerous closely spaced load-induced transverse and longitudinal cracks, rather severe spalling or raveling, or initial evidence of punchout failures.

The estimate of condition factor C for plain concrete pavement may be made from the SCI of the existing rigid pavement. The SCI is that part of the PCI related to structural distress types or deduct values. The relationship is shown in TM 5-825-3-1/AFM 88-6, Chap. 3, Section A. However, when determining C_b, the only distresses considered are those associated with structural loading. These include:

a. Longitudinal, transverse, and diagonal cracks of medium to high severity.

b. Corner breaks of any severity.

c. All large patches of load associated failures.

d. Pumping.

e. Settlement or faulting of any severity.

f. Shattered slabs of any severity.

g. Certain types of joint spalls believed to be load-associated.

If the PCI is calculated using only these structural distresses (SCI), C_b can be obtained from figure 8-2.

(1) The F-factor is a function of the foundation k value and design traffic, an is determined as follows.

(2) The modulus of subgrade reaction k may be estimated using the following relationship between subgrade modulus and static modulus of soil reaction or from table 4-2:

$$k = 10^x \qquad \text{(eq 8-5)}$$

where

$$X = \frac{\log_{10} E - 1.415}{1.284}$$

k = modulus of subgrade reaction, pci

E = subgrade modulus, psi

(2) If a base or subbase is present above the subgrade, an effective k is determined from figure 8-3.

(3) The F-factor is then obtained from figure 8-4.

8-7. Flexible Overlay of Flexible Pavements.

The flexible overlay thickness above a flexible pavement is the difference between the existing pavement thickness and a new pavement thickness determined using the layered elastic procedure and the modulus value of the existing subgrade. For instance, if the existing flexible pavement is 16 inches (i.e., 4-inch bituminous concrete, 6-inch base, and 6-inch subbase) and the new pavement thickness is determined by the layered elastic method to be 19 inches, the flexible overlay thickness will be 3 inches.

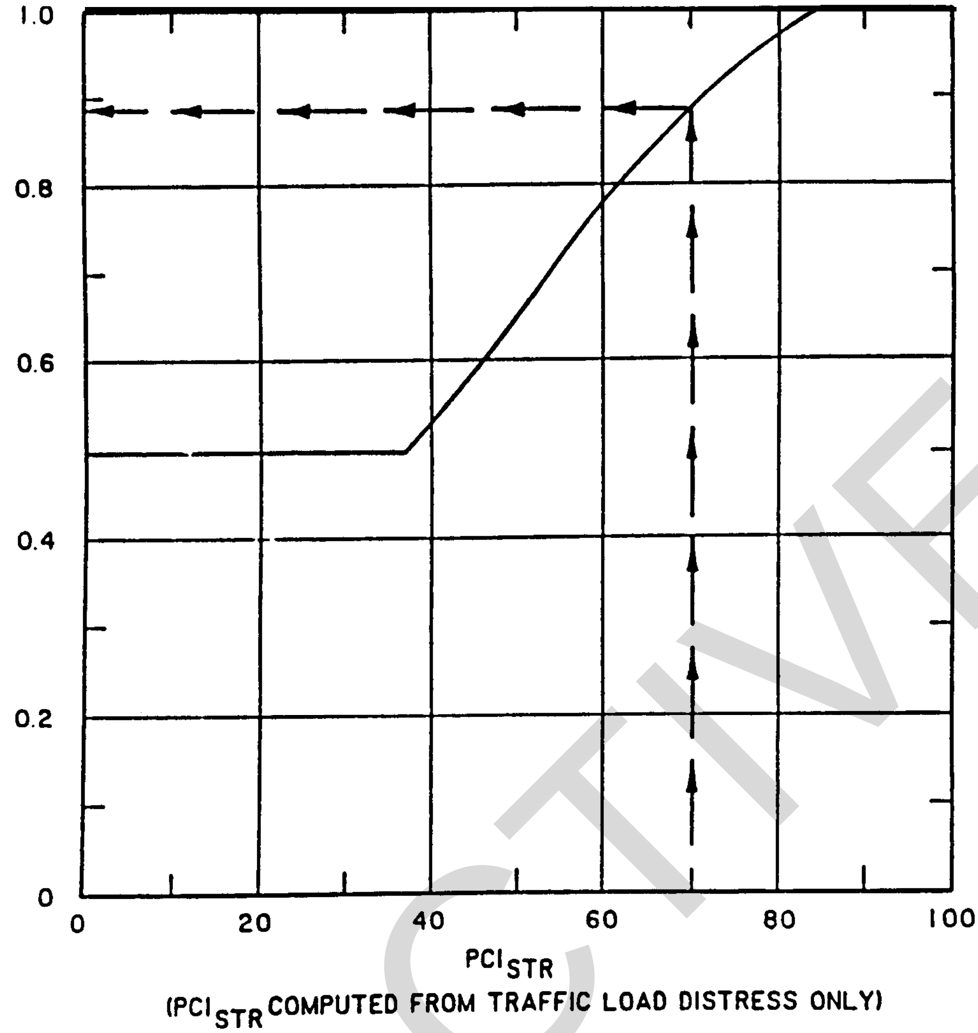

Figure 8-2. Chart for Determining C_b for Flexible Overlays.

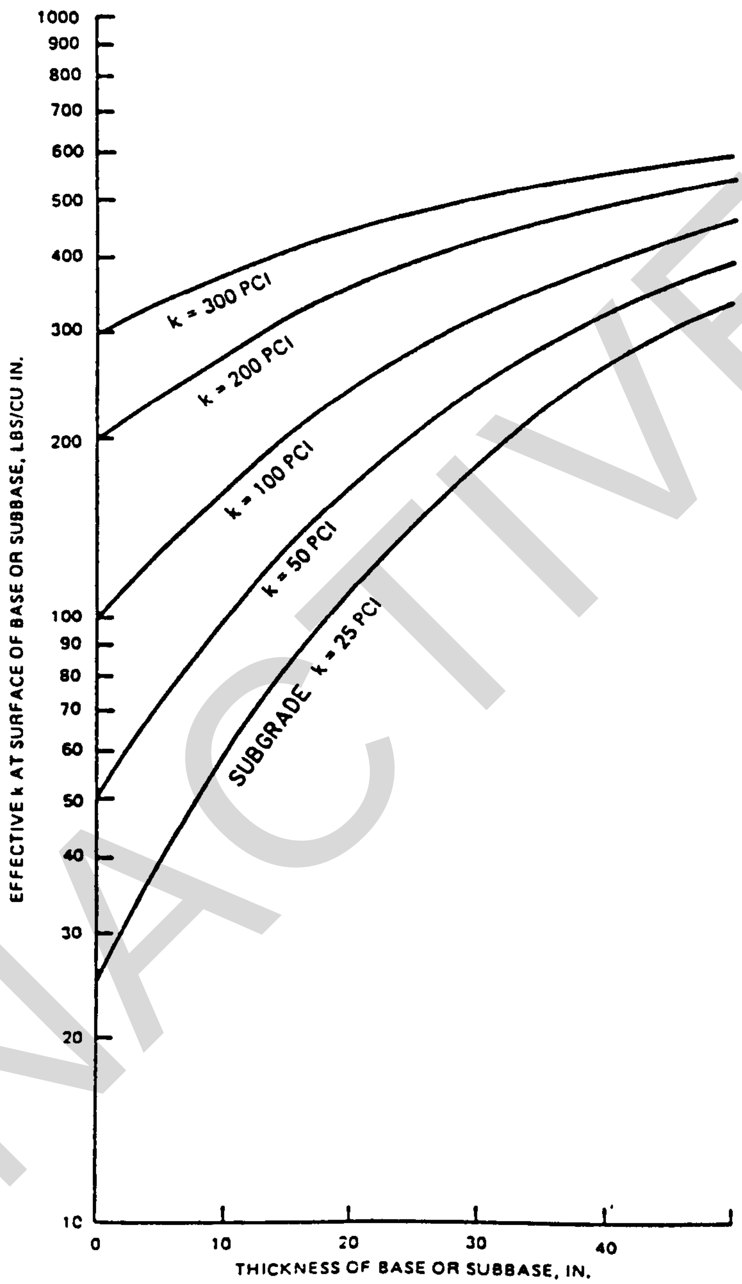

Figure 8-3. Determination of Effective k Value on Top of Base Course.

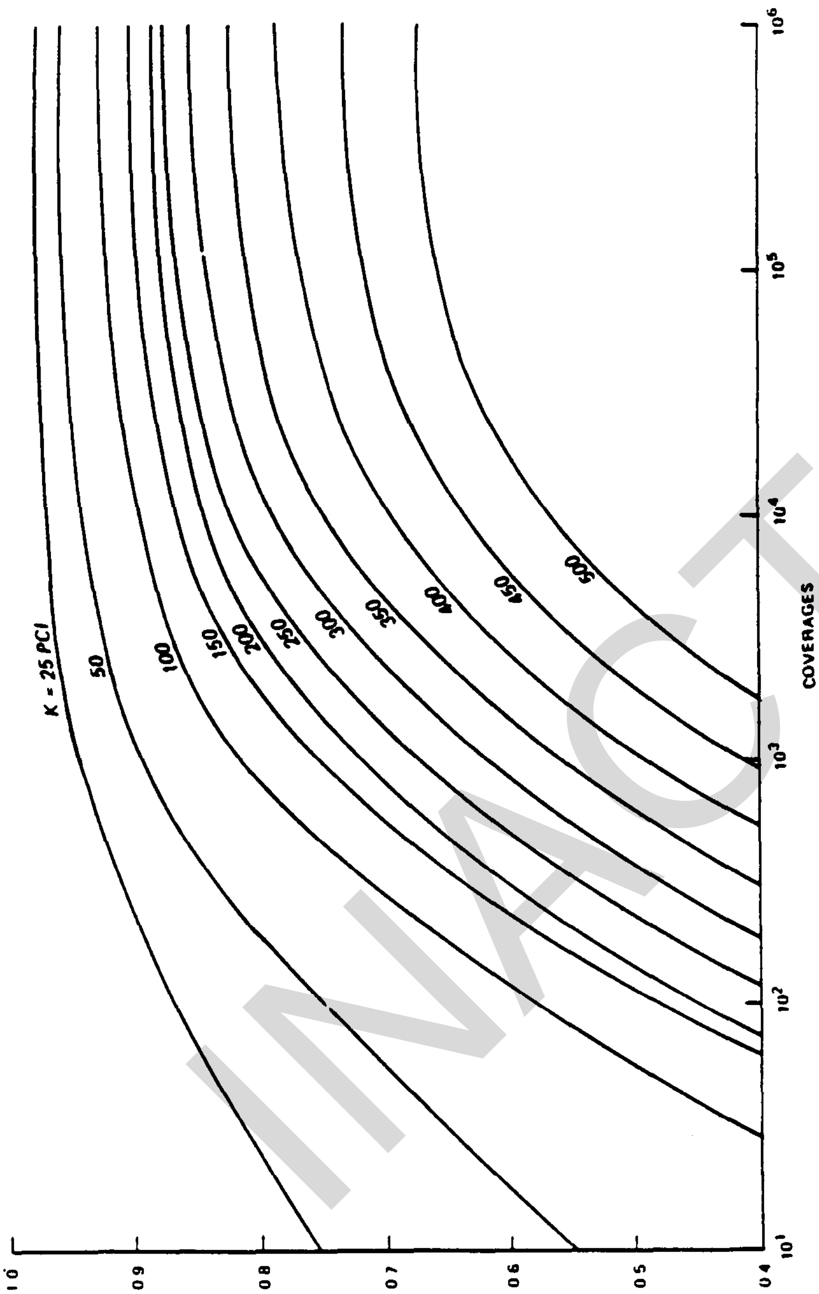

Figure 8-4. Chart for Determining F-Factor for Flexible Overlays.

APPENDIX A
REFERENCES

Government Publications

Departments of the Army and Air Force

TM 5-623	Pavement Maintenance Management
TM 5-822-2/AFM 88-7, Chap. 5	General Provisions and Geometric Design for Roads, Streets, Walks and Open Storage Areas
TM 5-822-5/AFM 88-7, Chap. 3	Pavement Design for Roads, Streets, Walks, and Open Storage Areas
TM 5-822-7/AFM 88-6, Chap. 8	Standard Practice for Concrete Pavements
TM 5-822-14/AFJMAN 32-1018	Soil Stabilization for Pavements
TM 5-825-2-1/AFM 88-6, Chap. 2, Section A	Flexible Pavement Design for Airfields, Elastic Layered Method
TM 5-825-3-1/AFM 88-6, Chap. 3, Section A	Rigid Pavement Design for Airfields, Elastic Layered Method
TM 5-826-5/AFP 88-24, Chap. 5	Nondestructive Procedures for Airfield Pavement Evaluation

Nongovernment Publications

American Society for Testing and Materials (ASTM) Specifications: 1961 Race Street, Philadelphia, PA 19103

D 3202-83	Recommended Practice for Preparation of Bituminous Mixture Beam Specimens by Means of the California Kneading Compaction
C 78-84	Flexural Strength of Concrete (Using Single Beam with Third-Point Loading)

APPENDIX B

PROCEDURE FOR DETERMINING THE MODULUS OF ELASTICITY OF UNBOUND GRANULAR BASE AND SUBBASE COURSE MATERIALS

B-l. Procedure.

a. The procedure is based on relationships developed for the resilient modulus of unbound granular layers as a function of the thickness of the layer and type of material. The modulus relationships are shown in figure B-l. Modulus values for layer n (the upper layer) are indicated on the ordinate, and those for layer n + 1 (the lower layer) are indicated on the abscissa. Essentially linear relationships are indicated for various thicknesses of base and subbase course materials. For subbase courses, relationships are shown for thicknesses of 4,5,6,7, and 8 inches. For subbase courses having a design thickness of 8 inches or less, the applicable curve or appropriate interpolation can be used directly. For a design subbase course thickness in excess of 8 inches, the layer should be divided into sublayers of approximately equal thickness and the modulus of each sublayer determined individually. For base courses, relationships are shown for thicknesses of 4, 6, and 10 inches. These relationships can be used directly or by interpolation for design base course thicknesses up to 10 inches. For design thicknesses in excess of 10 inches, the layer should also be divided into sublayers of approximately equal thickness and the modulus of each sublayer determined individually.

b. To determine modulus values from this procedure, figure B-l is entered along the abscissa using modulus values of the subgrade or underlying layer (modulus of layer n + 1). At the intersection with the curve applicable to this value with the appropriate thickness relationship, the value of the modulus of the overlying layer is read from the ordinate (modulus of layer n). This procedure is repeated using the modulus value just determined as the modulus of layer n + 1 to determine the modulus value of the next overlying layer.

B-2. Examples.

ct. Assume a pavement having a base course thickness of 4 inches and a subbase course thickness of 8 inches over a subgrade having a modulus of 10,000 psi. Initially, the subgrade is assumed to be layer n + 1 and the subbase course to be layer n. Entering figure B-l with a modulus of layer n + 1 of 10,000 psi and using the 8-inch subbase course curve, the modulus of the subbase (layer n) is found to be 18,500 psi. In order to determine the modulus value of the base course, the subbase course is now assumed to be layer n + 1 and the base course to be layer n. Entering figure B-l with a modulus value of layer n + 1 of 18,500 psi and using the 4-inch base course relationship, the modulus of the base course is found to be 36,000 psi.

b. If, in the first example, the design thickness of the subbase course had been 12 inches, it would have been necessary to divide this layer into two 6-inch-thick sublayers. Then, using the procedure described above for the second example, the modulus values determined for the lower and upper sublayers of the subbase course and for the base course are 17,500, 25,500, and 44,000 psi, respectively.

c. The relationships indicated in figure B-l can be expressed as follows for base course materials:

$$E_n = E_{n+1} (1 + 10.52 \log t - 2.10 \log E_{n+1} \log t)$$

where

n = a layer in the pavement system

E_n = resilient modulus (in psi) of layer n

E_{n+1} = the resilient modulus (in psi) of the layer beneath

t = the thickness (in psi) of layer n

The relationship can be expressed as follows for subbase course materials:

$$E_n = E_{n+1} (1 + 7.18 \log t - 1.56 \log E_{n+1} \log t)$$

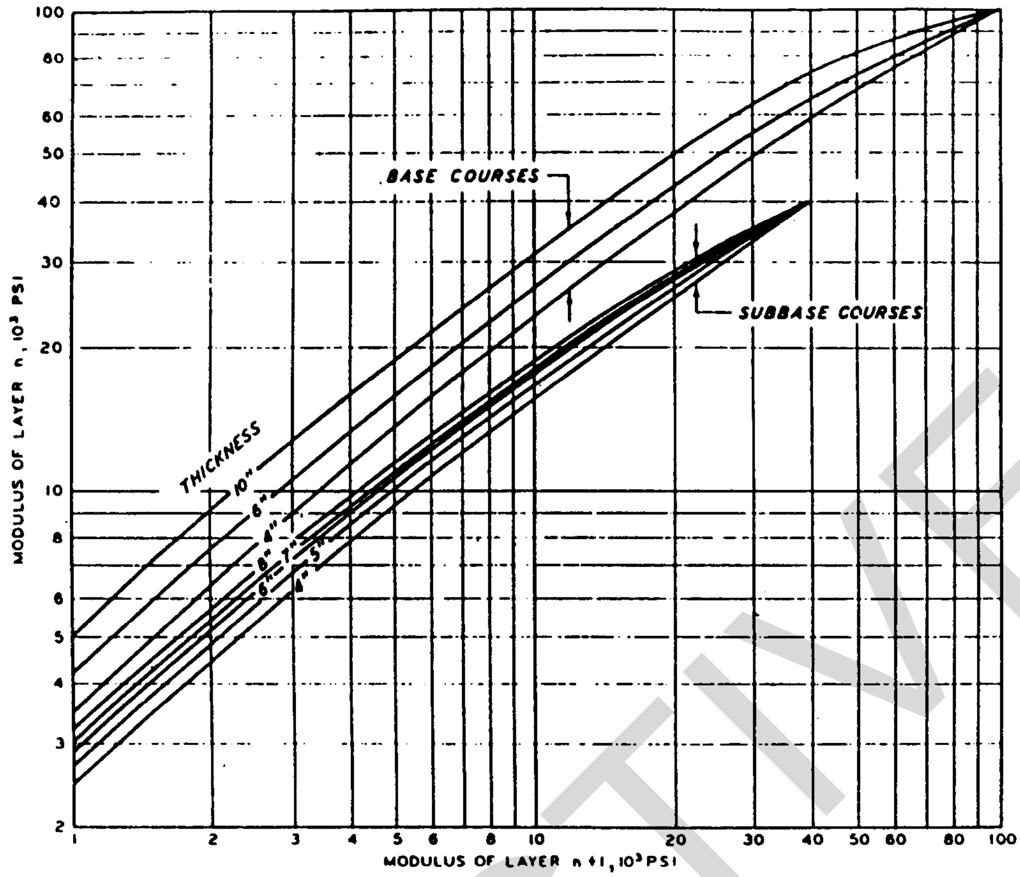

Figure B-1. Relationships Between Modulus of Layer n and Modulus of Layer n + 1 for Various Thicknesses of Unbound Base Course and Subbase Course.

APPENDIX C

PROCEDURES FOR DETERMINING THE FATIGUE LIFE OF BITUMINOUS CONCRETE

C-l. laboratory Test Method.

a. *General.* A laboratory procedure for determining the fatigue life of bituminous concrete paving mixtures containing aggregate with maximum sizes up to 1½ inches is described in this appendix. The fatigue life of a simply supported beam specimen subjected to third-point loadings applied during controlled stress-mode flexural fatigue tests is determined.

b. *Definitions.* The following symbols are used in the description of this procedure:

(1) ϵ = initial extreme fiber strain (tensile and compressive), inches per inch.

(2) N_f = fatigue life of specimen, number of load repetitions to fracture.

Extreme fiber strain of simply supported beam specimens subjected to third-point loadings, which produces uniaxial bending stresses, is calculated from

$$\epsilon = \frac{12td}{(3L^2 - 4a^2)}$$

where

t = specimen depth, inches
d = dynamic deflection of beam center, inches
L = reaction span length, inches
a = L/3, inches

c. *Test equipment.*

(1) The repeated flexure apparatus is shown in figure C-l. It accommodates beam specimens 15 inches long with widths and depths not exceeding 3 inches. A 3,000-pound-capacity electrohydraulic testing machine capable of applying repeated tension-compression loads in the form of haversine waves for 0.1-second durations with 0.4-second rest periods is used for flexural fatigue tests. Any dynamic testing machine or pneumatic pressure system with similar loading capabilities is also suitable. Third-point loading, i.e., loads applied at distances of L/3 from the reaction points, produces an approximately constant bending moment over the center 4 inches of a 15 inch-long beam specimen with widths and depths not exceeding 3 inches. A sufficient load, approximately 10 percent of the load deflecting the beam upward, is applied in the opposite direction, forcing the beam to return to its original horizontal position and holding it at that position during the rest period. Adjustable stop nuts installed on the flexure apparatus loading rod present the beam from bending below the initial horizontal position during the rest period.

(2) The dynamic deflection of the beam's center is measured with a Linear Variable Differential Transformer (LVDT). An LVDT that has been found suitable for this purpose is the Sheavitz type 100 M-L. The LVDT core is attached to a nut bonded with epoxy cement to the center of the specimen. Outputs of the LVDT and the electrohydraulic testing machine's load cell, through which loads are applied and controlled, can be fed to any suitable recorder. The repeated flexure apparatus is enclosed in a controlled-temperature cabinet capable of controlling temperatures within ± ½ degree F. A Missimer's model 100 x 500 carbon dioxide plug-in temperature conditioner has been found to provide suitable temperature control.

d. *Specimen preparation.* Beam specimens 15 inches long with 3½-inch depths and 3¼-inch widths are prepared according to ASTM D 3202. If there is undue movement of the mixture under the compactor foot during beam compaction, the temperature, foot pressure, and number of tamping blows should be reduced. Similar modifications to compaction procedures should be made if specimens with less density are desired. A diamond-blade masonry saw is used to cut 3-inch or slightly less deep by 3-inch or slightly less wide test specimens from the 15-inch-long beams. Specimens with suitable dimensions can also be cut from pavement samples. The widths and depths of the specimens are measured to the nearest 0.01 inch at the center and at 2 inches from both sides of the center. Mean values are determined and used for subsequent calculations.

e. *Test procedures.*

(1) Repeated flexure apparatus loading clamps are adjusted to the same level as the reaction clamps. The specimen is clamped in the fixture using a jig to position the centers of the two loading clamps 2 inches from the

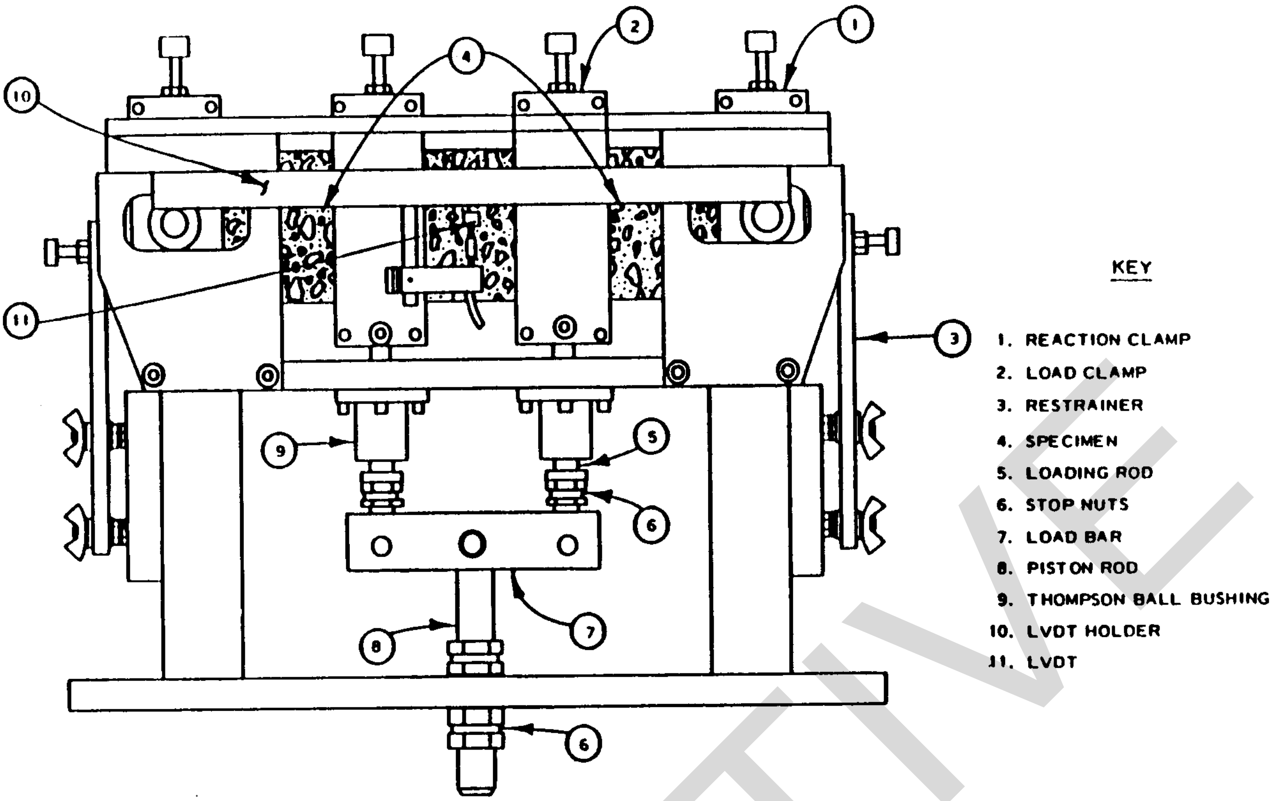

Figure C-l. Repeated Flexure Apparatus.

beam center and to position the centers of the two reactions clamps 6½ inches from the beam center. Double layers of Teflon sheets are placed between the specimen and the loading clamps to reduce friction and longitudinal restraint caused by the clamps.

(2) After the beam has reached the desired test temperature, repeated loads are applied. Duration of a load repetition is 0.1 second with 0.4-second rest periods between loads. The applied load should be that which produces an extreme fiber stress level suitable for flexural fatigue tests. For fatigue tests on typical bituminous concrete paving mixtures, the following ranges of extreme fiber stress levels are suggested:

Temperature, degrees F.	Stress Level Range, psi
55	150 to 450
70	75 to 300
85	35 to 200

The beam center point deflection and applied dynamic load are measured immediately after 200 load repetitions for calculation of extreme fiber strain ϵ. The test is continued at the constant stress level until the specimen fractures. The apparatus and procedures described have been found suitable for flexural fatigue tests at temperatures ranging from 40 to 100 degrees F. and for extreme fiber stress levels up to 450 psi. Extreme fiber stress levels for flexural fatigue tests at any temperature should not exceed that which causes specimen fracture before at least 1,000 load repetitions are applied.

(3) A set of 8 to 12 fatigue tests should be run for each temperature to adequately describe the relationship between extreme fiber strain and the number of load repetitions to fracture. The extreme fiber stress should be varied such that the resulting number of load repetitions to fracture ranges from 1,000 to 1,000,000.

f. Report and presentation of *results.* The report of flexural fatigue test results should include the following:

(1) Density of test specimens.
(2) Number of load repetitions to fracture, N,.
(3) Specimen temperature.
(4) Extreme fiber stress, σ.

The flexural fatigue relationship is plotted in figure C-2.

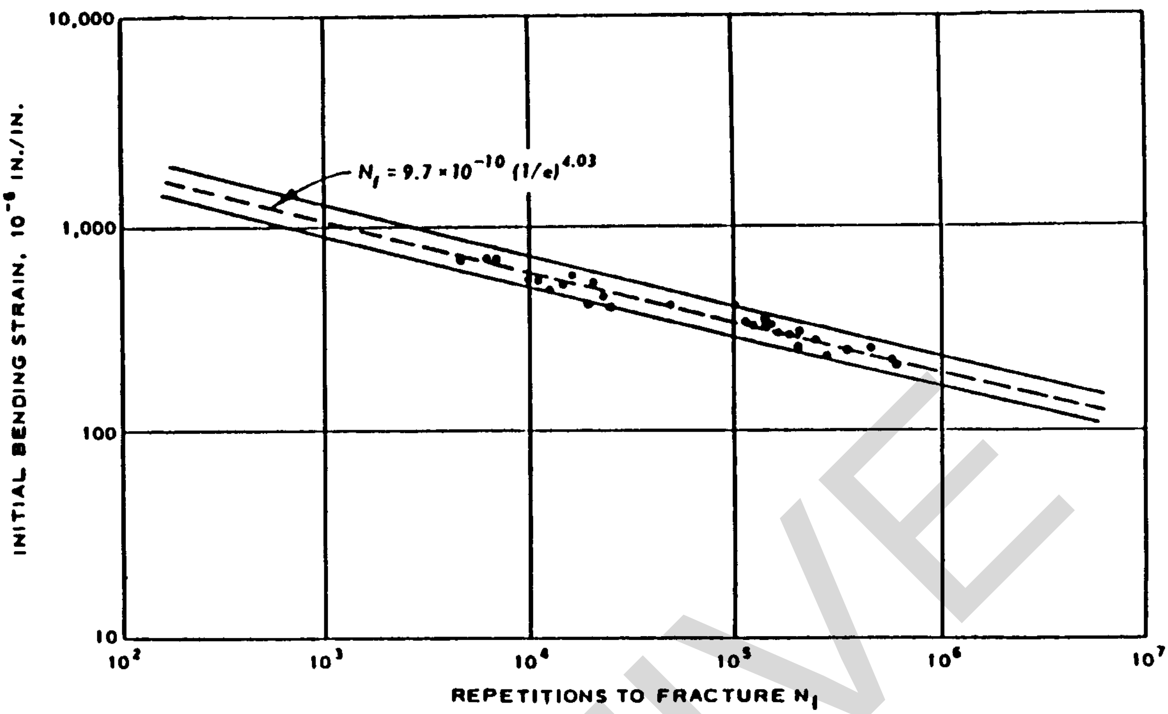

Figure C-2. Initial Mixture Bending Strain Versus Repetitions to Fracture in Controlled Stress Tests.

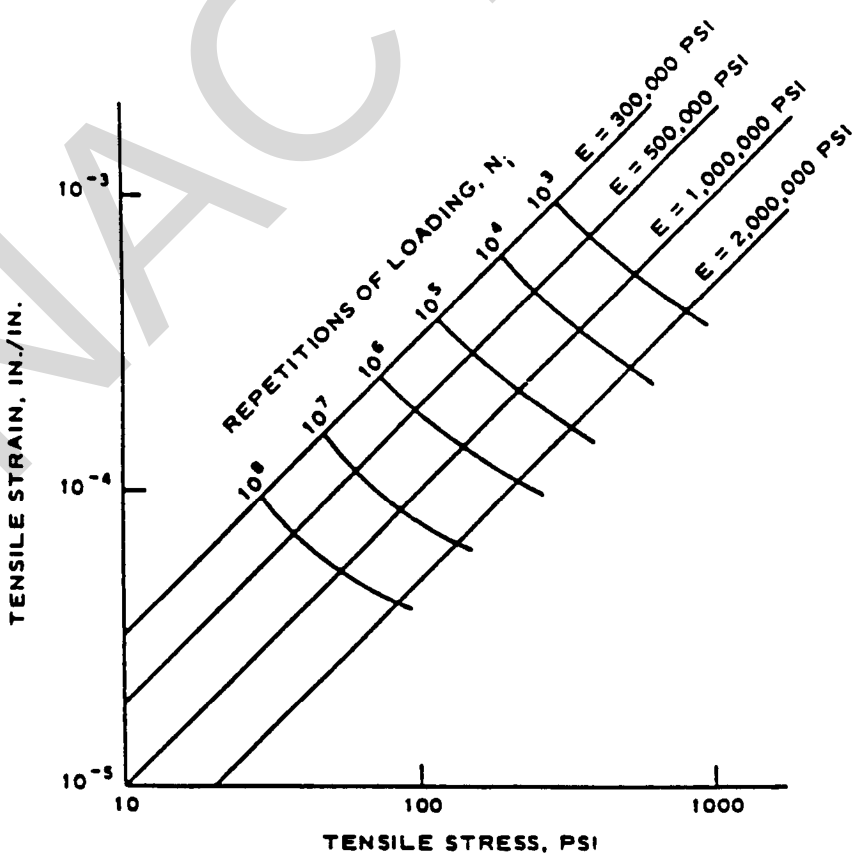

Figure C-3. Provisional Fatigue Data for Bituminous Base Course Materials.

C-2. Provisional Fatigue Data for Bituminous Concrete.

Use of the graph shown in figure C-3 to determine a limiting strain value for bituminous concrete involves first determining a value for the elastic modulus of the bituminous concrete. Using this value and the design pavement service life in terms of load repetitions, the limiting tensile strain in the bituminous concrete can be read from the ordinate of the graph.

APPENDIX D

COMPUTER AIDED SIGN FOR PAVEMENT DESIGN FOR ROADS, STREETS, AND OPEN STORAGE AREAS, ELASTIC LAYERED METHODS

Computer aided programs for Pavement Design for Roads, Streets and Open Storage Areas, Elastic Layered Methods, LEDROADS Version 1.0 are located in the tools area on CCB.

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