PDHonline Course C135 (6 PDH)

Pavement Design

Instructor: John C. Huang, Ph.D., PE

2012

PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone & Fax: 703-988-0088
www.PDHonline.org
www.PDHcenter.com

An Approved Continuing Education Provider

```
+)))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))),
* CCB Application Notes:                                               *
*                                                                      *
* 1. Character(s) preceded & followed by these symbols (. -) or (+ ,)  *
*    are super- or subscripted, respectively.                          *
*    EXAMPLES:  42m.3-  =  42 cubic meters                             *
*               CO+2,   =  carbon dioxide                              *
*                                                                      *
* 2. All degree symbols have been replaced with the word deg.          *
*                                                                      *
* 3. All plus or minus symbols have been replaced with the symbol +/-. *
*                                                                      *
* 4. All table note letters and numbers have been enclosed in square   *
*    brackets in both the table and below the table.                   *
*                                                                      *
* 5. Whenever possible, mathematical symbols have been replaced with   *
*    their proper name and enclosed in square brackets.                *
.))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))-
```

DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
200 Stovall Street
Alexandria, VA 22332-2300

APPROVED FOR RELEASE

NAVFAC DM-5.4

CIVIL ENGINEERING

PAVEMENTS

DESIGN MANUAL 5.4
OCTOBER 1979

DISTRIBUTION

DISTRIBUTION: (1 copy each unless otherwise specified)
SNDL 21A3; 23Al (COMNAVFORAZORES only); 24J1; 27G; 39B; 39C1; 39D1; 39D2; 39E1; 39E2; 42A3; 45B; 45Q (First FSSG only); 51A; 51B1; 51B3; B1 (SECDEF only); B2 (JCS, NSA, DLA, and DNA only); B3 (AFSC only); B5 (USCG only); C37D (Port Hueneme only); E3A (Washington and Oakland only); FA6 (Bermuda, Brunswick, Cecil Field, Key West, Jacksonville, Virginia Beach only); FA7 (Guantanamo, Keflavik, Mayport, Roosevelt Roads only); FA10; FA18; FA23 (Antigua, Brawdy, Buxton, Eleuthera, Lewes, Turks Island only); FA25; FA32; FB6; FB7 (Alameda, Barbers Point, Fallon, Lemoore, Oak Harbor, Miramar, North Island, Moffet Field only); FB10 (Adak only); FB21; FB31 (Guam only); FB34; FB36 (Big Sur, Coos Head, Ferndale, and Pacific Beach only); FB41, FC3 (London only); FC4 (Sigonella only); FC5; FC7; FC12; FD2; FE2; FE4 (Edzell, Galeta Island, Homestead, Winter Harbor, Sabana Seca, and (Edzell, Galeta Island, Hometead, Winter Harbor, Sabana Seca, and Sonoma only); FF1 (Washington only); FF5; FF6; FF19 (Brooklyn, Long Beach, New Orleans, and Seattle only); FG2 (Balboa, Diego Garcia, Harold Holt, Nea Makri, Stockton, and Ponce only); FG3 (Cheltenham and East Machia only); FG6 (Wahiawa, and Norfolk only); FH3 (Beaufort only); FH6 (Bethesda only); FH8 (Cairo only); FH25 (Philadelphia, Portsmouth, VA, Camp Lejeune, Oakland, Newport, Great Lake., and Long Beach only); FKA6A1, FKA6A2; FKA6A3A; FKA6A3B; FKA6A9; FKA6A12; FKA6A15 (Code LA 151); FKA6A16; FKM8; FKM9; FKM12; FKM13; FKM15 (Philadelphia only); FKN1 (Wet and Lant only (85 copies each)); FKN1 (South and North only (50 copies each); FKN1 (Pac and Che only (25 copies each)); FKN1 (Che, FPO-1 only); FKN2; FKN3 (6 copies each); FKN5; FKN8; FKN10; FKP1B (less Concord); FKP1B (Concord only - 3 copies); FKP1J; FKP1M; FKP3A; FKP7; FKP8; FKP11; FKQ3; FKR1A; FKR1B (2 copies); FKR2A (Dallas only); FKR3A; FKR3H; FKR4B; FKR5; FKR7E (3 copies); FR3; FR4; FT1; FT2; FT5; FT6; FT13; FT18; FT19 (San Diego only); FT22; FT27 (Idaho Falls only); FT28; FT31; FT37; FT55; FT64; FT73; FT74A (Colorado, MIT, and Texas only); FT74B (California, Illinois, Rensselaer, Georgia Tech, and Tulane only); FT78; V2; V3; V5; V8; V12; V14; V15; V16 (less Camp Smith); V17; V23 (Albany only)

Copy to: (1 copy each unless otherwise specified)
SNDL 21A; A2A (ONR only); A3; A4A; A5; A6 (Code LFF); C7 (Brazil and Chile only); FD1; FE1; FG1; FKA1A; FKA1B (2 copies); FKA1C (Code 043 - 50 copies); FKA1F; FKN2 (Port Hueneme (Code 156) only); FR1

Additional copies are available from:

Commanding Officer
Naval Publications and Forms Center
5801 Tabor Avenue
Philadelphia, PA 19120

ABSTRACT

Design criteria for use by qualified engineers are presented for the design of pavements and supporting materials for roads, parking areas, and walks. The contents include procedures for conducting preliminary site reconnaissance, soil investigations, and traffic analyses, and criteria for the design of subgrade, subbase, and base courses, flexible and rigid pavements, low-cost roads, and sidewalks.

FOREWORD

This design manual is one of a series developed from an evaluation of facilities in the shore establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command (NAVFACENGCOM), other Government agencies, and the private sector. This manual uses, to the maximum extent feasible, national professional society, association, and institute standards in accordance with NAVFACENGCOM policy. Deviations from these criteria should not be made without prior approval of NAVFACENGCOM HQ (Code 04).

Design cannot remain static any more than can the naval functions it sends or the technologies it uses. Accordingly, recommendations for improvement are encouraged from within the Navy and from the private sector and should be furnished to NAVFACENGCOM HQ, Code 04. As the design manuals are revised they are being restructured. A chapter or a combination of chapters will be issued as a separate design manual for ready reference to specific criteria.

This publication is certified as an official publication of the Naval Facilities Engineering Command and has been reviewed and approved in accordance with SECNAVINST 5600.16.

D. G. ISELIN
Rear Admiral, CEC, U.S. Navy
Commander
Naval Facilities Engineering Command

CONTENTS

FIGURES

TABLES

Section 1. INTRODUCTION

1. SCOPE. This manual presents criteria for the design of pavements and supporting materials for roads, parking areas, and walks. For design criteria for soil mechanics problems associated with pavement design (such as consolidation and stability of compressible or weak subsoils underlying fills, and soil compaction procedures), see Soil Mechanics, Foundations, and Earth Structures, NAVFAC DM-7. For additional criteria on traffic speeds, use classification and loads, geometry, and related factors applicable to roads and parking areas; see General Provisions and Geometric Design for Roads, Streets, Walks, and Open Storage Areas, NAVFAC DM-5.5. Pavement design criteria given in this manual should be supplemented or modified by local state highway department practices, where investigation has shown that they are adequate and economical or are required for local conditions.

2. RELATED CRITERIA. Criteria for the design of some features related to pavements are delineated in this and other manuals in the design manuals series, as cited below:

Subject	Source
Structural Engineering	NAVFAC DM-2
Bridge pavement	
Hydrology and Hydraulics	NAVFACDM-5.2
Surface drainage	
Subsurface drainage	
Drainage Systems	NAVFACDM-5.3
Surface drainage	
Subsurface drainage	
Soil Mechanics, Foundations, and Earth Structures.	NAVFAC DM-7
Soil exploration, identification, and testing	
Subsurface drainage	
Airfield Pavements	NAVFAC DM-21
Airfield pavements	
Subsurface drainage	

3. CANCELLATION. This manual, Pavements, NAVFAC DM-5.4, cancels and supersedes Chapter 4, Civil Engineering, NAVFAC DM-5, of April 1974.

4. PAVEMENT TYPES. Both rigid and flexible pavements are satisfactory for roads, streets, and parking areas.

a. Rigid Pavements. Rigid pavements are constructed of a portland cement concrete surfacing and usually include a granular base course. Rigid pavements are resistant to petroleum products and should be used in vehicle fueling and service areas. Consider using rigid pavements in areas designated for motorcycle parking where high unit loads on kickstands may distort flexible pavement in hot weather.

b. Flexible Pavements. The term flexible pavement refers to all pavement types having a bituminous surface. For most types of road construction, flexible pavement is preferred due to lower initial cost. Flexible-type pavements are more readily adaptable to stage construction and may also be more suitable where settlements are expected.

5. **PAVEMENTS COMPONENTS.**

a. Rigid Pavements. Rigid pavements are usually composed of a concrete surfacing and granular base on a prepared subgrade. For most types of road construction, the surfacing is unreinforced. The base course is composed of select granular material or granular material stabilized with cement, bitumen, or lime. In some cases, when constructing rigid pavements on high quality subgrades, the base may not be required.

b. Flexible Pavement. See Figure 1 for a description of flexible pavement components. The three primary components are the surface, base, and subbase.

(1) Surface. For most roads and streets, the surface is composed of hot-mixed asphalt concrete. A guide to the use of other types of bituminous surfacings is given in Table 1.

(2) Base. Base is high quality granular or stabilized material able to withstand high stresses. The base is a major load carrying component of a flexible pavement.

(3) Subbase. Subbase is a lower quality granular material having certain requirements. The subbase is placed on the subgrade and is intended to further reduce the stresses transmitted to the subgrade. Where a good quality granular subgrade exists, or where anticipated loading is light, the subbase may often be omitted.

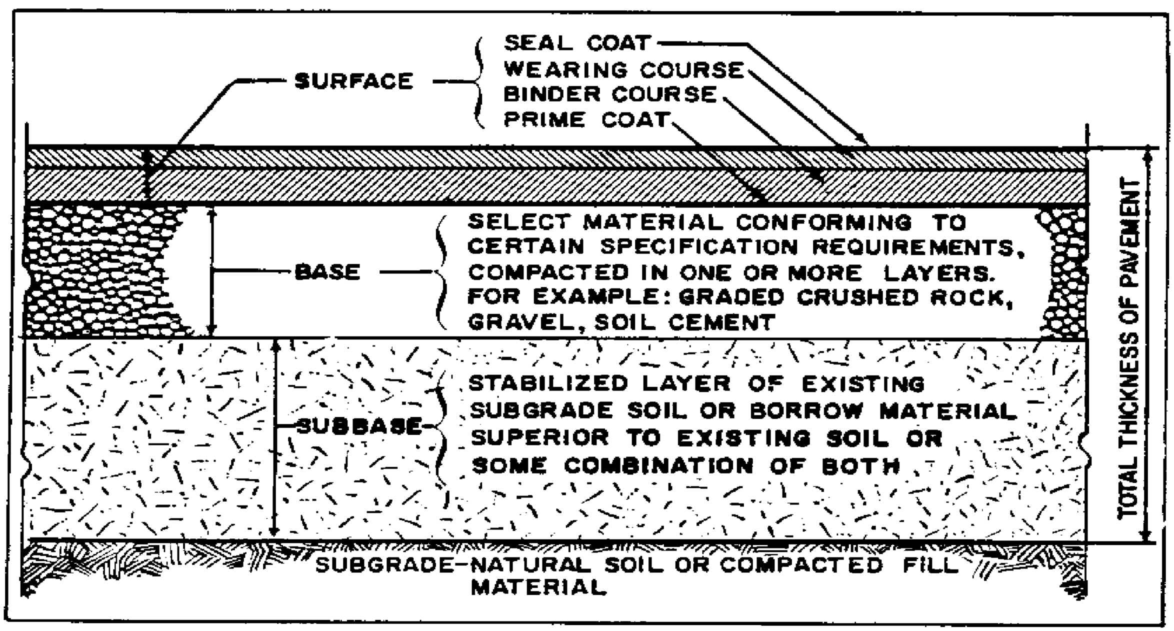


FIGURE 1
Flexible Pavement Terminology

TABLE 1
Types of Bituminous Surfaces

Description	Parking lots	Primary roads	Secondary roads	Tertiary roads
	Suitable Surfaces			
Hot-mix asphalt concretes	Yes	Yes	Yes	Yes
Cold-Mix bituminous mixes mixed in place..............................	No	No	Yes	Yes
Sand asphalt........................	Yes	No	Yes	Yes
Bituminous surface treatment........	Yes	No	No	Yes
Penetration macadam.................	Yes	No	Yes	Yes

Section 2. SOIL EXPLORATION AND SUBGRADE TESTING

1. PRELIMINARY INVESTIGATIONS. Preliminary site reconnaissance and soil investigations include the use of soils and geologic maps, aerial photographs, and geophysical exploration to ascertain the general soil conditions. See NAVFAC DM-7 for a complete description of techniques and procedures for preliminary surveys.

2. EXPLORATORY BORINGS. Use appropriate auger and split tube sampling to determine subsurface soil types and to develop soil profiles.

a. Spacing of Borings. The maximum spacing of borings along the centerlines of proposed roads should be 300 feet. In areas of widely varying soil types, a spacing of 100 feet or less may be required. Locate additional borings in areas where abrupt changes in profile occur.

b. Depth of Borings. Borings should be deep enough to develop soil profiles which are representative of the local soil conditions. As a general guide, for most sections of roadway, the following minimum depths should be used:

(1) Cut Sections. To 6 feet below finished grade.

(2) Shallow Fill Sections. In shallow fill sections where the weight of the fill is small compared with traffic loads, conduct borings to a minimum depth of 6 feet below existing grade.

(3) Other. Deeper borings are required wherever structures are located, in high fill areas, and where soft compressible soils are encountered. For guidance on proper boring depth, see NAVFAC DM-7.

3. SOIL CLASSIFICATION. Classify all soils using the Unified Soil Classification System according to Military Standard (MIL-STD) 619. The engineering characteristics of soils classified by the Unified Method are given in Table 2.

4. SOIL PROFILES. Plot soil profiles from the data obtained in the exploration program. A typical soil profile is shown as Figure 2. The soil profile should indicate the soil classification, moisture contents, blow counts (where applicable), Atterburg Limits, in-place density, and ground water levels. Examine the completed profiles to determine:

a. Location of grade lines.
b. Existence of unsuitable soils which may require excavation.
c. Soils in cut which are suitable as fill.
d. Location of ground water levels and potential compaction and drainage problems.

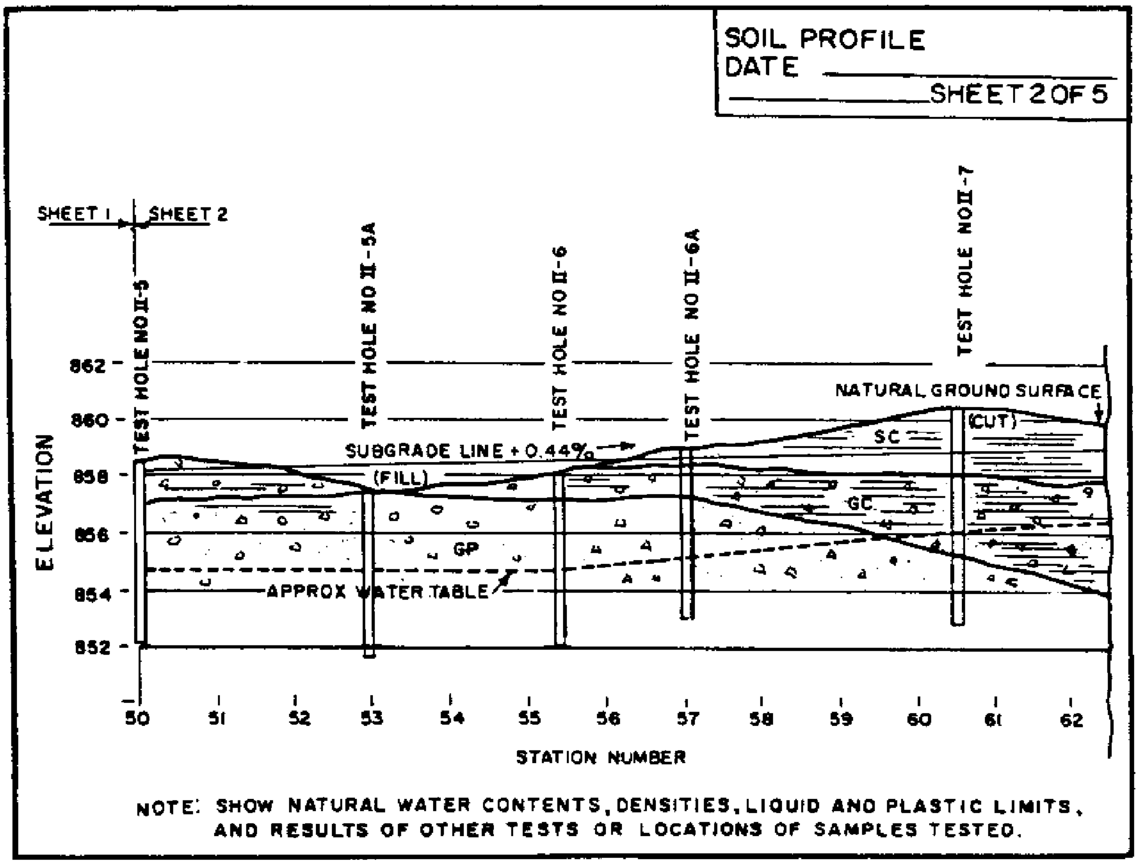


FIGURE 2
Section of a Typical Soil Profile Sheet

5. TEST PITS. Supplement the borings with test pits in the predominate surface soils. Use test pits for conducting in-place strength and density tests on potential subgrade materials. Observe and log the thickness of the strata and obtain bag samples for laboratory tests.

6. SUBGRADE TESTING. See Table 3 for American Society for Testing and Materials
(ASTM), American Association of State Highway and Transportation Officials (AASHTO), and MIL-STL test methods

CCB IS UNABLE TO REPRODUCE FOLD-OUT PAGES FROM ORIGINAL DOCUMENTS - TABLE 2 Soil Characteristics Pertinent to Roads and Airfields - NOT INCLUDED.

PAGE 6 INTENTIONALLY BLANK

for soil exploration and subgrade testing. In general, preference should be given to the use of ASTM test standards.

a. Soil Classification. Perform Atterburg Limits and grain size distribution tests to classify the soil. Use the Unified Classification System according to MIL-STD 619.

b. Moisture-Density Relationships.

(1) Standard Proctor. For the design of secondary roads and parking areas, use the standard Proctor test (ASTM D698) to determine the moisture-density relationship of subgrade soils.

(2) Modified Proctor. The Modified Proctor Compaction Test (ASTM D1557) should b used when designing primary roads or other heavy duty pavement areas.

(3) In-Place Density. From test pits, during exploration, determine the in-place density of the subgrade using the sand-cone method given by ASTM D1556. For subgrade compaction control the inplace density may be determined using nuclear gage procedures. Refer to ASTM D2922.

c. CBR. Use the California Bearing Ratio (CBR) test to determine the strength of the subgrade soil. Procedures for in-place testing and laboratory testing are given in MIL-STD-621. For a discussion of the selection of CBR values for use in pavement design, see Section 4.

TABLE 3
Subgrade Sampling and Testing Standards

Category	Description	ASTM	AASHTO	MIL-STD Test Method
Exploratory borings	Auger Samples	D1452	T203	
	Split Barrel sampling	D1586		
	Thin Walled sampling	D1587		
Identification and classification tests	Liquid limit	D423	T89	621A—Method 103
	Plastic limit	D424	T90	
	Sieve analysis	D422	T88	
	Finer than #200 sieve	D1140	T11	
	Classification (Unified Soil Classification)	D2487		619B
Test pits	Undisturbed samples, bulk samples, field tests			
Design tests				
Laboratory tests	Moisture-density relations (Modified Proctor)	D1557 (Method D)		621A—Method 100 (CE 55)
	Remolded CBR	D1883		621A—Method 101
	Moisture content	D2216		621A—Method 101
	Unconfined compression	D2166	T208	
	Permeability test	D2434	T215	
	Consolidation test	D2435	T216	
In-place tests	Density & Moisture content			
	Sand cone	D1556	T191	
	Drive cylinder	D2937		621A—Method 102
	Rubber balloon	D2167	T205	
	Nuclear method (density)	D2922		
	Nuclear method (moisture content)	D3017		
	In-place CBR			621A—Method 101

d. Subgrade Modulus. The modulus of subgrade reaction (K) is the unit load per inch of deflection on a 30-inch-diameter rigid steel plate. Determine the subgrade modulus when designing rigid pavements. Use the test procedure given in ASTM D1196 and compute the K value at the unit load corresponding to .05 inches deflection. For an estimation of K from CBR test results, see the relationship given by Figure 3.

e. Frost Susceptibility. As a general rule, inorganic soils containing greater than 3 percent by weight finer than .02 millimeters are frost susceptible. Where frost-susceptible soils arc encountered in regions of freezing temperatures, design pavements to limit the depth of frost penetration into the subgrade. For a specific design procedure, see Airfield Pavement, NAVFAC DM-21.

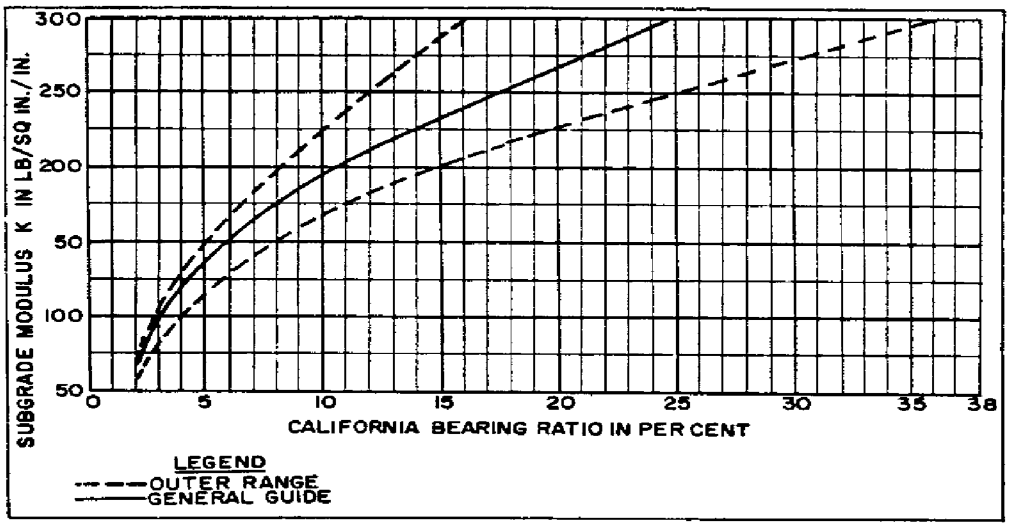


FIGURE 3
Approximate Relationship Between CBR and K

7. BORROW MATERIAL. From the developed soil profiles, determine the quality of material available for fill.

a. Fill Material. Soil types shown in Table 2 are listed in decreasing order of their value as fill material. Generally, granular soils are the preferred fill material and should bc used in the top of the subgrade. Avoid the use of expansive clays and organic soils.

b. Borrow. When borrow is required, locate pits in proximity to the proposed roadway using soil maps and other forms of exploration. To determine the suitability and extent of borrow material, conduct borings in a grid pattern on approximately 100-foot centers. The depth of borings should be 2 to 4 feet below the anticipated depth of borrow.

c. Base and Subbase Materials. Suitable materials for base and subbase are frequently available on Government-owned land. Determine the cost of processing available materials against the cost of commercial sources.

Section 3. TRAFFIC ANALYSIS

1. TRAFFIC SURVEYS. Traffic surveys should be conducted to determine the number and weight of the vehicles anticipated to use the pavement in question. The prediction of traffic intensity should include the present volumes modified by an appropriate factor for growth. Rely on local practice or the practice of the state highway department for specific procedures for conducting surveys. Guidance on traffic studies for military installations is contained in Military Traffic Management Command Pamphlet No. 55-8, "Traffic Engineering Study Reference." When designing new roads and streets, consider traffic requirements for a 20-year design period.

a. Average Daily Traffic. Determine the average daily traffic (ADT) from available records or vehicle counts for the road under consideration or for an existing roadway of similar traffic conditions. Where data is not available, a detailed traffic study may be required.

b. Traffic Weight. The percentage of trucks (T) in a traffic stream should be determined by traffic counts or current records. A tabulation of the number of axles observed within certain load groups should be made using the Federal Highway Administration loadometer tables.

c. Equivalent 18 Kip Repetitions. The basic method of measuring the effects of mixed traffic on highway pavements is with the use of equivalent 18 kip single-axle loads (EAL). The concept of the equivalent axle load was developed from the AASHTO Road Test. A detailed discussion on the development of the load equivalency factors is contained in AASHO Interim Guide for Design of Pavement Structures--1972.[1] Load equivalency factors for single and tandem axle loads are given by Figure 4. For an example of their use see Table 4.

d. Traffic Distribution. Assign 50 percent of the total two-way traffic to each direction. For two-lane roads 100 percent of the unidirectional traffic is assigned to the design lane. For four-lane roads 90 percent of the unidirectional traffic should be assigned to the outside lane.

2. DESIGN INDEX. A design index (DI) is used in the flexible pavement thickness design procedures to account for the effects of traffic intensity and weight.

a. Vehicle Groups. Where detailed traffic survey and axle load data are not available, spot counts or estimates can be made to ascertain the general characteristics and volume of traffic. As an aid to determining a DI, vehicles should be grouped according to the following categories:

(1) Group 1: Passenger cars and panel and pickup trucks.
(2) Group 2: Two-axle trucks.
(3) Group 3: Trucks having three or more axles.

b. Selection of Design Index. From detailed traffic surveys or general vehicle groups given above, select the DI from Table 5.

c. Design Index for Tracked Vehicles and Forklift Trucks. The DIs given in Table 5 do not include the effects of tracked vehicles or forklift trucks. Where significant volumes of tracked vehicles and forklifts are indicated, a higher DI may be required for thickness design. Procedures for considering these exceptional vehicles are contained in Flexible Pavements for Roads, Streets, Walks, and Open Storage Areas, DA TM5-822-5.

))))))))))))))))

[1] The American Association of State Highway Officials, AASHO, was renamed American Association of State Highway and Transportation Officials in 1973.

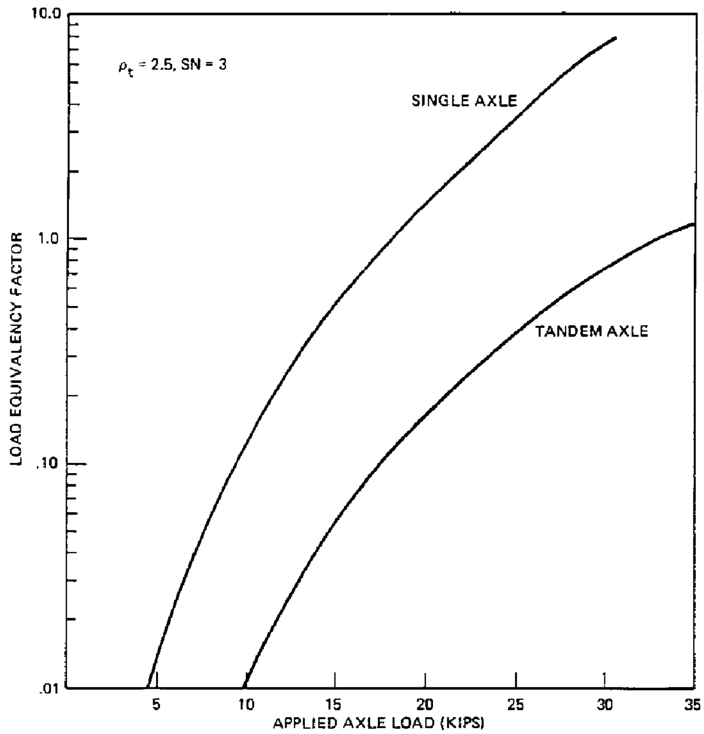


FIGURE 4
Load Equivalency Factors

TABLE 4

Example of Computation of Equivalent 18 Kip Axle Load (EAL)

Given: During a 24-hour period the following traffic was noted to have occurred at a certain location:

a. 3200 automobiles and pickup trucks carrying approximately 2 kips per axle.

b. 650 two-axle trucks carrying loads of approximately 5 and 9 kips on the front and rear axles, respectively.

c. 150 truck combinations carrying approximately 10, 16, and 30 kips on the front, middle, and rear axles. The front and middle axles are single, and the rear axle is tandem.

Compute the total number of equivalent 18 kip axle load applications.

TABLE 4 (Continued)

Solution:

a. From Figure 4 the following load equivalency factors are determined:

Load (Kips)	**Equivalency Factor (F)**
2	.0001 (approx)
5	.01
9	.08
10	.12
16	.66
30 (tandem)	.74

b. By multiplying the equivalency factors by the number of repetitions and summing the total, the total EAL is computed:

N	**F**	**EAL**
3200x2	.001	6.4
650	.01	6.5
650	.08	52
150	.12	18
150	.66	99
150	.74	111
		Sum 293

c. The pavement area should be designed for 293 daily equivalent 18 kip repetitions. From Table 5 the DI would be 5.

TABLE 5

Vehicular Traffic Design Index

DI	Traffic Characteristics	Approx. Daily EAL
1	Passenger Vehicles and Light Trucks. No trucks in Groups 2 or 3.	1-5
2	Medium-Light Traffic, less than 1000 VPD. 10% in Group 2 and none in Group 3.	6-20
3	Medium traffic up to 3000 VPD. Up to 10% Group 2 plus Group 3. 1% Group 3 vehicles.	21-75
4	Medium-heavy traffic up to 6000 VPD. Up to 15% Group 2 plus Group 3. 10% Group 3 vehicles.	76-250
5	Heavy traffic to 6000 VPD. Maximum 25% Group 2 plus Group 3 and 15% Group 3.	251-900
6	Very heavy traffic exceeding 6000 VPD. Over 25% Group 2 or Group 3.	901-3000

Section 4. SUBGRADES

1. EXPLORATION. Sec Section 2 of this manual for criteria for subgrade exploration, identification, and testing. Additional criteria for the determination of the design subgrade strength is given below.

2. SUBGRADE STRENGTH.

a. Flexible Pavements. Flexible pavement thickness design procedures are based on the CBR method of design, which requires an appraisal of the ultimate moisture content and CBR of the subgrade soil. The objective of the procedure is to design the pavement on the basis of the predominant subgrade moisture content anticipated during the life of the pavement. To determine the design subgrade CBR, use the following procedures:

(1) Field-in-place tests.

(a) Determine field-in-place CBR of the natural subgrade with corresponding water content and density at proposed subgrade elevation whenever possible.

(b) Conduct in-place CBR tests in subgrades under existing adjacent pavements that may have reached equilibrium moisture conditions and may be indicators of the long-term strength.

(c) Use in-place tests in coarse-grained subgrade soils where little increase in moisture content is anticipated.

(d) Use in-place tests in clays which would lose strength when excavated and remolded, in silts and fine sands which become quick or spongy under high water table, and in subgrade soils that are near saturation in their natural state.

(2) Tests on Laboratory Molded Samples. In the absence of reliable field information, perform laboratory CBR tests on subgrade samples molded at varying moisture contents and compactive effort and subjected to four days soaking. Follow the procedure contained in MIL-STD 621, Method 101. Perform one complete series of tests for each distinct type of soil.

(3) Determine design CBR. Where a range of soil types is encountered in the proposed roadway and CBR test results are variable, judgment must be made as to whether variable design thicknesses are necessary and economically feasible. Where variable design thicknesses are not warranted, determine the CBR value for design, as that value is equal to or less than 85 percent of the CBR test values along the proposed roadway.

(4) Approximate Values. Use the following approximate values of CBR for checking and estimating purposes and for preliminary design of minor paved areas:

Subgrade Soil Type	**Approx. CBR**
Well and poorly graded gravels, well graded sands	>18
Silty and clayey sands	12-18
Low plastic clays, inorganic silts, very fine sands	6-12
Highly plastic and organic clays, micaceous silts	1-6

b. Rigid Pavements. Use the subgrade modulus K for the design of rigid pavements. See Section 2.

3. SUBGRADE DRAINAGE.

a. Conditions Requiring Subgrade Drainage. Consider the use of subgrade drains whenever the following conditions exist:

(1) High ground-water levels which may reduce subgrade stability and provide a source of water for frost action.

(2) In subgrade soils of silts and very fine sands which may become quick or spongy when saturated.

(3) Consider intercepting drains where water seeps from underlying water-bearing strata or from subgrades in cut areas.

b. Design Details. Use subsurface drains (perforated collector pipes and filters) in lieu of deep ditches for collecting and transporting ground water. For typical subgrade drain installation, see Figure 5. For design criteria see NAVFAC DM-7 and NAVFAC DM-21.

4. SUBGRADE COMPACTION.

a. Fill Sections. All granular fill materials should be compacted to at lest 95 percent of maximum density. Cohesive fill material should be completed to no less than 90 percent.

b. Cut Sections. In cut, the depth and degree of compaction required varies with the pavement design index. Specific guidance on compaction depth is given in DA TM 5-822-5. When existing subgrade soils do not meet minimum compaction requirements, consider the following alternatives:

(1) Compact soils from the surface.

(2) Remove and process soil to attain the approximate optimum moisture and replace and compact.

(3) Replace subgrade soil with suitable borrow material.

(4) Raise the grade so that existing natural densities meet required values.

5. SETTLEMENT. When designing roadways in fill sections, examine soil profiles to ascertain possible settlement due to the existence of compressible layers. For settlement analysis, see NAVFAC DM-7.

6. SUBGRADE STABILIZATION. Native subgrade and lower quality borrow materials may be improved for use in the pavement structure with the use of a cement, bitumen, or lime stabilizing agent. For stabilization or modification of cohesive subgrade soils, hydrated lime is the most widely used. Lime is applicable in clay soils (CH, CL) and in granular soils containing clay binder (GC, SC). Lime reduces the plasticity index (PI) and renders a clay soil less sensitive to moisture changes. Consider the use of lime whenever the PI of the soil is greater than 10.

a. Lime Treatment. Lime treatment or modification consists of the application of from 1 to 3 percent hydrated lime to aid drying of the soil and permit compaction. As such it is useful in the construction of a "working platform" to expedite construction. Lime modification may also be considered to condition a soil for follow-on stabilization with cement or bitumen. Lime treatment of subgrade soils is intended to expedite construction, and no reduction in the required pavement thickness should be made.

b. Lime Stabilization. For lime stabilization of clay subgrades, the lime content should be from 3 percent to 8 percent of the dry weight of the soil, and the cured mass should have an unconfined compressive strength of at least 50 psi in 28 days. The optimum lime content should be determined with the use of unconfined compression and Atterburg Limits tests on laboratory lime-soil mixtures molded at varying percentages of lime. Determine the laboratory CBR of the optimum lime soil mixture for use in pavement thickness design procedures.

Section 5. SUBBASE

1. FUNCTIONS AND REQUIREMENTS.

a. Rigid Pavements. Subbase normally is not used in rigid pavements. The course directly beneath the concrete is termed "base."

b. Flexible Pavements. In flexible pavements, the subbase is composed of a selected borrow or stabilized material used to reduce the thickness of the base. The subbase is placed on the subgrade and serves as a load-distributing medium to reduce subgrade stress.

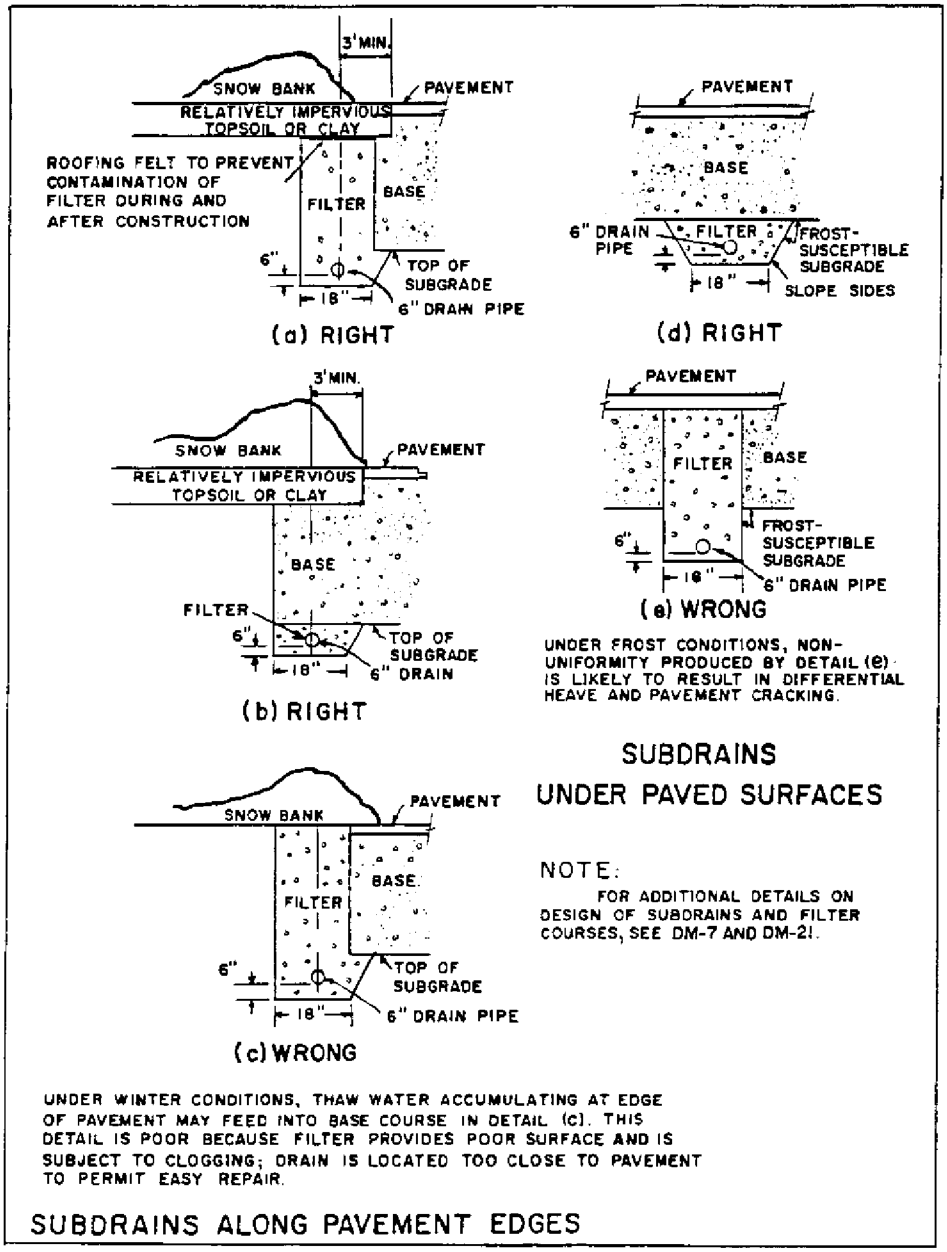


FIGURE 5
Typical Details of Subgrade Drainage Installations

2. MATERIALS. Subbase materials can consist of any of the following:

a. Naturally occurring course-grained soils such as gravel, well-graded sands, and disintegrated granite.
b. Naturally occurring and processed materials such as limerock, coral, caliche, quarry and mine wastes, slag, shell, and sand-shell mixtures.
c. Naturally occurring or processed materials which are stabilized with cement, lime, or bitumen.
d. Mechanically stabilized mixtures in which borrow or processed materials are blended with on-site soils to form a more dense and stable layer. Mechanical stabilization of subgrade soils may be used only where the liquid limit (LL) and PI of the existing soil meet the requirements for subbase.

3. SUBBASE CBR.

a. Laboratory Tests. Perform laboratory CBR tests on remolded soaked samples as outlined in MIL-STD 621, Method 101. Laboratory CBR tests are to be supplemented with grain size and plasticity requirements to arrive at a CBR value for design. Where proposed subbase materials exist in place under similar conditions, the in-place CBR value should be determined and used for design.
b. Maximum design CBR. When laboratory CBR values have been determined, the maximum value for use in design may be controlled by the following gradation and plasticity limitations:

Max. Permissible	Gradation, Max. % Passing				
Design CBR	Max. Size	#10 Sieve	#200 Sieve	Max. LL	Max. PI
50	3"	50	15	25	5
40	3"	80	15	25	5
30	3"	100	15	25	5

For additional general requirements and recommended gradations of subbase materials, see "AASHTO Specification M-147" in Standard Specifications for Transportation Materials and Methods for Sampling and Testing.

4. COMPACTION. Compact all granular subbase course materials to 100 percent of maximum density.

Section 6. BASE

1. FUNCTIONS AND REQUIREMENTS.

a. Rigid Pavements. Use base course under rigid pavements where subgrades do not meet the gradation, plasticity, and CBR requirements for base. Base courses are required under the following conditions:
(1) Frost Action. Use base courses to prevent or reduce frost penetration into subgrades.
(2) Subgrade Pumping. Provide a base course over subgrade soils classified as CH, CL, ML, MH, and OL to prevent pumping.
(3) Uneven Support. Provide base courses to provide uniform support to pavement slabs.
(4) High Volume Change Subgrade Soils. Provide base courses as overburden on expansive soils to minimize potential heaving and faulting at joints.
b. Flexible Pavements. A base course is a major load-carrying component in a flexible pavement. The base must have high structural strength and be densely compacted.

2. BASE DRAINAGE.

a. Conditions Requiring Drainage. Consider the use of a base course drainage system wherever the following conditions exist:

(1) Where ground water levels approach the bottom of the base.
(2) Where frost action penetrates the subgrade.
(3) In sag vertical curves where the subgrade soil has low permeability.

b. Design Details. For typical basic drainage details, see Figure 6. For design criteria for subdrains filter materials see NAVFAC DM-7. For drainage computation procedures, see NAVFAC DM-21.

3. BASES FOR RIGID PAVEMENT.

a. Materials. Materials used as a subbase in flexible pavements are suitable for base courses in rigid pavements. Refer to Section 5.

b. Gradation and Plasticity. Base materials should be well graded, conforming to AASHTO Specification M-147. The LL should be no greater than 25 and the PI no greater than 5.

c. CBR. The minimum required CBR is 30.

d. Thickness. The minimum thickness of granular base should be 6 inches. Thicker bases may be required in order to reduce frost penetration into the subgrade or to increase K modulus value in weak subgrade soils. For thickness design procedures for base courses, see NAVFAC DM-21.

e. Compaction. Base courses under rigid pavements should be compacted to at least 95 percent of maximum density.

4. BASES FOR FLEXIBLE PAVEMENTS.

a. Materials. The selection of a base course material for flexible pavements should be based on the economic availability. Generally the following natural and processed materials can be used as base:

Crushed or uncrushed gravel
Graded crushed rock
Waterbound macadam
Drybound macadam
Limerock
Coral
Sand-shell
Blast furnace slag
Cement, bitumen, or lime stabilized soil mixtures

b. Gradation and Plasticity. Recommended gradations for drybound and waterbound macadam bases are given in Graded Aggregate Base Course for Flexible Pavement, TS-02686. For other local materials including limerock, sand-shell, and coral, use locally available and proven gradations. For all base types for flexible pavements the LL should be no greater than 25 and the PI no greater than 5.

c. Design CBR. For flexible pavement thickness design, use the following CBR values, without testing, for the following materials:

Base Type	Design CBR
Graded, Crushed Aggregate	100
Waterbound Macadam	100
Drybound Macadam	100
Cement- and Asphalt-treated Aggregate	100
Limerock	80
Sand-shell	80
Coral	80

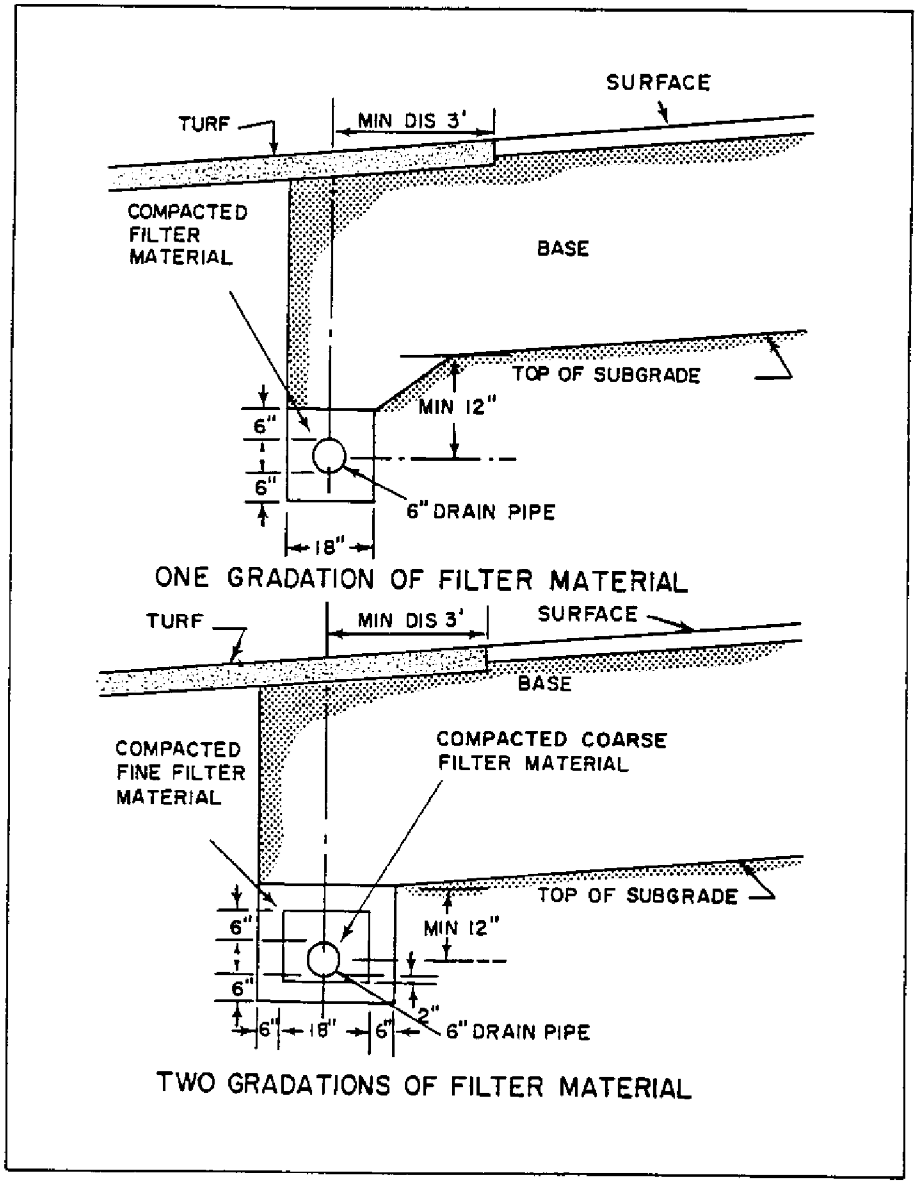


FIGURE 6
Typical Details of Base Drain Installations

TABLE 6
Drybound Macadam Base

Sieve designation	Percentage by weight passing square mesh sieve						
	Coarse--aggregate gradation				Choker aggregate graduation		Screen-ings
	No 1	No 2	No 3	No 4	No 5	No 6	No 7
3"	100	100	---	---	---	---	---
2-1/2"	90-100	90-100	100	---	---	---	---
2"	35-70	---	90-100	100	---	---	---
1-1/2"	0-15	25-60	35-70	90-100	---	---	---
1"	---	---	0-15	20-55	---	---	---
3/4"	0-5	0-10	---	0-15	100	---	---
1/2"	---	0-5	0-5	---	90-100	---	---
3/8"	---	---	---	0-5	---	100	100
No. 4	---	---	---	---	---	85-100	85-100
No. 100	---	---	---	---	10-30	10-30	5-25

TABLE 7
Waterbound Macadam Base

Sieve designation	Percentage by weight passing square mesh sieve				
	Coarse--aggregate gradation			Screenings gradation	
	No 1	No 2	No 3	No 4	No 5
3"	100	100	---	---	---
2-1/2"	90-100	90-100	100	---	---
2"	35-70		90-100	---	---
1-1/2"	0-15	25-60	35-70	---	---
1"	---	---	0-15	---	---
3/4"	0-5	0-10	---	100	---
1/2"	---	0-5	0-5	90-100	---
3/8"	---	---	---	---	100
No. 4	---	---	---	---	85-100
No. 100	---	---	---	10-30	10-30

d. Thickness. The required thickness of base should be determined using the flexible pavement thickness design procedures in Section 7. The minimum base thickness is 6 inches.

e. Compaction. Compact all base courses in flexible pavements to 100 percent of maximum density.

Section 7. FLEXIBLE PAVEMENT THICKNESS DESIGN

1. DESIGN PRINCIPLES. The CBR method of pavement design is based on the principle of providing sufficient thickness and quality of pavement base and subbase courses to prevent subgrade shear deformation under traffic. The procedure is largely empirical but has been validated through extensive experience and traffic testing of prototype pavements. The design procedure also provides for adequate compaction of the subgrade and each course to prevent settlement under traffic. Where freezing temperatures occur, the design procedure must give consideration to the depth of frost penetration and subgrade weakening during the thaw period.

2. STRESSES IN FLEXIBLE PAVEMENTS.

a. Single Wheels. Distribution of vertical stresses under a surface load has a bell-shaped pattern. Stresses are at a minimum directly beneath the wheel, and decrease with increasing depth. See NAVFAC DM-7 and NAVFAC DM-21 for stress distribution in soils.

b. Dual Wheels. When dual wheels support the same total load as a single wheel, pavement stresses are reduced. At shallow depth, stresses are caused principally by individual wheels acting singly, and are at a maximum beneath the center of each wheel. At greater depths, stresses are at a maximum midway between wheels, and approximate the stress caused by a single wheel supporting the total load. Thus stresses in pavement are determined principally by individual wheel loads, and especially by tire pressure, whereas required total thickness of pavement, base, and subbase are determined principally by total load.

c. Stress Repetition. The effects of stress repetition arc considered in the design procedures by the concepts of equivalent 18 kip axle loads and the DI. Although flexible pavements may sustain limited applications of a heavy load, they may distort or fail under a high number of repetitions of the same load.

3. THICKNESS DESIGN PROCEDURES. Use the following procedures for the design of flexible pavements:

a. Design Index. Determine the DI using the procedures of Section 3.

b. Subgrade CBR. From Section 4, determine the design subgrade CBR.

c. Total Thickness. Determine the total thickness of pavement required from the design curve, Figure 7. Enter the design curve with the subgrade CBR, proceed vertically to the ''break line," then horizontally to the DI, and vertically to the design thickness.

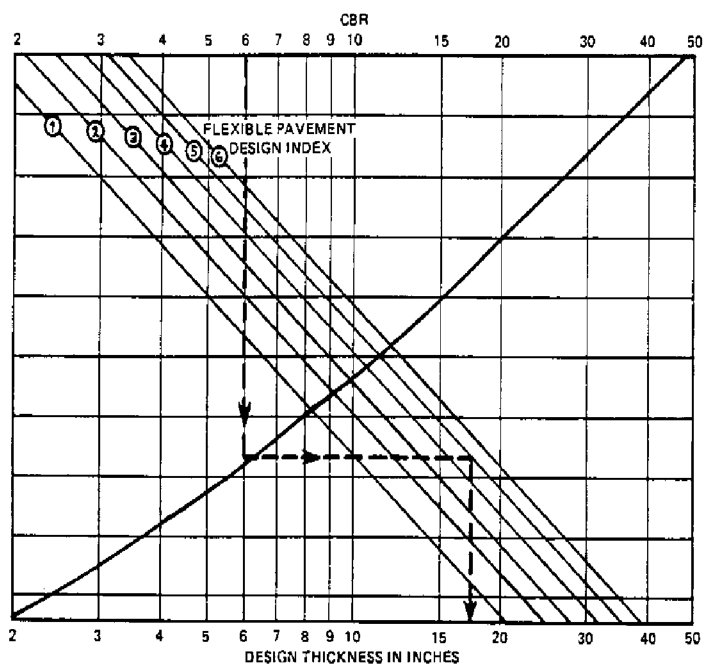


FIGURE 7
CBR Thickness Design Chart—Flexible Pavements

d. Thickness of Base and Subbase. Enter Figure with the CBR of the subbase material and determine the total required thickness of base and surfacing.

e. Repeat Step d for other available subbase materials to determine the most economical combination of base and subbase material and thickness.

f. Minimum Base and Subbase. Use a minimum base thickness of 6 inches. Minimum subbase thickness should be 4 inches.

g. Minimum Thickness of Surface. Minimum thickness of asphalt concrete surfacings should be as follows:

Type of Surface	Minimum Thickness (inches)
Primary Road	3
Secondary and Tertiary Roads	2
Parking Area	2
Driveway	1.5
Sidewalk	1
Surfacing Used by Tracked Vehicles	4

Where exceptionally stable bases, such as cement-treated aggregate, natural cementing materials (limerock), or asphalt concrete bases are used, the 2-inch minimum thickness may be reduced to 1.5 inches.

4. COMPACTION AND SETTLEMENT. Nonuniform settlement or inadequate compaction of the pavement components can result in premature pavement rutting and cracking. See requirements for subgrade compaction and settlement analysis contained in Section 4. Subbase and base course compaction requirements are contained in Sections 5 and 6.

5. FROST DESIGN. In areas having freezing temperatures, ascertain the need for designing for frost effects from state, county, or city highway departments. Determine the depth of frost penetration from the highway department or local utility companies. Use local design procedures. For a complete discussion of frost effects and two methods of design, see NAVFAC DM-21.

Section 8. DESIGN OF BITUMINOUS SURFACES

1. FUNCTIONS AND REQUIREMENTS. Bituminous surfaces provide a resilient, waterproof, load distributing medium that protects the base course against the detrimental effects of water and the abrasive action of traffic. Bituminous surfaces permit slight adjustments in the pavement structure, due to consolidation, without detrimental effect, and are more readily adaptable to stage construction. The types of bituminous surfacings commonly used for roads and streets are given in Table 1.

2. TERMINOLOGY. See Figure 1 for a description of flexible pavement components and see Table 8 for terminology related to bituminous mixes.

3. BITUMINOUS MATERIALS. Bituminous materials used in road construction include asphalts, tars and tar-rubber blends. The applicable specifications for bituminous materials are given in Table 9.

a. Asphalt. Asphaltic materials are the usual choice for use in bituminous pavements due to their widespread availability and economy. Asphaltic materials are available as asphalt cements, liquid asphalts, or emulsified asphalts.

(1) Asphalt cements are most widely used in hot-mix asphalt concrete mixtures as binder and wearing courses. The material is available in varying degrees of hardness (penetration) and is a solid at room temperature.

(2) Liquid asphalts consist of asphalt cements dissolved in petroleum solvents and are widely used for in-place mixes and surface treatments. Liquid asphalts are graded according to their cure rate and viscosity and are usually designated as rapid curing (RC), medium curing (MC), and slow curing (SC). The newer designations for liquid asphalts and their viscosities are given in Figure 8.

TABLE 8
Specialized Terminology for Bituminous Mixes

Item	Description
Coarse aggregate	Material larger than the No 4 sieve.
Fine aggregate	Material passing the No 4 sieve.
Mineral filler	Stone dust finer than the No 200 sieve.
Wearing coarse	The top layer of a tar or asphalt concrete surface.
Binder course	The leveling or transition layer of tar or asphalt. concrete placed directly on the base course.
Prime coat	A surface treatment of liquid asphalt applied to a nonbituminous pavement is placed Purpose is to penetrate and seal surface of base course.
Tack coat	Asphalt emulsion or liquid asphalt material placed on an existing concrete or bituminous pavement to provide good bond with a superposed bituminous pavement.
Seal coat	A type of pavement surface treatment usually applied as a maintenance procedure.
Marshall stability value	The load in pounds causing failure in a compacted specimen of hot-mix asphaltic concrete when tested in the Marshall apparatus.
Flow	Total deformation in hundredths of an inch at point of maximum load in the Marshall Stability Test.
Percent voids total mix	That part of the compacted asphalt mixture not occupied by aggregate or asphalt, expressed in percent of total volume.
Percent voids filled with asphalt	Percentage of voids in a compacted aggregate mass that are filled with asphalt cement.
Optimum bitumen content	The percentage of bitumen satisfying mix design criteria for Marshall Stability Design Procedure.
Penetration	The relative hardness or consistency of an asphalt cement Measured by the distance a standard needle will penetrate vertically into a sample of asphalt under known conditions of temperature, loading, and time.
Viscosity	A measure of the ability of a bitumen to flow at a given temperature The stiffer the bitumen the higher the viscosity.

TABLE 9
Specifications for Bituminous Materials

Bitumen	Specification
Asphalt cement (penetration grades)	ASTM D946
Asphalt cement (AC and AR grades)	AASHTO M226 or ASTM D3381
Asphalt, liquid (slow-curing)	ASTM D2026
Asphalt, liquid (medium-curing)	ASTM D2027
Asphalt, liquid (rapid-curing)	ASTM D2028
Asphalt, emulsified	ASTM D977
Asphalt, cationic emulsified	ASTM D2397
Tar	ASTM D490
Rubberized tar cement	ASTM D2993

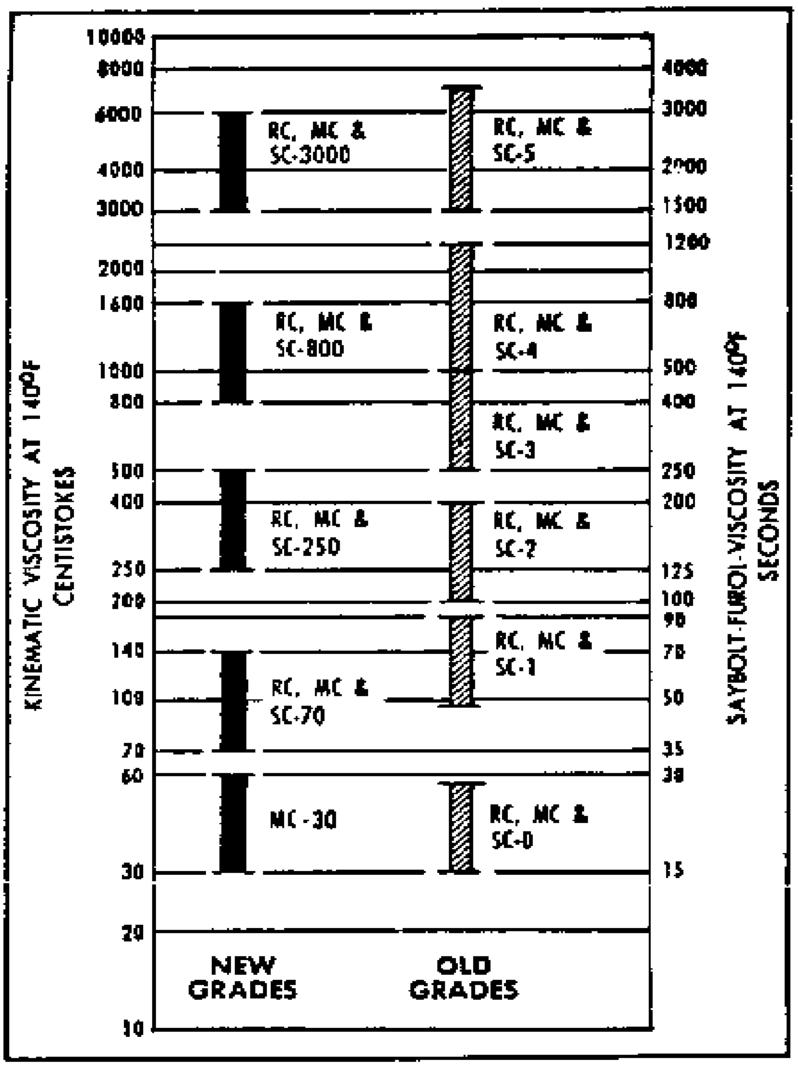


FIGURE 8
Liquid Asphalts—New and Old Grades

(3) Emulsified asphalts consist of an asphalt cement suspended in water with us of an emulsifying agent. Emulsified asphalts are commonly used for tack coats, slurry seal coats, and in road mixes. Emulsified asphalts may be either the anionic (negative charge) or cationic (positive charge) type and are further classified as to curing rate, that is, rapid setting (RS), medium setting (MS), and slow setting (SS). Recommended type and grades of bitumen for road and street pavements are given in Table 10.

b. Tar. Road tar is not as readily available as asphalt. Tar is softer at high temperatures and more brittle at lower temperatures than comparable grades of asphalt cement. However, tars are resistant to fuel spillage and will not strip from hydrophilic aggregates in the presence of water. Applicable ASTM specifications for tars are included in Table 9.

c. Tar-Rubber Blends. Tar-rubber blends combine resistance to fuels with higher resistance to temperature changes. These mixes are normally used for specialized areas, particularly on airfield pavements. For a complete discussion, see Bitumnous Pavement Standard Practice, DA TM 5-822-8.

TABLE 10
Recommended Types and Grades of Bitumen for Bituminous Surfaces

Surface	Grade or designation					
	RC (rapid curing)	MC (medium curing)	SC (slow curing)	AC (asphalt cement) with penetration of	AE (asphalt emulsion)	RT (road tar)
Dust palliative	....	MC-30-70..	SC-30-70...	....	....	RT-1.
Prime coats	RC-70.....	MC-70 ...	SC-70.....	....	....	RT-2.
Tack coats	RC-30.....	....	....	....	RS-1, SS-1[1]	......
Surface treatment and seal coats:						
Course sand cover	RC-250....	MC-250-800	....	....	RS-1....	......
Clean coarse aggregate	RC-250....	MC-250-800	....	120-300...	....	......
Graded gravel aggregate cover	....	MC-250-800	....	....	....	......
Mixed in place.—road mix:						
Open-graded aggregate:						
Sand	RC-250....	MC-250...	....	....	....	......
Maximum diameter 1 in., high percentage passing 10 mesh	RC-250....	MC-250-800	....	....	MS-1....	......

[redacted]

[retrieve Table 10 - Recommended Types & Grades of Bitumen for Bituminous Surfaces]

4. AGGREGATES.

a. Suitability. Basic or alkaline rocks (limestone, dolomite), provide better adhesion with asphaltic films than do acid or silicious rocks (granite, quartzite). Where acid rocks are used, the addition of an antistripping agent or hydrated lime may be required.

b. Coarse Aggregate. Coarse aggregates should be clean, hard, and durable. In asphaltic concrete mixtures, crushed rock is preferable for its higher stability and performance. Other requirements for coarse aggregate are contained in ASTM D692.

c. Fine Aggregate. Fine aggregate for bituminous concrete mixes may be composed of naturally occurring sand or of aggregate particles produced from crushed stone or crushed gravel. Fine aggregates should otherwise conform to ASTM D1073.

d. Mineral Filler. In bituminous concrete mixtures, mineral filler should be limestone dust, portland cement, or other similar inert materials. At least two-thirds of the material passing the No. 200 sieve in a bituminous mix should be nonplastic material meeting the requirements of ASTM D242.

5. BITUMINOUS MIX DESIGN.

a. Hot-Mix Asphalt Concrete. Use the Marshall mix design method for designing hot-mix asphalt concrete mixture. Detailed instructions for the design procedure are contained in DA TM 5-822-8. For test methods, see MIL-STD 620.

(1) Asphalt Cement. Use penetration grade, AC viscosity grade, or AR viscosity grade of asphalt cement in the mix design. Figure 9 provides recommended grades for each area of the United States. These recommendations should be tempered by local practice. In areas where only the viscosity grades are available, determine those sources having acceptable penetrations for use in the project.

(2) Aggregates. Use aggregates in the mix design which meet the requirements of ASTM D692 and D1073 for coarse and fine aggregates, respectively. Mineral filler, when required, should conform to ASTM D242. Aggregates used for mix design should be identical to those anticipated to be used in construction. Gradation of aggregates should conform either to ASTM D1663 or Asphalt Binder & Wearing Courses for Flexible Pavement, NAVFAC TS-02681. In general, the maximum aggregate size for wearing courses should not exceed 3/4 inches. For binder and intermediate courses, the maximum aggregate size should not exceed two-thirds the course thickness.

(3) Marshall Requirements. Use the 75-blow compaction procedures for designing primary roads and streets. For secondary roads, streets, and parking areas, use the 50-blow procedure. Follow the procedures given in DA TM 5-822-8 for preparing and testing the trial mixes. Criteria for determining the optimum bitumen content and the adequacy of the mix are given in Tables 11 and 12. A minimum bitumen content of 5 percent is recommended.

(4) Optional VMA Method. This optional method of mix design utilizes the concept of the voids in the mineral aggregate (VMA) to determine the optimum bitumen content. The VMA represents the volume of voids in the compacted aggregate mixture and includes the percent of air voids plus the effective asphalt content expressed as a percent of the total volume. The mix design method requires that a minimum volume of voids be contained in the aggregate mix in order to accommodate sufficient bitumen for stability and durability. Procedures for computing the VMA are given in Mix Design Method for Asphalt Concrete and Other Hot-Mix Types, The Asphalt Institute Publication MS-2. Criteria for minimum percent VMA are given in Table 13. In using the design procedure, no correction is required for highly absorbent aggregate.

b. Mixed-In-Place Bituminous Pavement. Mixed-in-place bituminous pavements can be used on secondary and other low-volume roads. The pavement should consist of one layer with compacted thickness of 2 inches. For recommended limits for aggregate gradation and bitumen contents, see Table 14. For recommended grades of bitumen, see Table 10.

Area	Pen Grade	Viscosity Grade
I	120-150	AC-5 or AR-2000
II	85-100	AC-10 or AR-4000
III	60-70	AC-20 or AR-8000
Alaska	120-150 or 150-200	AR-1000 or AR-2000
Hawaii	60-70	AR-8000

Note: The penetration of viscosity graded asphalts do not necessarily fall within the ranges indicated. Where specific penetration requirements are desired, they should be so stipulated.

Figure 9. Selection Guide For Asphalt Cement

TABLE 11
Bituminous Pavement Design Criteria
for Use with Aggregate Blends Showing Water Absorption up to 2½ Percent[4]

For Determining Optimum Bitumen Content[1]

Test property	Type of mix	Point on curve	
		50 blows	75 blows
Marshall stability	Bituminous-concrete wearing course	Peak of curve	Peak of curve.
	Bituminous-concrete binder course	Peak of curve[2]	Peak of curve[2].
Unit weight	Bituminous-concrete wearing course	Peak of curve	Peak of curve.
	Bituminous-concrete binder course	Not used	Not used.
Flow		Not used	Not used.
Percent voids total mix	Bituminous-concrete wearing course	4	4.
	Bituminous-concrete binder course	5	6.
	Sand asphalt	6	(3)
Percent voids filled with bitumen	Bituminous-concrete wearing course	80	75.
	Bituminous-concrete binder course	70[2]	65[2].
	Sand asphalt	70	(3)

[1]For use in conjunction with ASTM apparent specific gravity.
[2]If the inclusion of bitumen contents at these points in the average causes the voids total mix to fall outside the limits, then the optimum bitumen content should be adjusted so that the voids total mix are within the limits.
[3]Criteria for sand asphalt to be used in designing pavements for 200-psi tires have not been established.
[4]When aggregates have water absorption over 2½ percent see DA, TM 5-822-8 for criteria.

TABLE 12
Bituminous Pavement Design Criteria
for Use with Aggregate Blends Showing Water Absorption up to 2½ Percent[3]

For Determining Satisfactoriness of Mix[1]

Test property	Type of mix	Criteria	
		50 blows	75 blows
Marshall stability	Bituminous-concrete wearing course	500 lb or higher.	1,800 lb or higher
	Bituminous-concrete binder course	500 lb or higher.	1,800 lb or higher
	Sand asphalt	500 lb or higher.	(2)
Unit weight		Not used	Not used.
Flow	Bituminous-concrete wearing course	20 or less	16 or less.
	Bituminous-concrete binder course	20 or less	16 or less.
	Sand asphalt	20 or less	(2)
Percent voids total mix	Bituminous-concrete wearing course	3-5	3-5.
	Bituminous-concrete binder course	4-6	5-7.
	Sand asphalt	5-7	(2)
Percent voids filled with bitumen.	Bituminous-concrete wearing course	75-85	70-80.
	Bituminous-concrete binder course	65-75	60-70.
	Sand asphalt	65-75	(2)

[1]For use in conjunction with ASTM apparent specific gravity.
[2]Criteria for sand asphalt to be used in designing pavements for 200-psi tires have not been established.
[3]When aggregates have water absorption over 2½ percent see DA, TM 5-822-8 for criteria.

TABLE 13
Minimum Percent Voids in Mineral Aggregate (VMA)

Nominal Max. Aggregate Size (inches)	Minimum Voids in Mineral Aggregate (percent)
3/8........................	16
1/2........................	15
3/4........................	14
1.0........................	13

TABLE 14
Recommended Limits for Gradation Control and Suggested Bitumen Content for Each Gradation, Bituminous Road Mixes (Surfaces)

Maximum particle size (in.)	Recommended percent bitumen	Percent passing each sieve (by weight)								
		Sieve designation								
		1 in.	3/4 in.	1/2 in.	3/8 in.	No. 4	No. 10	No. 40	No. 80	No. 200
1.......	5.0-8.0	100	85-100	......	61-90	43-79	30-65	16-38	10-24	5-12
3/4.....	5.0-8.5	....	100	82-100	68-93	48-82	32-68	17-44	11-28	5-12
1/2.....	5.0-9.0	....	......	100	82-100	57-88	38-74	18-46	11-30	5-12

c. Penetration Macadam. Penetration macadam surfacings are satisfactory for low-volume roads and for pavements in remote locations and low yardage. They should not be used for areas subjected to tracked vehicles. For recommended aggregate gradations, see Table 15. Recommended types of bitumen are given in Table 10.

d. Bituminous Surface Treatments. Bituminous surface treatments may be used on sound, strong base courses or on asphalt surfacings. The total thickness of the surface treatment should be less than 1 inch. Use surface treatments for temporary paved areas and where traffic volumes are light. Do not use surface treatments on pavements subjected to tracked vehicles or heavy trucks. Gradation and bitumen requirements are contained in Bituminous Surface Treatment, NAVFAC TS-02677.

e. Bituminous Stabilization. Liquid bitumen and emulsions may be used to stabilize in-place subgrade soils for use as temporary roads or as an intermediate surfacing in a program of stage construction. A subgrade soil may be suitable for stabilization if it contains less than approximately 25 percent by weight passing the No. 200 sieve and has a PI less than 8. Preference should be given to the use of emulsified asphalts for this form of stabilization.

(1) Stabilization With Asphalt Emulsion. Provide sufficient bitumen to thoroughly coat the soil particles and yield a stable, durable mass. Table 16 provides an estimate of the required emulsion content for various soil gradations. Confirm these quantities with laboratory tests prior to a final determination. Emulsion mixes require a brief period of aeration prior to compaction in order to support compaction equipment and gain stability.

TABLE 15
Recommended Gradings for Aggregates Used in Penetration Macadam Surfaces

Sieve designation	Percent passing (by weight)
Coarse aggregate:	
2-1/2-inch	100
2-inch	90-100
1-1/2-inch	35-70
1-inch	0-15
1/2-inch	0-5
Intermediate aggregate (key stone):	
1-inch	100
3/4-inch	90-100
3/8-inch	20-55
No. 4	0-10
No. 8	0-5
Fine aggregate[1] (stone chips):	
3/4-inch	100
1/2-inch	90-100
3/8-inch	40-75
No. 4	5-25
No. 8	0-5

[1] Use fine aggregate only after second application of bitumen.

TABLE 16
Emulsified Asphalt Requirements for Subgrade Stabilization

Percent Passing No. 200 Sieve	Pounds of Emulsified Asphalt per 100 pounds of Dry Soil When Percent Passing No. 10 sieve is--					
	50	60	70	80	90	100
0	6.0	6.3	6.5	6.7	7.0	7.2
2	6.3	6.5	6.7	7.0	7.2	7.5
4	6.5	6.7	7.0	7.2	7.5	7.7
6	6.7	7.0	7.2	7.5	7.7	7.9
8	7.0	7.2	7.5	7.7	7.9	8.2
10	7.2	7.5	7.7	7.9	8.2	8.4
12	7.5	7.7	7.9	8.2	8.4	8.6
14	7.2	7.5	7.7	7.9	8.2	8.4
16	7.0	7.2	7.5	7.7	7.9	8.2
18	6.7	7.0	7.2	7.5	7.7	7.9
20	6.5	6.7	7.0	7.2	7.5	7.7
22	6.3	6.5	6.7	7.0	7.2	7.5
24	6.0	6.3	6.5	6.7	7.0	7.2
25	6.2	6.4	6.6	6.9	7.1	7.3

(2) Stabilization With Liquid Asphalt. For an estimate of liquid asphalt requirements, use the following expression:

where:

$$p = .02(a) + .07(b) + .15(c) + .02(d)$$

p = percent of residual asphalt by weight of dry aggregate.
a = percent of aggregate retained on No. 50 sieve.
b = percent of aggregate passing No. 50 and retained on No. 100 sieve.
c = percent of aggregate passing No. 100 and retained on No. 200 sieve.
d = percent of aggregate passing No. 200 sieve.

Section 9. RIGID PAVEMENT DESIGN

1. BASIC FACTORS. Design criteria for rigid pavements are outlined below.

a. Load Bearing Capacity. Rigid pavements distribute superposed wheel loads over effective areas much larger than tire contact areas, greatly reducing stress intensity on subgrade and eliminating the need for high quality bases. While bases normally are not required for structural reasons, they usually are required for other reasons.

b. Bending Stresses and Curvature. Assume subgrade reaction or support at every point proportional to vertical deflection of the slab at the point and elastic pavement. Assume subgrade support is continuous with no areas where slab has deflected away from the subgrade.

(1) Analysis. Stress analysis utilizes a basic relationship between bending moment and radius of curvature at any point:

$$M = \frac{EI}{r}$$

where:

r = radius of curvature of the pavement,
M = bending moment of the pavement,
E = modulus of elasticity of the pavement,
I = moment of inertia of the pavement.

(2) Maximum Stress. Maximum pavement stresses occur when wheel loads are near joints and exterior edges of slabs.

c. Effects of Friction and Warping. Frictional forces between slab and subgrade interfere with pavement expansion and contraction, often resulting in pavement cracking. Design properly spaced contraction joints to control cracking caused by contraction. Excessive expansion and blowups occur infrequently because most pavements are laid in warm weather. However, expansive aggregates or wide temperature variations can cause blowups.

(1) Vertical Temperature Gradients. Vertical temperature gradients in slabs cause warping. If the top of a slab is cooler than the bottom, the slab tends to curl up at the edges because of tension in the top surface. Tension is an additive to tensile stresses caused by external load applied to slab edges.

(2) Stress Analysis. Analysis for warping stresses usually is not considered in pavement design; use an adequate factor of safety instead.

d. Subgrade and Base Uniformity. The thickness design procedure assumes a constant modulus of subgrade reaction. Local variations in subgrade modulus cause increased stresses with possible pavement overstressing and decreased life; therefore, provide a uniform subgrade.

(1) Pavements. Pavements perform better where construction traffic can be kept off the subgrade.

(2) Subgrade Modulus. Make plate bearing tests in each area of substantially different soil types or determine probable differences in subgrade module from previously made tests for comparable subgrade conditions. The subgrade modulus design value can vary for different areas.

e. Drainage. Provide adequate surface drainage to prevent ponding of water and adequate subsurface drainage to prevent loss of subgrade bearing capacity. See NAVFAC DM 5.3 for surface drainage and Sections 5 and 7 for subsurface and base drainage.

f. Frost. Use special design procedures in areas having freezing temperatures and frost-susceptible subgrade soil. (See Paragraph 5, below.)

2. RIGID PAVEMENT STRESSES. Design criteria for specific stresses are given below:

a. Wheel Configuration, Total Load, and Tire Pressure. Stresses developed in rigid pavement depend on total load, wheel configuration and spacing, and tire pressure.

(1) Maximum Stress. Maximum stress is primarily a function of individual wheel loads when axle spacing exceeds about 4-1/2 feet.

(2) Pavement Stress. For a given wheel load, pavement stress increases with increasing tire pressure.

b. Modulus of Subgrade Reaction. Obtain subgrade modulus (K) for a plate loading test. Make sufficient tests to obtain results for areas of different soil types. See Section 2.

(1) Highway Design. Normally, large numbers of tests are not required for highway design because of limited influence of subgrade modulus on required thickness of pavement.

(2) Estimated Value. Estimated values of subgrade modulus are acceptable if adequate subsoil investigations have been made. For approximate values of various soils, see Table 2. Do not use estimated values of subgrade modulus exceeding 300, unless substantiated by field-bearing test results. Values in excess of 500 should not be used regardless of test results.

c. Flexural Strength of Concrete. Determine concrete flexural strength at failure when tested at 28 days by third-point loading; use ASTM C78. Check results for probable reliability if compressive strengths are known from average relationships of Figure 10. Do not use this figure in lieu of flexural strength tests.

(1) Flexural Strength. For a typical plot of flexural strength variation with age of concrete, see NAVFAC DM-21.

d. Thickness Design Procedure. Use design curves of Figure 11 with stress equal to concrete flexural strength divided by a factor of safety of 2.0, and with subgrade modulus to obtain required thickness of slabs as shown by the dotted line. Thickness shall be rounded off to nearest 1/2 inch. Consider the need for modifying computed slab thickness when unusual concrete behavior occurs. Specific data for this modification are not available; obtain experience of local highway departments. Conditions indicating modification of computed thicknesses are:

(1) Abnormally slow rate of increase in concrete strength.

(2) Decrease of 28-day strength of concrete with time.

(3) High moisture absorption by aggregate or concrete with resulting abnormal shrinkage. This can develop excessive curling or tensile stresses.

3. BASES. Provide bases under rigid pavements, primarily to maintain design load bearing capacity of pavement. In some cases, structural benefits from the use of bases result in more economical construction.

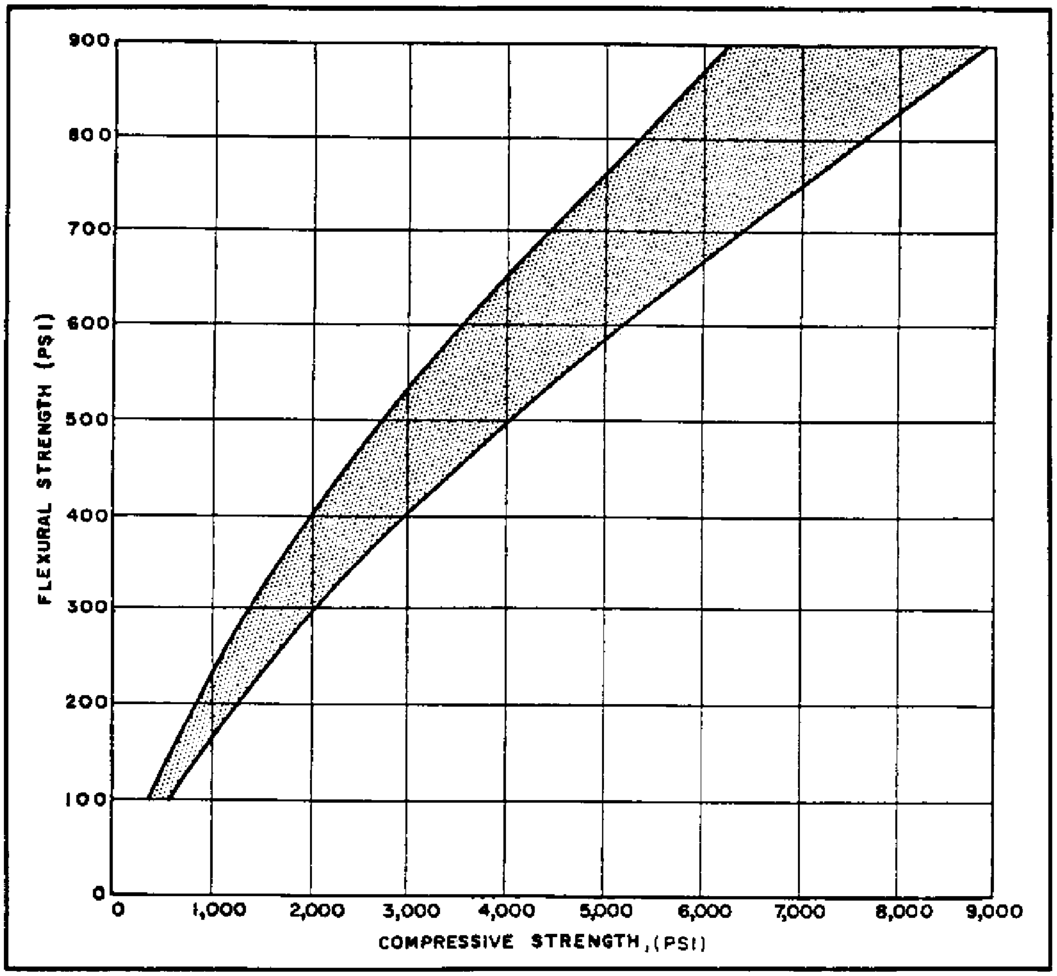
a. Uses. In addition to their structural functions, bases are used to:

(1) Prevent "pump" of subgrade.

(2) Provide uniform bearing surfaces for pavement slabs.

(3) Replace soft, expansive, or highly compressible soils.

(4) Replace frost-susceptible soils to protect subgrades from deterioration where subject to frost.



W/C RATIO — 4 TO 8 GAL PER SACK
AGE — 1 TO 28 DAYS
TYPES I and III PORTLAND CEMENT

FIGURE 10
Average Relationship Between Compressive Strength of 6 × 12 Inch Cylinder and Flexural Strength of Beams Tested by Third-Point Loadings

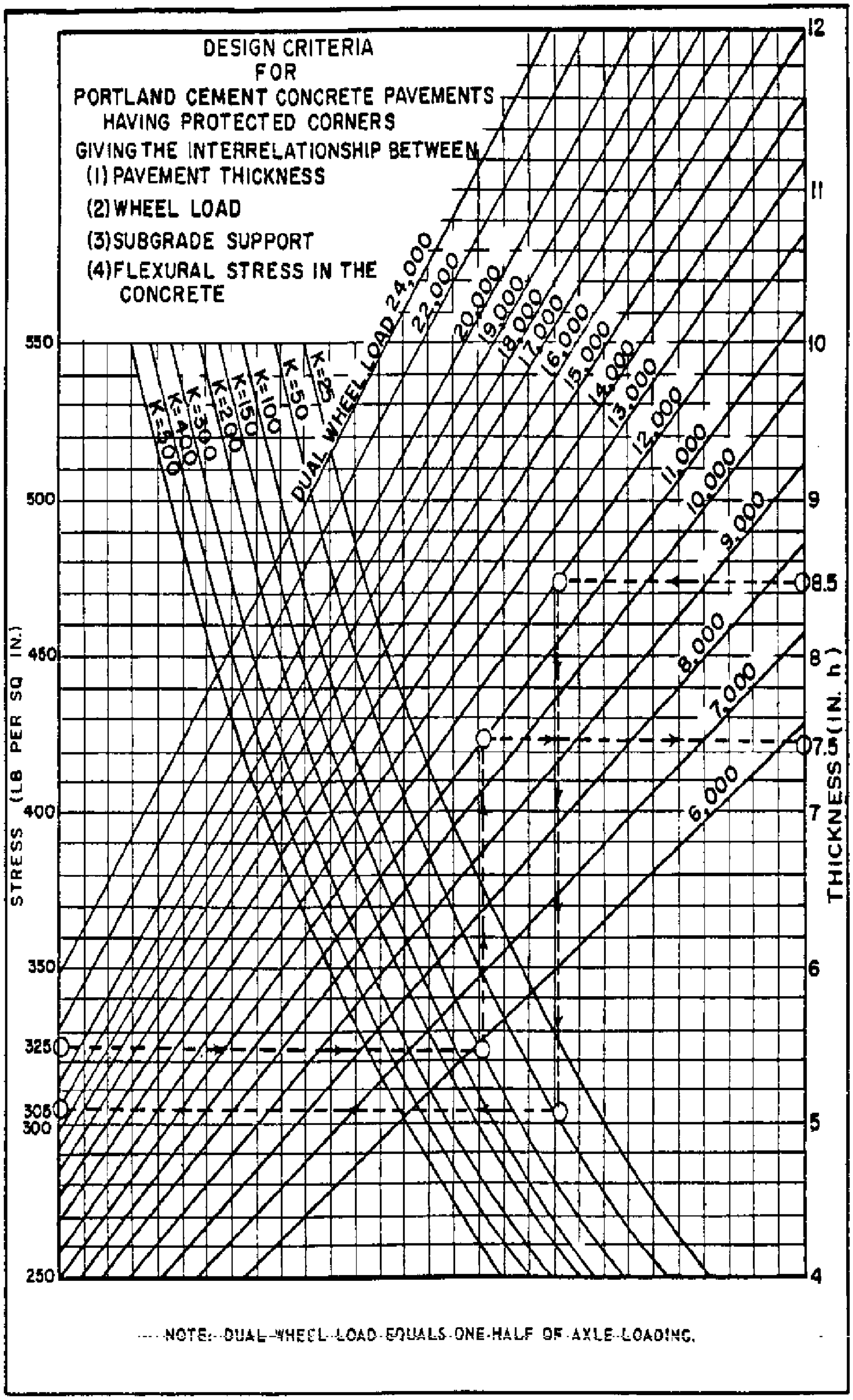


FIGURE 11

Design Curves for Concrete Pavement Thickness (Highways)

(5) Effect uniform movements in subgrade areas subject to frost heaving.

(6) Provide operating surfaces for construction equipment, especially during unfavorable weather.

b. Materials. Processed or stabilized, well-graded materials that are not frost susceptible usually are suitable base materials under concrete pavements; see Section 6. The plasticity index shall not exceed 5.

c. Compaction. Bases shall be constructed in layers. Design layers with maximum compacted thicknesses of 6 inches and minimum compacted densities of 95 percent of modified Proctor maximum density.

4. DRAINAGE. Provide surface drainage for water collection and removal from road surfaces, and for interception and collection of water flowing from adjacent areas. Provide subsurface drainage to intercept, collect, and remove ground water flow: (a) into subgrade, (b) to lower high water tables, (c) to drain perched water tables, and (d) to prevent frost action. For design criteria for surface drainage, see NAVFAC DM-5.3. For subsurface drainage, see subgrades in Section 4 and bases in Section 6.

5. DESIGN FOR FROST EFFECTS. In areas having freezing temperatures, determine the need for designing for frost effects from state, county, or city highway or street departments. Also, determine depths of frost penetration from highway departments and from local utilities. Where design for frost is necessary, use results of local experiences. For more complete discussion of frost design, see NAVFAC DM-21.

6. JOINTS. Use expansion and contraction and construction joints in pavements to prevent uncontrolled cracking caused by shrinkage and by contraction and expansion induced by temperature changes. Also provide joints to control random cracking results from uneven subgrade support and construction joints, as required. Use the kinds of joints and sealing compounds specified in Joints, Reinforcement, and Mooring Eyes Concrete Pavement, NAVFAC TS-02614.

7. DESIGN OF DISTRIBUTED REINFORCING STEEL. Distributed reinforcing steel (wire mesh and bar mat) is used to control cracking and to prevent cracks from enlarging. Provide in accordance with NAVFAC TS-02614.

Section 10. DESIGN OF PORTLAND CEMENT CONCRETE

1. MIX DESIGN. Concrete mixes for rigid pavements should be designed in accordance with Portland Cement Concrete Pavement for Roads and Airfields. NAVFAC TS-02613.

2. AIR ENTRAINMENT. Use air entraining admixture wherever available. Air entrainment usually causes moderate flexural strength decreases; consider this when selecting design flexural strength.

3. LOW ALKALI CEMENT. As a precaution against alkali aggregate reactions, use low alkali cement containing not more than 0.6 percent total alkalies.

Section 11. LOW-COST ROADS

1. BASIC FACTORS. Low-cost roads are suitable for low traffic volumes only and result in excessive maintenance costs and unsatisfactory service if used improperly. Where roads are upgraded in stages, plan the work in phases that will permit existing roads to be incorporated in upgraded phases with a minimum loss of existing construction.

a. Progressive Improvement of Roads. Stage construction of roads can be accomplished readily where a flexible type of construction is suitable and economical, as for normal pavement areas.

b. Stage Construction Steps. Construction steps are as follows:

(1) Untreated aggregate surface.
(2) Oil surface treatment.
(3) Single or double bituminous surface treatments.
(4) Mixed-in-place bituminous surfacings.
(5) Plant-mixed bituminous surfacings.

2. TYPES OF LOW-COST PAVEMENTS. Classification of low-cost pavements are:

(1) Oil and soil-cement treatments.
(2) Soil-lime.
(3) Untreated surfacings (sand-clay, shell, soft limestone, clay gravel).
(4) Single and double bituminous surface treatments.
(5) Road-mixed or mixed-in-place bituminous surfacings.
(6) Plant-mixed bituminous surfacings.
(7) Penetration macadam.
(8) Asphaltic concrete.

3. DESIGN. The design of low-cost roads usually is similar to that of mechanically stabilized subbases and bases. For basic requirements, see Table 17. Proper maintenance is an integral feature of satisfactory low-cost roads.

TABLE 17
Basic Requirements for Low-Cost Roads

Property	Requirements
Load Bearing Capacity	Must be able to support traffic loading and volume.
Abrasion Resistance	Adequate abrasion resistance to withstand anticipated traffic.
Stability	Must be stable when wet.
Slipperiness	Must not be excessively slippery when wet.
Volume change	Low shrink and swell properties.
Gradation	Should be a dense gradation for impervious surface, to minimize infiltration. Have slight excess of fines.
Compaction	Compact to high density at optimum water content for maximum stability and impermeability.
Plasticity	Maximum liquid limit = 35. Maximum plasticity index = 8.
Materials	Granular materials similar to base and subbase materials. Must utilize locally available materials to maximum extent. Use: Pit-run sands and gravels, caliche, chert, and other suitable local materials, possibly modified.

SECTION 12. SIDEWALKS

1. OVERALL REQUIREMENTS. Sidewalks should be designed to provide an economical, all-weather surface suitable for pedestrian traffic. See NAVFAC DM-5.5 for widths and grades.

2. DESIGN. Use one of the sidewalk types discussed below, as appropriate for local conditions. Where sidewalks cross driveways and private entrances, design portions of sidewalks to be used by vehicular traffic for anticipated loads.

a. Aggregate Base and Bituminous Surface. Use a stabilized base about 4 inches thick, consisting of gravel, slag, stone, or other approved materials; and a minimum l-inch-thick surface course consisting of a bituminous sand-mix or a bituminous concrete-mix.

b. Concrete Walks. Use 2500-psi concrete, minimum 4 inches thick, grooved longitudinally and transversely at 3- to 5-foot intervals to a depth of at least 1/4 inch per inch of slab thickness, to provide weakened plane joints.

(1) Use expansion joints to separate walks from buildings or structures.

(2) Provide a wood float or broom finish with tooled edges at sides and transverse joints.

c. Temporary Walks. Use stabilized soil mixtures that will be stable during adverse weather conditions (see low-cost roads, Section 11). Utilize available materials, mixing with other materials for stabilization as necessary. Use bituminous surface treatment where justified, or stabilize soil in-place where it is suitable, without any additional surfacing.

Section 13. UTILIZATION OF REINFORCING FABRICS IN ASPHALT PAVEMENT

1. FUNCTIONS. Reinforcing fabric may be used in asphalt pavement to serve two functions: a) interlayer between base course and subgrade to not only provide some reinforcement, but also to prevent intrusion of subgrade fines into granular base layers and to provide planar flow of water between base and subgrade, and b) tensile reinforcement of a thin asphalt overlay. Fabrics may be used to retard or minimize reflection cracking in asphalt resurfacings. Asphalt and portland cement concrete pavements of all types are frequently overlayed with additional layers of asphalt concrete to strengthen pavement that has been weakened due to fatigue cracking or environmentally induced cracking. Limited experience and test data indicate that fabrics can function to enhance the service life of asphalt pavement overlays.

2. FABRIC MATERIALS

a. Description. Fabrics available for use in pavement construction are made of synthetic fibers. The synthetic fiber fabrics are made with uniformity in production. Some are and some are not resistant to rot and mildew. The pore sizes in the fabrics are reasonably uniform. Fabric strength and resistance to chemicals vary from fabric to fabric. Available fabrics are either one of two types, woven or nonwoven. The woven fabrics are manufactured using the weaving process whereas the nonwoven fabrics are formed by bonding fibers together using heat fusion, chemical fusion or needle punching. The types of fibers used include polyester, polypropylene, polyethylene, polyamides, nylon or glass.

Representative types and styles of fabrics are summarized in Table 18. This list was prepared using information provided by fabric manufacturers and not all data is available for every brand and type of fabric.

b. Fabric Properties. The important fabric properties that affect pavement performance are described as follows:

(1) Grab Tensile Strength. The tensile strength of the fabric is important when the fabric serves as a reinforcement. As a pavement system deforms elastically, the fabric also deforms, thereby inducing tensile stresses in the fabric. The fabric must have sufficient tensile strength to resist these stresses.

(2) Trapezoidal Tear Strength. Once a hole or tear has been introduced into a fabric, the resistance of the fabric to the spreading of the damage is its tear resistance.

(3) Puncture Resistance. A fabric located between a granular material and the subgrade is subject to puncture by the granular material during the placement of the aggregate. The ability of the fabric to resist penetration is its puncture resistance.

(4) Burst Strength. The ability to resist stresses applied uniformly over a large area and in all directions is the burst strength of the fabric. This is a special case of the tensile type of failure.

Table 18. Representative Fabric Properties and Applications. (j)

Fabric	Style or Grade	Fiber Type(a)	Process Type(b)	Weight oz/yd	Thickness (mils)	EOS Sieve No.	Grab Tensile Strength (lb)	Grab Elongation %	Burst Strength (psi)	Trapezoidal Tear Strength (lb)	Recommended Usage: Stress Relief (g)	Recommended Usage: Layer Separation(h)	Recommended Usage: Filtratic (i)
Adva (d)	I	1	1	6.8	17	100	244		528				X
Filter (d)	II	1	1	8.1	22	35	232		532				X
Amoco (c)	Amopav	1	2	5.4			90	55	230		X		X
(f)	Propex 2002	1	2	5.0		100	200	20	400			X	
	Propex 4245	1	2	5.0		70	90	60	230				X
BIDIM (d)	C22	2	2	4.5	60	50	115	85	225	62	X		
	C28	2	2	6.0	75	50	160	80	360	93	X		
	C34	2	2	8.0	90	70	225	75	400	125	X	X	X
	C38	2	2	10.0	110	100	300	65	500	170			X
	C42	2	2	16.2	190	100	610	60	850	250		X	X
Fibretex(d)													
	150	1	2	4.8	50	50	120	110	220	50			X
	200	1	2	6.3	60	70	140	125	250	60			X
	300	1	2	8.5	90	80	210	140	350	75			X
	400	1	2	11.8	110	80	260	160	450	100		X	
MIRAFI (d)	140N	1	1	4.5	60	100	120	55	210	50			X
(e)	500X	1	3	4.0	9	20	200	30	375	100		X	
	600X	1	3	6.0	12	20	300	35	600	120		X	
	900N	1	1	4.0	50		115	60			X		
Petromat(d)		1	2	4.3			115	65			X		
Poly (c)	X	1	3	7.2		70	380	23	540				X
Filter(c)	GB	1	3	6.6		40	200	23	500				X
STABILENKA (c)	T80	2	2	2.3	20	230	64	55	100	29			X
	T100	2	2	3.4	30	100	90	41	140	29			X
	T140N	2	2	4.0	40	80	125	75	149	48			X
SUPAC (c)		1	2	5.3	50		150	80	300	73			X

Table 18. Representative Fabric Properties and Applications (cont'd). (j)

Fabric	Style or Grade	Fiber Type(a)	Process Type(b)	Weight oz/yd	Thickness (mils)	EOS Sieve No.	Grab Tensile Strength (lb)	Grab Elongation %	Burst Strength (psi)	Trapezoidal Tear Strength (lb)	Recommended Usage: Stress Relief (g)	Recommended Usage: Layer Separation(h)	Recommended Usage: Filtratic (i)
TREVIRA(c)	S1115	2	2	4.5	85	70	130	85	220	50	X		X
	S1120	2	2	6.0	100	50	175	85	300	65			X
	S1127	2	2	8.0	125	70	260	85	380	100		X	
	S1135	2	2	10.0	150	100	340	90	500	130		X	
	S1145	2	2	13.0	175	100	430	90	600	185		X	
	S1155	2	2	16.0	210	120	525	90	800	205		X	
TYPAR(d)	3401	1	1	4	15	70	135	62	200	74			X
	3601	1	1	6	19	140	207	63	263	103			X

NOTE: Blanks in the table indicate information not available from manufacturer's literature.

a) Fiber Type: 1 - Polypropylene
2 - Polyester

b) Process Type: 1 - Nonwoven, Spun bonded
2 - Nonwoven, Needled or Mechanically bonded
3 - Woven.

c) Manufacturer's literature did not indicate the fabric to be rot proof and mildew proof

d) Rot proof and mildew proof

e) Asphalt retention is 3.5 oz/ft^2

f) Asphalt retention is 2.5 oz/ft^2

g) One of the characteristic functions that fabric can provide. Fabrics used between layers of asphalt paving provide stress relief by absorbing the tensile stresses imparted from lower layer to upper layer. Hence, net result is a reduction in reflection cracking

h) One of the characteristic functions that fabric can provide. Fabrics are placed between fine grain or clay soils subgrade and granular or aggregate base layers. This separation prevents contamination of bases where frost penetration is a consideration and also is used to expedite pavement construction on wet subgrade.

i) One of the characteristic functions that fabric can provide. Fabrics may be used in drainage application where the fabric envelopes the filter stone and acts as a filter medium, or is used together with other drainage appurtenance such as perforated pipes or vertical drainage devices.

j) Fabrics given in this Table were representative of the Industry at the time this Table was prepared (1984). The information is subject to change. Fabric names and properties should not be cited on project drawings or in project specifications.

(5) Grab Elongation. Elongation may be due to the reorientation of the fibers in a fabric when stressed or due to the stretching of the fibers. Increased elongation reduces the amount of stress in the fabric and thereby the effectiveness of the fabric as a reinforcement.

(6) Asphalt Retention. The characteristic of paving fabric that measures the ability to retain and hold asphalt while in place. The normal units on this measure is weight/unit area.

(7) Equivalent Opening Size. The openings in a fabric noted in standard sieve sizes which are commonly used to refer to soil particle sizes.

(8) Modulus of Elasticity. The rate of increase of stress with respect to strain below the proportional limits. The modulus of elasticity is thus equal to the slope of the initial straight line portion of a stress-strain diagram.

(9) Coefficient of Water Permeability. A measure of the flow of water through a permeable media. This coefficient has units of velocity, e.g. cm/sec.

Test procedures for evaluating the above properties are summarized in Table 19.

3. CRITERIA FOR USE OF FABRICS

a. General. To achieve reinforcement from the use of fabrics in asphalt pavement, their range of application must not be overextended. Fabrics have been used successfully in many applications but, likewise, have failed to improve pavement performance in many of the same situations. Experience has shown, although no long-term performance data is yet available, that some of the fabrics do enhance the life of thin asphaltic resurfacings. When used with asphalt overlays of 3 inches (75mm) or less, reduced reflection cracking can be achieved. The fabric not only retards or reduces reflection cracking but prevents surface infiltration of water. Fabrics have shown good performance when used on pavements with fatigue cracking (alligator skin pattern), longitudinal construction joint cracks in asphalt pavement, and the longitudinal joint between portland cement concrete pavement widened with flexible pavement. In general, fabrics have not proven to serve as well on cracks that are greater than 1/4 inch (6.25mm) wide. In these cases, the fabrics have not prevented a significant amount of reflection cracking but are believed to protect the pavement from surface water intrusion.

b. Overlay Thickness. Overlay thickness design should be accomplished using approved methods. Fabrics should not be used with overlays thicker than 3 inches (75mm). Performance to date has not verified any economic advantage in thicker overlays. Likewise, fabrics

Table 19. Fabric Properties and Standard Test Procedures

Fabric Property	Test Procedure
Asphalt Retention	TX SDHPT 3002
Burst Strength	ASTM D 3786
Grab Elongation	ASTM D 1682
Equivalent Opening Size	ASTM D 422
Modulus of Elasticity	ASTM D 1682
Puncture Resistance	ASTM D 3787
Trapezoidal Tear Strength	ASTM D 1117
Grab Tensile Strength	ASTM D 1682
Thickness	ASTM D 1777
Weight	ASTM D 3776
Coefficient of Water Permeability	CFMC-GET-2 *

Note: * = Celanese Fibers Marketing Company -
Geotextile Evaluation Test - 2 (No ASTM equivalent)

should not be used with overlays 1 inch (25mm) or thinner. If a leveling course is placed prior to the overlay, then the fabric should be between the leveling and overlay courses.

c. Tack Coat. The fabrics are bonded to the existing asphalt surface or the surface of a leveling course by means of a tack coat of asphalt cement.

The selection of a tack coat should be a function of the temperature of the asphalt pavement surface at the time of construction. As with the tack coat quantities, the type of tack coat is somewhat a variable with fabric type. For most fabrics, asphalt cement grades from AC-5 (AR-2000) through AC-20 (AR-8000) cover the range of applicability. When selecting a final tack coat material and the temperature is known, the fabric manufacturer's requirements should be consulted.

The amount of tack coat required is dependent on the condition and texture of the asphaltic surface on which the fabric is to be placed and on the type of fabric. Most common fabrics require about 0.20 - 0.30 gal/sq. yd. of residual asphalt. Figure 12 relates surface texture to tack coat quantity. The designer may use the word description of the existing pavement surface or perform texture tests. The texture measure in Figure 12 is based on the putty impression test. The test equipment consists of 1) a 6-inch (150 mm) diameter by 1-inch (25mm) thick metal plate with a 4-inch (1OOmm) diameter, 1/16-inch (1.56mm) deep recess machined into one side, and 2) a 15.90-gram ball of silicone putty. When placed on a smooth surface, 15.90 grams of putty will smooth out to a 4-inch (1OOmm) diameter circle, 1/16-inch (1.56mm) deep, thus completely filling the recess.

The silicone putty is formed into an approximate sphere and placed on the pavement surface. The recess in the plate is centered over the putty, and the plate is pressed down in firm contact with the road surface. The more irregular the surface texture (the higher the macro-texture) the smaller the resulting putty diameter because more material is required to fill the surface texture. Average texture depth, based on volume per unit area, is calculated from an average of four diameter measurements.

d. Overlay Reinforcement. Fabrics that are suitable for use over distressed asphalt pavement surfaces shall meet the specifications noted in Table 20. Generally, all the fabrics available and in use that meet these specifications are of the nonwoven type. Some products have had more widespread use than others. The designer should check the data furnished herein against any other manufacturers' literature, information or data that may be more current.

e. Layer Separation. Fabrics may be used as layer separators to prevent contamination of base materials in flexible pavements. Layer separation also permits expeditious construction in soft, yielding subgrades. Layer separation may be a valuable treatment to consider in frost potential areas. The fabric will prevent the contamination of nonfrost susceptible materials by minimizing subgrade intrusion into base

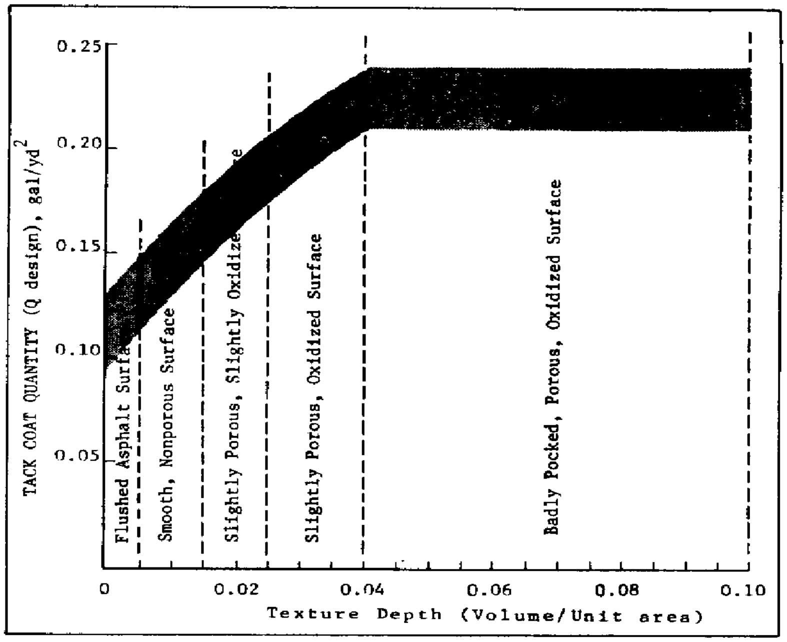


FIGURE 12
Tack Coat Quantity as Related to Pavement Surface Texture

REFERENCE: Report No. 3424-1, entitled "Mirafi Fabric Tack Coat Requirement for Asphalt Overlays", July 1977, Texas Transportation Institute, Texas, A & M University, by J.W. Button and J.A. Epps

Change 1, Mar 1986

Table 20. Specifications for Fabrics Used as Asphalt Overlay Reinforcement

Fabric Property		Test Method	Fabric Requirements (Minimum Values)
I.	Resistance to Installation Stresses		
a.	Grab Tensile Strength, lb.	ASTM D 1682	90
b.	Grab Tensile Elongation, %	ASTM D 1682	55
II.	Performance Criteria During Service Life		
a.	Shrinkage from Asphalt (275 F), %	Texas SDHPT Item 3002	10 (max)
b.	Asphalt Retention, oz/ft.2-	Texas SDHPT Item 3002	2.5

layers. The fabrics available and used for layer separation in flexible pavements are more numerous than those for overlay reinforcement. These fabrics should meet the requirements identified in Table 21. Generally these are much stronger fabrics than those used in overlays and are of the woven and nonwoven type. When considering the use of fabrics between layers the designer should refer also to local experience.

4. ECONOMICS OF FABRIC USE. Fabric uSe must not only be an engineering improvement, it must be a cost-effective improvement. The cost of fabric and its installation as a layer separator will vary with the type of fabric, experience of the contractor and size of the project. The cost of fabric has been associated with the cost of an additional 1 (25mm) or 2 (50mm) inches of base layer thickness or about the same as lime treated subgrade. The designer should select thicknesses of layers as indicated in Section 7 Flexible Pavement Thickness design. Base or subbase thickness may be reduced by 2 inches (50mm) when layer separation fabrics are specified but should not be less than minimum values set forth in Section 7. Furthermore, on subgrades with a CBR less than 5 no reduction in base should be applied. In cases where designs with fabric still cost more than conventional designs, such designs should be recommended only when there is demonstrated experience of longer pavement life.

The use of fabric in conjunction with an asphalt overlay of an existing pavement must be a cost-effective application. There are no demonstrated data that reliably indicate the relative load carrying value of fabric in terms of asphalt overlay thickness. There is evidence that with the use of fabrics over "alligator" or fatigued cracked asphalt pavement, reflection cracking is minimized and longer pavement life can be expected. The type of considerations that might warrant the extra expenditure for fabrics in asphalt overlays include: 1) areas with vertical clearance problems, and 2) high traffic areas which are difficult to close for repairs and/or rehabilitation.

Table 21. Specifications for Subgrade Separation Fabrics Used in Flexible Pavement Construction

Fabric Property		Test Method	Fabric Requirements (Minimum Values) Category A	B
I.	Resistance to Installation Stresses.			
a.	Grab Tensile Strength, lb.	ASTM D 1682	280	200
b.	Grab Tensile Elongation, %	ASTM D 1682	50	50
c.	Burst Strength, psi	ASTM D 3786 (Diaphragm Method)	600	400
d.	Trapezoid Tear Strength, lb.	ASTM D 1117	110	110
II.	Performance Criteria During Service Life			
a.	Modulus of Elasticity (Load at 10% Elongation) lb	ASTM D 1682	125	105
b.	Water Permeability, k, cm/sec (H, 20 cm to 10 cm)	CFMC-GET-2*	.001	.001

Category A: Soft soil, heavy traffic conditions and situations which warrant a high margin of safety.

Category B: Firmer soil, lighter traffic conditions and situations which do not warrant a high margin of safety.

Note: * = Celanese Fibers Marketing Company - Geotextile Evaluation Test - 2 (No ASTM equivalent)

BIBLIOGRAPHY-FABRICS

Bell, J. R., R. G. Hicks, et al., "Evaluation of Test Methods Use Criteria for Geotechnical Fabrics in Highway Applications." Report No. FHWA/RD-80/021, Federal Highway Administration, Washington, D.C., June 1980.

Bushey, Roy W., "Experimental Overlays to Minimize Reflection Cracking," Report No. FHWA-CA-TL-3167-76-28, California Department of Transportation, Sacramento, California, September 1976.

Button, Joe W. et al., "Fabric Interlayers for Pavement Overlays," Texas A&M University, Harmon, Celanese Fibers Marketing Company, North Carolina.

Carey, Donald E., "Evaluation of Synthetic Fabrics for the Reduction of Reflective Cracking," Research Project No. 70-1B(B) Louisiana Department of Highways, Baton Rouge, Louisiana, April 1975.

Donnelly, Denis E. et al., "Reflection Cracking in Bituminous Overlays," Report No. CDOH-P&R-R-76-6, Federal Highway Adminsitration, Washington, D.C., December 1976.

DuPont Company, "Paving Fabric for Longer-Lasting Asphalt Overlays," Reepav and Typar Sales, Wilmington, Delaware.

Eaton, Robert A. and Randy Godfrey, "Fabric Installation to Minimize Reflection Cracking on Taxiways at Thule Airbase, Greenland," Special Report 80-10, U.S. Air Force, Washington, D.C., May 1981.

Federal Highway Administration, "Sample Specifications for Engineering Fabrics," Report No. FHWA-TS-78-211, Washington, D.C., 1978.

Finn, F. N. et al., "Minimizing Premature Cracking of Asphalt Concrete Pavements," Prepared for 1976 Annual Meeting of the Association of Asphalt Paving Technologists, February 1976.

Gallaway, Bob M. and Jerry G. Rose, "Macro-Texture, Friction, Cross Slope and Whell Track Depression Measurements on 41 Typical Texas Highway Pavements," Research Report No. 138-2 Texas Transportation Institute, College Station, Texas, June 1970.

Haliburton, T., et al., "Potential Use of Geotechnical Fabric in Airfield Runway Design," Report No. AFOSR-TR-80-1192, Oklahoma State University, Stillwater, Oklahoma, October 1980.

Hensley, M. J., "Open Graded Base Course for Control of Reflective Cracking," Presented at AASHTO, South Carolina, October 13, 1975.

Hoover, Thomas P., "Nonwoven Geotextile Fabrics: Evaluation and Specification for Subdrainage Filtration," Report No. FHWA/CA/TL-80/11, California Department of Transporation, Sacramento, California, May 1981.

Fabric Material (Petromat), Open-Graded Friction Courses, and Conventional Hot Mix," Report No. FHWATX78-606-3, Texas State Department

Jackson, Ralph D., "Use of Fabrics and Other Measures for Retarding Reflective Cracking of Asphaltic Cocnrete Overlays," Report No.

Washington, D.C., March 1980.

Kanarowski, Stanley, "Study of Reflection Cracking in Asphaltic

Air Force Weapons Laboratory, New Mexico, March 1972.

Koerner, Robert M. and Joseph P. Walsh, "Construction and

& Sons, Inc., 1980.

Ladd, Donald M., "A Review of Fabric Usage in Pavements Constructed

Transporation, Washington, D.C., December 1979.

McDonald, E. B., "Reduction of Reflective Cracking by Use of

Highways, Pierre, South Dakota.

McGhee, K. H. "Efforts to Reduce Reflective Cracking of Bituminous

Highway & Transportation Research Council, Charlottesville, Virginia, November 1975.

for Airport Pavements, A State of the Art," Report No. FAA-RD-79-57, U.S. Department of Transportation, Washington, D.C., May 1979.

FAA-RD-80-8, Department of Defense and U.S. Department of Transportation, Washington D.C., September 1979.

Carolina.

Monsanto Textiles Company, "BIDIM Engineering Fabric for Pavement

Nixon, John F., "A Survey of Reflective Crack Retardation by Fabric Materials in Texas," Report No. 606-2, State Department of Highways and

Phillips Fibers Corporation, "The Petromat System" Greenville, South Carolina.

Mix Overlaying," Bartlesville, Oklahoma.

Skog, John B. et al., "Statewide Flexible Pavement Performance and Deflection Study," Report No. FHWA-CA-TL-78-28, California, December 1978.

Smith, Richard D., "Prevention of Reflection Cracking in Asphalt Overlays with Structofors, Petromat, and Cerex," Project HR-158, Iowa Department of Transportation, May 1977.

Steward, J., R. Williamson and J. Mohney, "Guidelines for Use of Fabrics in Construction and Maintenance of Low-Volume Roads," Report No. FHWA-TS-78-205, USDA Forest Service, Portland, Oregon, June 1977.

Trevira, "Trevira Spunbound Engineering Fabric for Asphalt Pavement Systems - Full Depth, Layered, and Overlayed," Division of American Hoechst Corporation, Spartanburg, South Carolina.

Vedros, Phillip J., "Evaluation of the Effectiveness of Membranes for Prevention of Crack Reflection in Thin Overlays," Report No. GL-79-4, Vicksburg, Mississippi, March 1979.

Vedros, Phillip J., "Evaluation of Membrane Interlayers for Prevention of Crack Reflection in Thin Overlays," Report No. GL-81-8, Vicksburg, Mississippi, October 1981.

Way, George, "Prevention of Reflective Cracking in Arizona Minnetonka - East (A Case Study)," Report No. FHWA-AZ-HPR-224, Arizona Department of Transportation, Phoenix, Arizona, May 1972.

Way, George, "Prevention of Reflective Cracking Minnetonka - East (1979 Addendum Report)," Arizona Department of Transportation.

Wood, William A., "Methods of Minimizing Reflection Cracking in Bituminous Overlays," FHWA Notice N 5140.9, U.S. Department of Transportation, January 19, 1976.

REFERENCES

1. AASHTO Interim Guide for Design of Permanent Structures, GDPS 2-72, Chapter III Revised, 1981; American Association of State Highway and Transportation Officials (formerly American Association of State Highway Officals), Suite 225, 444 N. Capitol St., N.W., Washington, D.C. 20001.

2. Airfield Pavements; NAVFAC DM-21, June 1973 (Reprinted with Change 1, June 1976 incorporated); U.S. Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.

3. Asphalt Binder & Wearing Courses for Flexible Pavement (Central Plant Hot Mix), NAVFAC TS-02681, August 1980; U.S. Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.

4. Bituminous Pavements Standard Practice, TM 5-822-8, June 1972; Department of the Army, Corps of Engineers, U.S. Army Engineer Waterways Experiment Station; P.O. Box 631, Vicksburg, MS 39180.

5. Bituminous Surface Treatment, NAVFAC TS-02677, August 1980, U.S. Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.

6. Density of Soil in Place by the Sand-Cone Method, Test Method for, ASTM D 1556-82, American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103.

7. Civil Engineering-Drainage Systems, NAVFAC DM-5.03, June 1979 (Change 1, December 1980); U.S. Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.

8. Flexible Pavements for Roads, Streets, Walks, and Open Storage Areas, TM 5-822-5, May 1980; Department of the Army, Corps of Engineers, U.S. Army Engineer Waterways Experiment Station; P.O. Box 631, Vicksburg, MS 39180.

9. Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading), Test Method for, ASTM C 78-84, American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103.

10. General Provisions and Geometric Design for Roads, Streets, Walks, and Open Storage Areas, NAVFAC DM-5.05, April 1977; U.S. Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.

11. Graded Aggregate Base Course for Flexible Pavement, NAVFAC TS-02686, October 1980; U.S. Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.

12. Civil Engineering-Hydrology and Hydraulics, NAVFAC DM-5.02, June 1979; U.S Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.

TS-02614, January 1979; U.S. Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.

Embankments, and Foundations, MIL-STD (Military Standard) 619B, June 1968; U.S. Naval Publications and Forms Center, 5801 Tabor Ave.,

15. Test Methods for Bituminous Paving Materials, MIL-STD (Military Standard) 620A, January 1966, with Notice 1, May 1967; U.S. Naval

19120.

16. Subgrade, Subbase, and Test Method for Pavement Base-Course

Notice 2, December 1968; U.S. Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.

Publication MS-2-84; The Asphalt Institute, The Asphalt Institute Building, College Park, MD 20740.

Using 5.5 lb (2.49-Kg) Rammer and 12-Inch (305-mm) Drop, Test Methods for, ASTM D 698-78; American Society for Testing and

19. Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 10-lb (4.54-Kg) Rammer and 18-Inch (457-mm) Drop, Test Methods

1916 Race St., Philadelphia, PA 19103.

20. Nonrepetitive Static Plant Load Tests of Soils and Flexible Pavement

Pavements, Method for, ASTM D 1196-64 (R 1977), American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103.

NFGS-02559 (October 1983); U.S. Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.

Structures, NAVFAC DM-7.02, May 1982; Soil Dynamics, Deep Stabilization, and Special Geotechnical Construction, NAVFAC

Tabor Ave., Philadelphia, PA 19120.

23. Transportation Materials and Methods for Sampling and Testing,

(AASHTO) HM-13 PT 1-82; Suite 225, 444 N. Capitol St., N.W. Washington, D.C. 20001.

24. Structural Engineering: General Requirements, NAVFAC DM-2.01, May 1980; Loads, NAVFAC DM-2.02, November 1981; Steel Structures, NAVFAC DM-2.03, May 1980; Concrete Structures, NAVFAC DM-2.04, May 1980; Timber Structures, NAVFAC DM-2.05, May 1980; Aluminum Structures, Masonry Structures, Composite Structures, Other Structural Materials, NAVFAC DM-2.06, May 1980; U.S. Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.