ENGINEER MANUAL

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April 1984

ENGINEERING AND DESIGN

Flexible Pavements for Roads, Streets, Walks and Open Storage Areas

Mobilization Construction

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

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
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Engineer Manual
No. 1110-3-131

9 April 1984

Engineering and Design
FLEXIBLE PAVEMENTS FOR ROADS, STREETS, WALKS,
AND OPEN STORAGE AREAS
Mobilization Construction

1. **Purpose.** This manual provides guidance for designing flexible pavements
for roads, streets, walks, and open storage areas for U.S. Army mobilization
facilities.

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

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

FOR THE COMMANDER:

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

Engineering and Design
FLEXIBLE PAVEMENTS FOR ROADS,
STREETS, WALKS, AND OPEN STORAGE AREAS
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CHAPTER 1

INTRODUCTION

1-1. **Purpose and scope.** This manual presents criteria for designing flexible pavements for roads, streets, walks, and open storage areas. It is intended for use in designing flexible pavements subject to the geometric design criteria set forth in EM 1110-3-130. Requirements for flexible pavement design for frost conditions are presented in EM 1110-3-138. State and county agencies have developed codes and regulations on criteria tailored to local needs in their jurisdiction. In most cases these agencies have approved sources of material as well as some stockpiled base and subbase material. These codes and regulations along with the potential for materials should be taken into consideration when planning roads, streets, walkways, and open storage areas.

1-2. **Flexible-pavement structure.** A typical flexible-pavement structure is shown in figure 1-1, which illustrates the terms used in this manual to refer to the various layers.

1-3. **Soil classification and soil and pavement tests.** The procedures for classifying soils and for testing and evaluating soils and pavement mixtures given in EM 1110-3-141 are applicable.

1-4. **Explorations and investigations of sources of supply.** Subgrade conditions, borrow areas, and sources of (a) select materials, (b) subbase, base, and paving aggregates, and (c) materials for roads, streets, and open storage areas will be investigated prior to pavement design, in accordance with EM 1110-3-141 except as modified herein. In determining subgrade conditions in cut sections of roads, streets, and open storage areas, borings will be carried to the depth of frost penetration, but in no case to less than 6 feet below final grade.
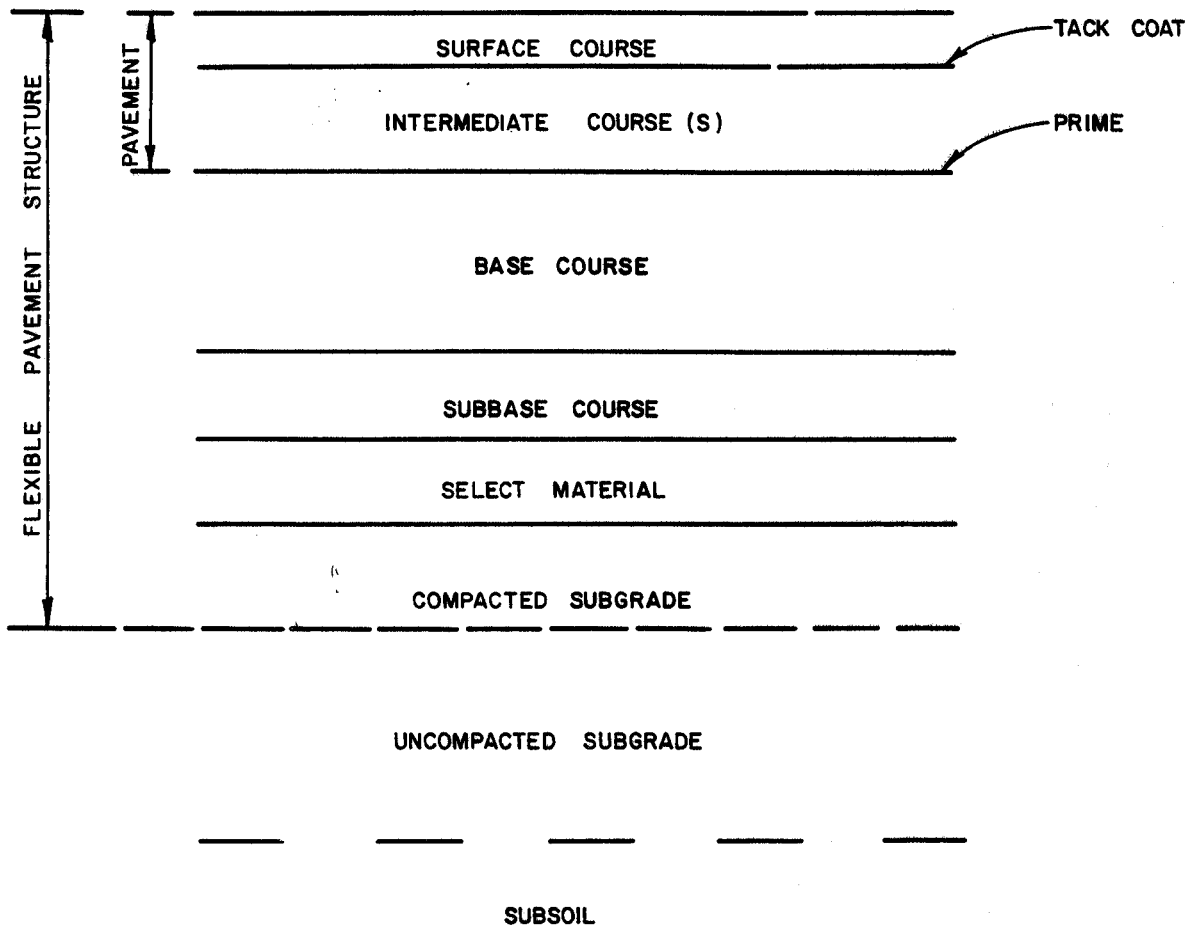
NOTE: 1. The word "structure" is often deleted from the phrase "flexible pavement structure."

2. All layers and coats are not present in every flexible pavement structure. Intermediate courses may be placed in one or more lifts. Tack coats may be required on surface of each intermediate course.

3. Demarcation between subgrade and subsoil is indefinite.

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FIGURE 1-1. TYPICAL FLEXIBLE PAVEMENT STRUCTURE

CHAPTER 2

SELECT MATERIALS, SUBGRADE, AND SUBBASE COURSES

2-1. Materials. The discussions of select materials, subgrade, and subbase courses in EM 1110-3-141 apply. Drainage requirements and facilities are described in EM 1110-3-136. When conditions require design for frost, select materials and subbases should be treated in accordance with frost design provisions of EM 1110-3-138, as applicable.

2-2. Grade line. The procedure for locating the grade line of the top of the subgrade is given in EM 1110-3-141.

2-3. Compaction of select materials, subgrade, and subbases. The procedures for compacting select materials, subgrade, and subbases in normal cases are presented in EM 1110-3-141.

2-4. Subgrade compaction, special cases. The procedures for compacting subgrades of (a) clays that lose strength when remolded, (b) silts that become "quick" when remolded, and (c) soils with expansive characteristics are described in EM 1110-3-141.

2-5. Selection of design CBR for select materials, subgrade, and subbases. Design CBR values for select materials, subgrade, and subbases are to be selected in accordance with EM 1110-3-141, except as modified in table 2-1. Where freezing temperatures will penetrate into frost-susceptible materials, design procedures outlined in EM 1110-3-138, as applicable, will be followed.

Table 2-1. California Bearing Ratio

		Maximum Permissible Value				
		Gradation Requirements				
	Maximum		Percent Passing			
	Design	Size,	No. 10	No. 200	Liquid	Plasticity
Material	CBR	Inches	Sieve	Sieve	Limit(a)	Index(a)
Subbase	50	2	50	15	25	5
Subbase	40	2	80	15	25	5
Subbase	30	2	100	15	25	5
Select material	20	3	---	--	35	12

Note: (a) Determinations of these values will be made in accordance with Method 103 of MIL-STD-621.

2-6. Stabilization or modification. Stabilization or modification of select materials, subgrade, and subbases is accomplished according to procedures in EM 1110-3-137.

CHAPTER 3

BASE COURSE

3-1. General. Only good-quality materials should be used in base courses of heavy-duty flexible pavements.

3-2. Base course compaction. Base courses must be compacted to the maximum degree practicable. Maximum compaction will generally be to 100 percent or more of maximum density, determined in accordance with Method 100 of MIL-STD-621 using CE 55 compaction effort, hereafter referred to as a percent of maximum density.

   a. Materials with design CBR values of 20 and above.

      (1) Base courses. The maximum density that can be obtained is generally in excess of 100 percent of maximum density.

      (2) Subbases and subgrades. Normally, density will be 100 percent of maximum density, except where it is known that a higher density can be obtained practicably, in which case the higher density should be required.

   b. Materials with design CBR values below 20.

      (1) Select material and subgrade in fills. Density will be as shown in figure 3-1 except that in no case will cohesionless fill be placed at less than 95 percent, nor cohesive fill at less than 90 percent.

      (2) Subgrade in cuts. Subgrade must have natural densities equal to or greater than the values shown in figure 3-1. Where such is not the case, the subgrade must either (a) be compacted from the surface to meet the densities shown; or (b) be removed and replaced, in which case the requirements given above for fills apply; or (c) be covered with sufficient select material subbase and base so that the uncompacted subgrade is at a depth where the in-place densities are satisfactory.

3-3. Design CBR of base course. The design CBR of the base course will be assigned in accordance with EM 1110-3-141 with the following addition: Where subbase material is used for base construction, the CBR will be at least 50 and the material must conform to the requirements for 50-CBR subbase as shown in table 2-1.

3-4. Minimum base course thickness. The minimum allowable thickness of the base course will be as shown in table 3-1, except that in no case will the total thickness of pavement plus base for B and D roads and streets be less than 6 inches nor less than frost design minimum specified in EM 1110-3-138 when frost conditions are controlling.
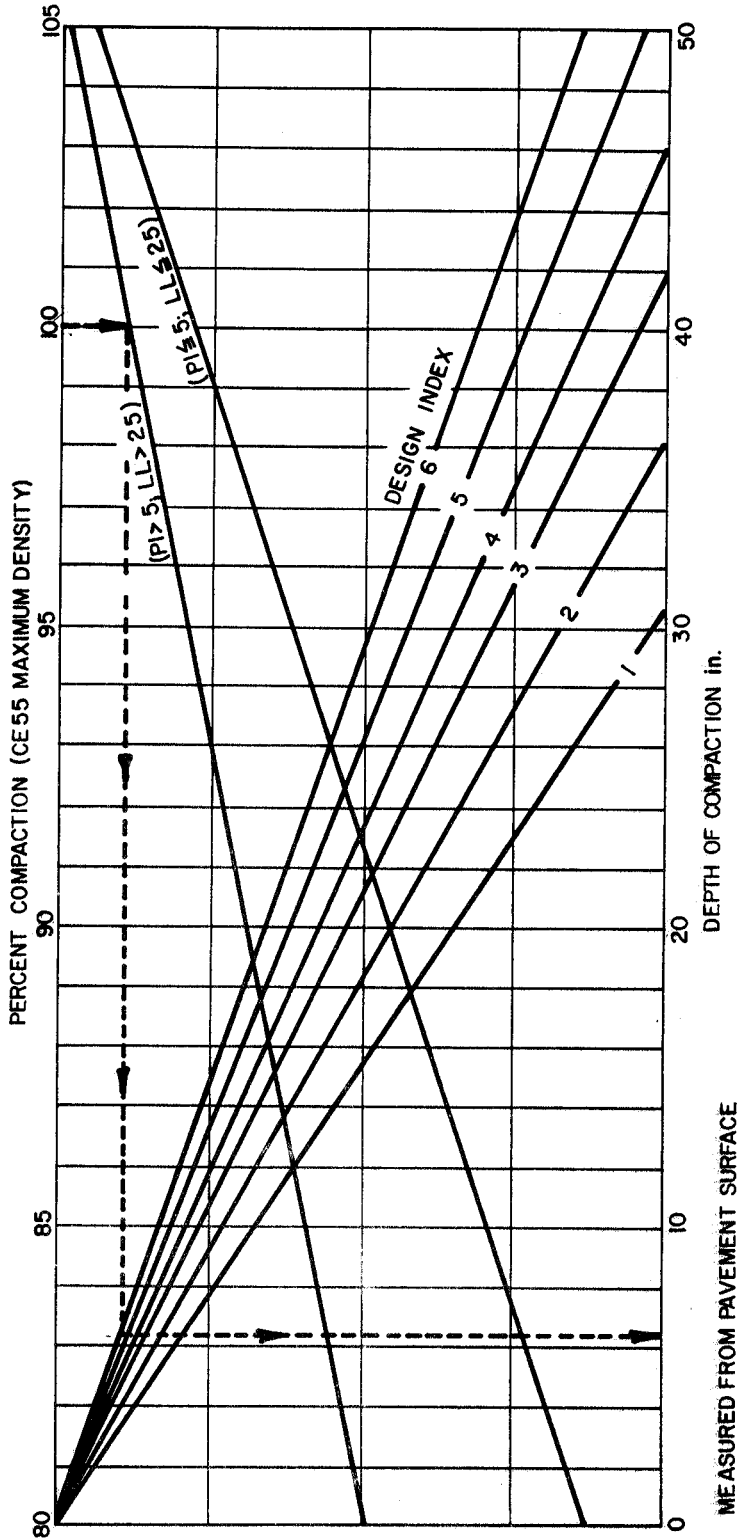
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FIGURE 3-1. DEPTH OF COMPACTION FOR SELECT MATERIALS AND
SUBGRADES OF CONVENTIONAL FLEXIBLE PAVEMENTS

Table 3-1. Minimum Thickness of Pavement and Base for Conventional Pavements

Minimum Base Course CBR

Design Index	Pavement In.	100		80			50a		
		Base In.	Total In.	Pavement In.	Base In.	Total In.	Pavement In.	Base In.	Total In.
1	ST^b	4	4-1/2^c	MST^d	4	4-1/2^c	2	4	6
2	MST^d	4	5^c	1-1/2	4	5-1/2^c	2-1/2	4	6-1/2
3	1-1/2	4	5-1/2^c	1-1/2	4	5-1/2^c	2-1/2	4	6-1/2
4	1-1/2	4	5-1/2^c	2	4	6	3	4	7
5	2	4	6	2-1/2	4	6-1/2	3-1/2	4	7-1/2
6	2-1/2	4	6-1/2	3	4	7	4	4	8

a In general 50-CBR base course will only be used for Class E roads and streets.
b Bituminous surface treatment (spray application).
c Minimum total thickness of pavement plus base for Classes B and D roads and streets will be 6 inches.
d Multiple bituminous surface treatment (spray application).

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3-5. Stabilization or modification. Stabilization or modification of base courses may be accomplished according to procedures in EM 1110-3-137.

CHAPTER 4

PAVEMENTS

4-1. General. Bituminous pavements provide a resilient, waterproof, load distributing medium that protects the base course from the detrimental effect of water and the abrasive action of traffic. Bituminous pavements are subject to maintenance due to wear, weathering, and deterioration from aging. Flexibility of bituminous pavement permits slight adjustments in the pavement structure, owing to consolidation of base course or effect of load, without detrimental effect. Hot-mix bituminous pavements will be designed by either the Marshall or gyratory method for normal traffic on roads and streets, using criteria for 100- or 200-psi tire pressure, as appropriate.

4-2. Bitumen. Bituminous materials used in paving are asphalt or tar products. Although asphalts and tars resemble each other in general appearance, they do not have the same physical or chemical characteristics. Tars are affected to a greater extent by temperature changes and weather conditions; however, they tend to have better adhesive and penetrating qualities than asphalts. Generally, asphalt seal coats and surface courses are preferable to tar seal coats and surface courses for roads. Generally, the heavier types and grades should be employed for the warm climates and the lighter types and grades for the cold climates.

4-3. Aggregates. The aggregates used in paving mixtures should conform to the pertinent specifications for durability, soundness, and other requirements. The aggregates used for tank roads must be crushed, processed material, except that fine aggregate portion of the mixture may contain percentages of natural sand.

    a. Gradation. As a general rule, the maximum size of the aggregate in a course should not be more than one-half the finished thickness of the surface course or more than two-thirds the thickness of the intermediate or base courses.

    b. Mineral filler. Mineral filler consists of processed materials such as limestone, portland cement, or other similar inert materials. Commercial fillers produced from limestone or other types of stone are readily available in most areas.

4-4. Hot-mix bituminous concrete pavements. Hot-mix bituminous concrete is a mixture composed of well-graded mineral aggregates, mineral filler, and bituminous cement and is particularly suitable for heavy-duty-traffic roads, streets, and storage areas. The procedures for the design of hot-mix bituminous concrete pavement are presented in EM 1110-3-141.

4-5. Plant-mix cold-laid bituminous pavements. Cold-laid bituminous pavements are composed of a mixture of asphalt cement and liquefier, liquid asphalt, powdered asphalt and flux oil, emulsified asphalt or tar, and well-graded mineral aggregate. Normally, the aggregate gradings are the same as used for hot-mix asphaltic concrete. Cold-laid plant-mix bituminous concrete is similar to hot-mix bituminous concrete in appearance and general physical characteristics. A discussion of plant-mix cold-laid bituminous pavements, design and control, is presented in appendix A.

   a. Main uses. In general, the cold-laid bituminous plant mixes are laid in the same manner and have the same paving uses as hot-mix bituminous concrete. They are specifically adaptable for patchwork and construction of small jobs such as open storage areas where the tonnage to be used does not justify the erection of a hot-mix plant. Cold-laid mixtures have special advantages in that they can be manufactured at a central plant and shipped by rail or truck to the site, and they can be purchased in small quantities. The specific types of cold-laid asphalt mixes that are considered satisfactory for paving roads and streets are as noted below.

   b. Types.

   (1) One type of cold-laid bituminous concrete is composed of graded mineral aggregate and liquid asphalt prepared in a standard paving plant. This type of pavement is commonly laid at or near normal atmospheric temperatures in the same manner as hot-mix bituminous concrete. Liquid asphalt mixtures require a curing period after mixing and prior to compaction to permit sufficient evaporation of the volatiles or excessive moisture to enable the mixture to gain sufficient stability to support the compaction rollers. Temperatures and moisture caused by rain will control the length of curing period. Aggregates for liquid asphalt mixes need to be heated only to the extent necessary to reduce their moisture content to 2 percent or less so they may be satisfactorily coated with liquid asphalt. In many cases, the moisture content can be reduced satisfactorily by exposure to sun and wind. The amount of asphalt required is, in general, the same as for hot-mix bituminous concrete.

   (2) Other types of cold-laid bituminous pavements are prepared in a standard paving plant using aggregates, containing not over 2 percent moisture, sprayed with a liquefier and asphalt cement of 80 to 120 penetration. Sometimes a small percentage of lime, usually about 0.5 to 1.5 percent, is added prior to adding the asphalt. The lime, combined with the liquefier, assists in coating the aggregate with asphalt cement. The curing period can be reduced by regulating the amount of liquefier used. Emulsified asphalt and tar are also used for producing cold-laid plant mixes.

4-6. **Bituminous road mix.** Bituminous road mixes are normally mixed in place by the use of travel plants or common types of road building equipment, such as, blade graders, disk harrows, drags, and pressure distributors.

   a. **Binders.** The binders used in road mix construction may be either liquid asphalts, emulsified asphalts, or tars. The percentage of bitumen required is, in general, the same as for cold-laid bituminous concrete and depends upon the type and gradation of the aggregate used.

   b. **Aggregates.** The aggregates used in road mixes may be existing subgrade materials, loosened existing subgrade materials blended with imported materials, or properly processed imported materials placed on the existing base or subgrade. The bitumen is normally applied by a pressure distributor to the processed aggregate on the base or subgrade and then thoroughly mixed with the aggregate.

4-7. **Surface treatments, spray application.** Surface treatments consist of a thin mat of mineral aggregate cemented together with various grades of bituminous materials. The bituminous material is applied by a pressure distributor to any prepared base, followed by an application of mineral aggregate of high quality, and finished by rolling. Surface treatments range from a light application of bituminous material followed by a light cover of sand and rolling to a succession of single treatments built up to various thicknesses, generally not exceeding 3/4 inch.

   a. **Grade.** The quantity and type of bitumen and aggregate to be used for the treatment are dependent upon the condition of the pavement. The bitumen should be of such fluidity and character that it will readily bond the cover aggregate in a uniform layer.

   b. **Uses.** Surface treatments are used for Class D and E roads and streets. Surface treatments provide wearing resistance as well as waterproofing to base courses and new pavements (such as plant-mixed cold-laid, mixed-in-place, and sand mixes). Multiple surface treatments are used to provide even greater wearing resistance and some structural strength.

CHAPTER 5

FLEXIBLE PAVEMENT DESIGN

5-1. Design requirements. Flexible pavement designs will provide the following:

- Sufficient compaction of the subgrade and of each layer during construction to prevent objectionable settlement under traffic.

- Adequate drainage of base course, when frost conditions are a factor, to provide for drainage of base course during spring thaw.

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

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

5-2. Design procedure.

   a. General. In designing flexible pavement structure, the design values assigned to the various layers are applied to the curves and criteria presented in this manual. Generally, several designs are possible for a specific site, and the most practicable and economical design is selected. Since the decision on the practicability of a particular design may be largely a matter of judgment, particulars regarding the selection of the final design (including cost estimates) will be included in the design analysis.

   b. Design index. The design of flexible pavements for roads, streets, and similar areas will be based on a design index, which is an index representing all traffic expected to use a flexible pavement during its life. It is based on typical magnitudes and compositions of traffic reduced to equivalents in terms of repetitions of an 18,000-pound, single-axle, dual-tire load. Appendix B explains design traffic and equivalency to a basic loading in more detail. The designer is cautioned that in selecting the design index, consideration will be given to traffic which may use the pavement structure during various stages of construction and to other foreseeable uses. For designs involving rubber-tired vehicles, traffic will be classified in three groups, as follows:

   Group 1. Passenger cars and panel and pickup trucks
   Group 2. Two-axle trucks

Group 3. Three-, four-, and five-axle trucks

Traffic composition will be grouped under the following four
categories:

Category I.   Traffic essentially free of trucks (99 percent
                     Group 1 plus 1 percent Group 2).

Category II.   Traffic including only small trucks (90 percent
                     Group 1 plus 10 percent Group 2).

Category III.   Traffic including small trucks and a few heavy
                     trucks (85 percent Group 1 plus 14 percent
                     Group 2 plus 1 percent Group 3).

Category IV.   Traffic including heavy trucks (75 percent
                     Group 1 plus 15 percent Group 2 plus 10 percent
                     Group 3).

Traffic intensities will be as determined for the selection of the
proper road or street Class, B, D, and E (See EM 1110-3-130). Where
half-track or full-track vehicles or forklift trucks are involved in
the traffic composition, the following considerations apply: (a)
half-or full-track vehicles or forklift trucks having gross weights of
less than 10,000 pounds may be treated as two-axle trucks in
determining design index; (b) half- or full-track vehicles weighing
less than 25,000 pounds and forklift trucks weighing less than about
15,000 pounds may be treated as three-axle trucks in determining design
index; and (c) three additional categories are considered to provide
for heavy half- or full-track vehicles and forklift trucks. These are
shown in the following tabulation.

| | Vehicle Weight, Pounds | |
Category	Tracked Vehicles	Forklift Trucks
V	50,000	30,000
VI	80,000	50,000
VII	120,000	---

    c. Roads and streets. The design traffic to be used in designing a
flexible pavement for a road or street for the usual pneumatic-tired
road vehicles will be selected from table 5-1.

Table 5-1. Design Traffic

Class Road or Street	Design Index
	Category I	Category II	Category III	Category IV
B	2	3	4	5
D	1	2	3	4
E	1	1	2	3

Roads and streets sustaining traffic of half- or full-track vehicles heavier than 25,000 pounds will be designed in accordance with design index 6.

d. Parking areas. In the design of parking areas, design-index values for Category I traffic (see table 5-1) will normally be used.

e. Motor pools and motor storage areas. The design of motor pools and motor storage areas will be based on the pertinent category of traffic to be expected in accordance with the criteria delineated in paragraph b. The proper class will be selected based on expected use intensities compared to the road and street class intensities of use delineated in tables 1-1 and 1-2 of EM 1110-3-130. Design-index values will be selected from table 5-1.

(1) General-purpose motor pools and motor storage areas are those accommodating all pneumatic-tired vehicles having gross weights (empty) not exceeding 30,000 pounds and half- or full-track vehicles weighing less than 25,000 pounds. The design will be based on a flexible-pavement design index of 2.

(2) Special-purpose motor pools and motor storage areas are those accommodating pneumatic-tired vehicles of unlimited gross weight and special- or general-purpose engineer and ordnance equipment such as graders, cranes, engineer or ordnance tractors, tanks, etc. Where less than 50,000-pound half- or full-track vehicle loads must be accommodated, the design will be based on a flexible-pavement design index of 4. Bituminous concrete should not be used for motor pool or motor storage areas for pavement for vehicles exceeding 50,000-pound gross weight or where fuel spillage is a problem.

f. Storage areas. Storage areas subject to traffic of forklift trucks will be designed for proper load and traffic intensity in accordance with paragraph 5-2.b. The design index will normally be selected for the pertinent load category for a Class E road or street shown in table 5-1.

5-3. Alternate design procedure. Roads and streets whose design index is less than 4 as determined in paragraph 5-2.b. may be designed by the governing state highway design procedures providing the following conditions exist:

- The traffic composition consists of rubber-tired vehicles only and no repeated use by half-track or full-track vehicles is anticipated.

- Repeated use of fork lift or other special vehicles exceeding 25,000 pounds is not anticipated.

- The resulting design is more economical than a design following the procedures of paragraph 5-2.

- Where frost and/or poor soil conditions exist, the criteria of EM 1110-3-137 and EM 1110-3-138 must be met.

5-4. Compaction criteria. The compaction criteria presented in EM 1110-3-141 are applicable except as modified herein. Data from tests made on flexible pavements that have been subjected to controlled traffic indicate that such traffic induces a significant compaction effort in the layers of the pavement structure. The compaction effort is highest near the surface, decreases with depth, and varies with axle load and repetitions of load. Figure 3-1 shows the compaction requirements to be used in the construction of roads, streets, and open storage areas. The data in figure 3-1 should be used to establish the percentage of compaction to be specified in the construction specifications for the various layers, or the thickness of overlying layers required to prevent densification in a given layer under traffic. Separate requirements are shown for soils with a plasticity index equal to or less than 5 and a liquid limit of 25 or less and those with a plasticity index greater than 5 and a liquid limit greater than 25. Examples of the use of figure 3-1 are given in appendix B.

5-5. Thickness criteria. The thickness criteria given in EM 1110-3-141 will apply except as modified herein. Statements concerning specific design curves for aircraft loading in EM 1110-3-141 are not applicable. Thickness design requirements are given in figure 5-1 in terms of CBR and the design index determined as discussed in paragraph 5-2. For frost condition design, thickness requirements will be determined from EM 1110-3-138. As applicable, reduction in thickness for rainfall and water table depth criteria in EM 1110-3-136 may be used.

a. Equivalency factors. The use of stabilized soil layers within a flexible pavement provides the opportunity to reduce the overall thickness of pavement structure required to support a given load. To design a pavement containing stabilized soil layers requires the application of equivalency factors to a layer or layers of a conventionally designed pavement. To qualify for application of equivalency factors, the stabilized layer must meet appropriate strength and durability requirements set forth in EM 1110-3-137. An equivalency factor represents the number of inches of a conventional base or subbase which can be replaced by 1 inch of stabilized material.
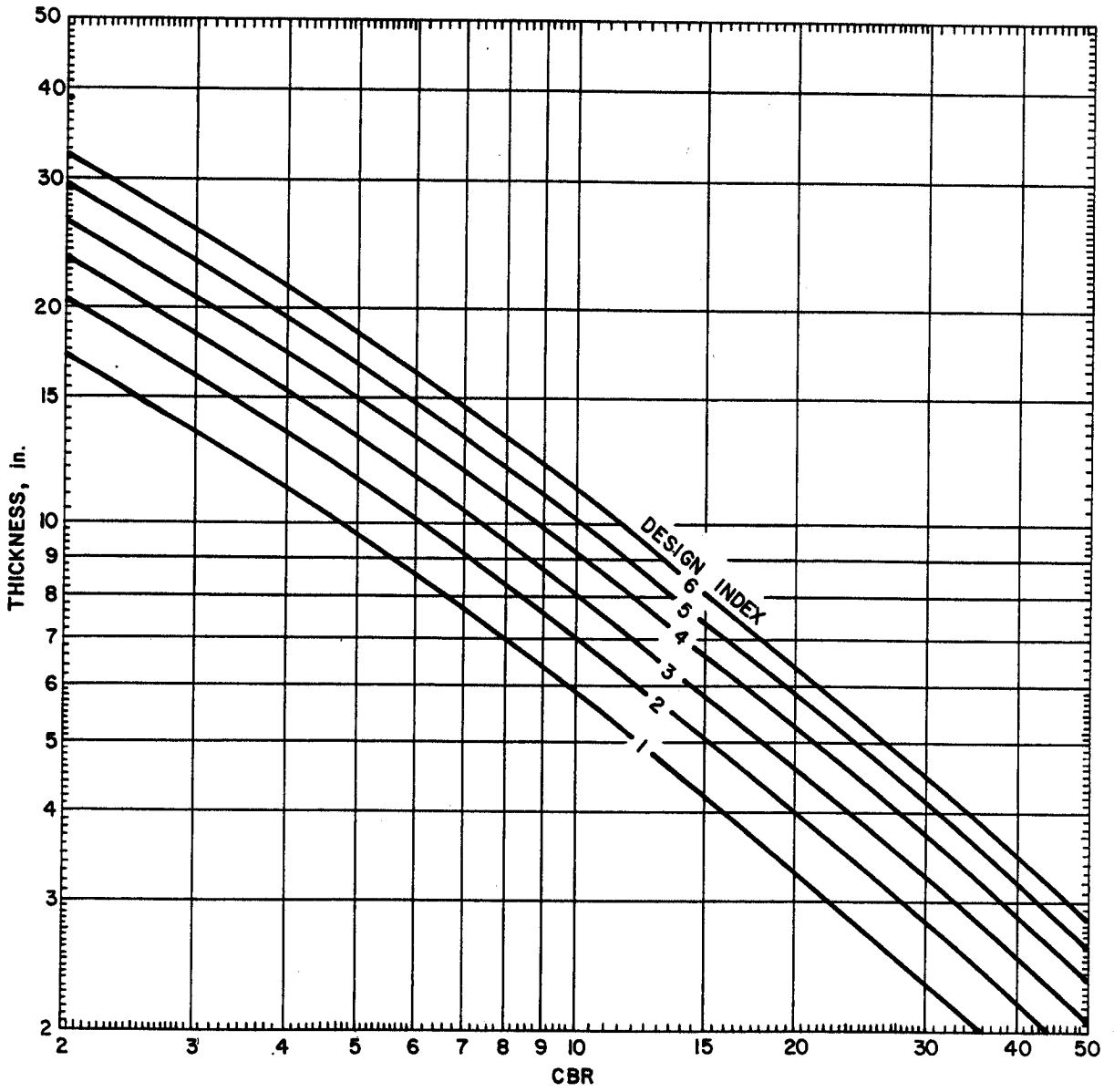
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FIGURE 5-1.   THICKNESS DESIGN REQUIREMENTS

Equivalency factors are determined as shown on table 5-2 for bituminous
stabilized materials, and from figure 5-2 for materials stabilized with
cement, lime, or a combination of fly ash mixed with cement or lime.
Selection of an equivalency factor from the tabulation is dependent
upon the classification of the soil to be stabilized. Selection of an
equivalency factor from figure 5-2 requires that the unconfined
compressive strength as determined in accordance with ASTM D 1633 be
known.

Table 5-2. Thickness Criteria

Material	Equivalency Factors	
	Base	Subbase
All-bituminous concrete	1.15	2.30
GW, GP, GM, GC	1.00	2.00
SW, SP, SM, SC	a	1.50

aNot used for base course material.

b. Minimum thickness. The minimum thickness requirements for a
stabilized base or subbase is 4.0 inches. The minimum thickness
requirements for the asphalt pavement are the same as shown for
conventional pavements in table 3-1.

5-6. Surface smoothness. Surface smoothness will be specified in
terms of maximum permissible deviation from a 10-foot-long
straightedge. All surface courses will have a maximum deviation of
1/4 inch. All intermediate courses will have a maximum deviation of
3/8 inch. More restrictive airfield construction tolerances will not
be imposed to roads and streets even when both road- and airfield-type
pavements are to be constructed under one contract.

5-7. Shoulders and similar areas. These areas are provided only for
the purpose of minimizing damage to vehicles using them accidentally or
in emergencies; therefore, they are not considered normal vehicular
traffic areas. Normally, shoulders will not be paved. Unpaved
shoulders will be surfaced with soils selected for their stability in
wet weather and will be compacted as required. Dust and erosion
control will be in accordance with EM 1110-3-136. Shoulders will not
block base-course drainage, particularly where frost conditions are a
factor. Where paving of shoulders is deemed necessary, the shoulders
will be designed for the expected traffic in accordance with procedures
delineated in paragraph 5-2 and appendix B.

5-8. Sidewalk construction. Permanent bituminous sidewalks will
consist of a 4-inch-thick base with a 1-inch-thick bituminous
surfacing. Material used locally in base construction for roads will
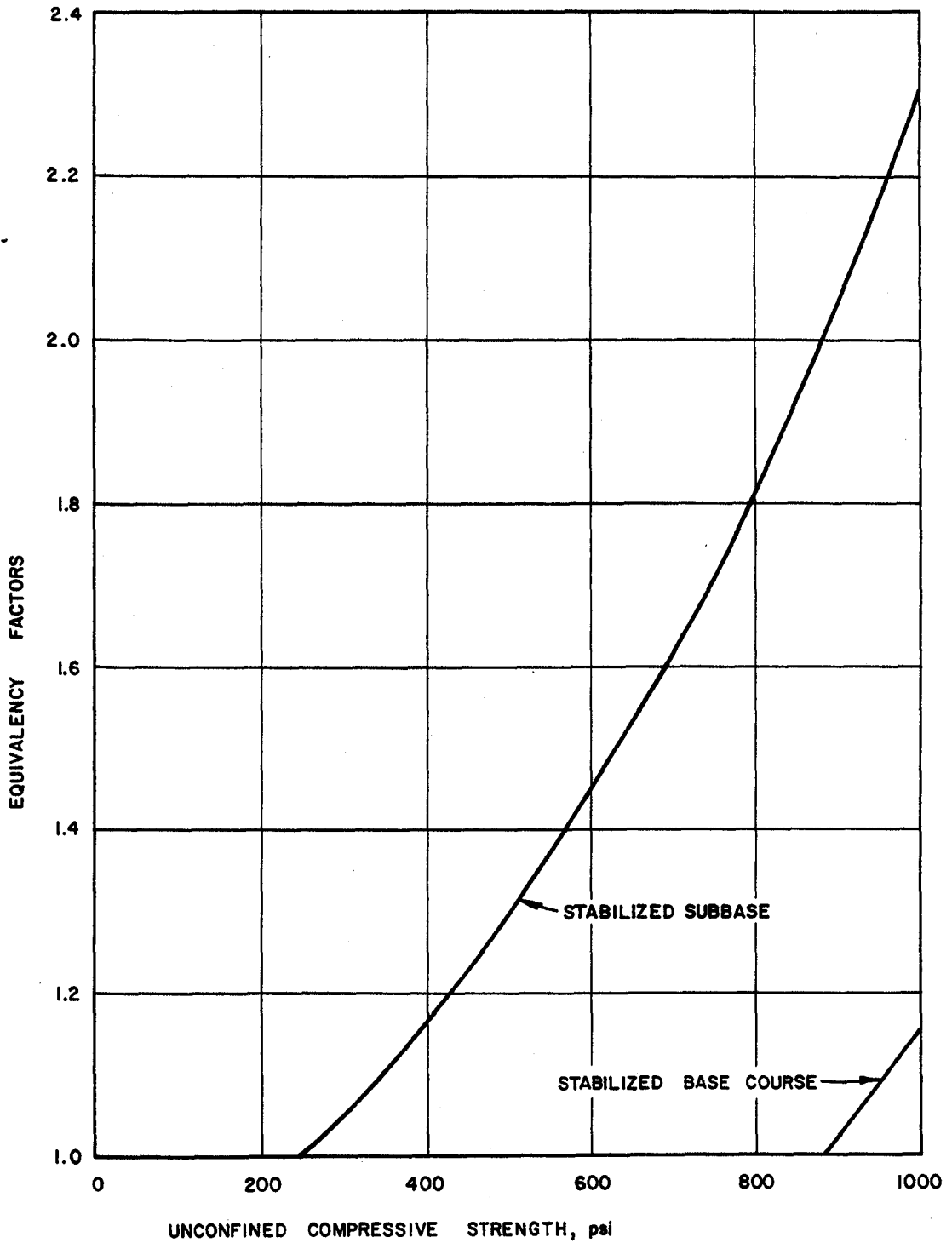
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FIGURE 5-2. EQUIVALENCY FACTORS FOR SOILS STABILIZED WITH
CEMENT, LIME, OR CEMENT AND LIME MIXED WITH FLY ASH

normally be suitable as sidewalk base material. Bases may also be constructed of soils stabilized in place with portland cement, lime, bituminous materials, or other acceptable stabilizers. In frost and permafrost areas, bases of sidewalks should be non-frost-susceptible in accordance with EM 1110-3-138, as applicable. The bituminous surfacing may consist of hot- or cold-mix bituminous concrete, sand-asphalt or sand-tar mixes, or sheet asphalt; in locations where the surface texture is not of prime importance, spray surface treatments may be used. Temporary walks or walks that are seldom used will be constructed of stable or stabilized soils or rock screenings containing granular and colloidal materials combined in the proportions necessary to insure maximum density and stability under varied weather conditions, including frost action. Where necessary, the life of these walks may be prolonged by the application of bituminous surface treatments or by the addition of suitable stabilizing agents.

5-9. Special considerations for open storage areas. In general, dense mixture types of asphalt concrete will provide adequate paving to meet special needs. In the design of open storage areas, consideration will be given to any special requirements necessary because of the use of a particular area. In repair yards, for instance, the final-surface texture will be one that will promote quick drying and will not contribute to the easy loss of nuts, bolts, and tiny parts. Such areas may receive a surface treatment of emulsified asphalt combined with selected fillers to provide a smooth resilient surface that is easy to clean and maintain. In areas primarily subjected to static loads, pavement types which require traffic to keep them alive should not be used. Mixtures in such areas will contain approximately 50 percent coarse aggregate. Areas subject to an appreciable amount of foot traffic will be designed to avoid the occurrence of free bituminous material on the surface. Foot traffic areas such as walkways should utilize the highest viscosity rated asphalt possible that is commensurate with the climatic conditions and aggregate properties of the mix.

APPENDIX A

PLANT-MIX COLD-LAID BITUMINOUS PAVEMENTS, DESIGN AND CONTROL

A-1. General.

a. Alternate approaches. It is anticipated that under emergency mobilization conditions bituminous pavement materials will be supplied by local sources. In most cases these sources have been utilized by Federal or state agencies in the past and have approved design mixes available to meet the needs as outlined in this manual. Review of the available mix results along with associated material test results and supplemented by field inspection and testing of present materials should supply sufficient information to proceed with design and construction. The following discussion is presented to provide the designer with design requirements as an aid to evaluating available materials and to provide information on methods of obtaining design data if not locally available.

b. Procedures and criteria. Procedures and criteria described in this appendix are applicable to the design and control of plant-mix cold-laid bituminous pavements using asphalt cement and liquefier, liquid asphalt, emulsified asphalt, or tar.

A-2. Design.

a. Preliminary work. A survey of the materials available in suitable quantities for use in construction of the pavement is the first step in the design of a paving mixture. Materials normally required for the paving mix are coarse aggregate, fine aggregate, mineral filler, and bitumen.

b. Sampling. Test reports reflecting the results of sampling and testing of the aggregates in bituminous materials will be necessary prior to design. Sufficient quantities of materials are to be obtained at time of sampling to meet the ASTM requirements and for laboratory pavement design tests subsequently described. Normally, 200 pounds of aggregates will produce the desired gradation and 5 gallons of bitumen will produce sufficient data during testing.

c. Tests on aggregates. Aggregates for use in bituminous pavements should be clean, hard, and durable. Aggregates that are angular in shape generally provide more stable pavements than do rounded aggregates. Most of the tests of aggregates required in the design of hot-mix, hot-laid bituminous concrete are also applicable to the cold-laid type. Therefore, many of the tests of EM 1110-3-141 appendix A will be referenced.

(1) Sieve analysis. A sieve analysis of the aggregates considered for use in a paving mix has the following advantages. An

experienced engineer can obtain general information from the grading curve as to the suitability of the aggregate for a paving mix, the quantity of bitumen required, and whether or not mineral filler should be added. Also, a sieve analysis is required if the aggregate is to be used in laboratory tests for paving mix design, as described later. Sieve analyses of fine and coarse aggregates should be in accordance with ASTM C 136. Figure A-1 is a form suggested for use in recording and calculating data obtained from laboratory sieve analyses. Mechanical analysis data for typical coarse aggregate, fine aggregate, sand, and mineral filler used in a paving mixture are shown in figure A-1.

(2) Specific gravity. Specific gravity values for aggregates used in a paving mix are required in the computation of percent voids total mix and percent voids filled with bitumen in the compacted specimens. Criteria have been established to furnish limiting values for these factors. However, specific gravity values must be determined with care and in accordance with specified procedures in order that application of the criteria will be valid. Two different specific gravity determinations are provided, and the selection of the appropriate test procedure depends on the water absorption of each aggregate blend.

(3) Wear requirements for coarse aggregates. The determination of percentage of wear for coarse aggregates may not be necessary if the aggregate has been found satisfactory by previous tests. However, coarse aggregates obtained from new or doubtful deposits can be tested for conformance to specification requirements using ASTM C 131.

d. Tests on mineral filler. Some mineral fillers have been found to be more satisfactory in asphalt paving mixtures than others. For example, fine sands and clays are normally less suitable fillers than limestone filler or portland cement. Well-graded materials are more suitable than poorly graded materials. The gradation of the mineral filler can be as determined by use of ASTM D 422. The specific gravity of the mineral filler is required in void computation and can be determined by testing except that when the bulk-impregnated specific gravity is used and the mineral filler is included in the blended aggregate. Figure A-2 is a form suggested for tabulation and computation of these data; typical data have been entered in this form to illustrate its use.

e. Tests on bituminous materials. The specific gravity of the bituminous material is necessary in determining the percent by volume of bituminous materials in the mix. Since only the residual asphalt will be used in calculating the percent binder, the amount of residual asphalt cement in liquid asphalts and asphalt emulsions must be determined in addition to residual asphalt or asphalt cement.

SIEVE ANALYSIS

JOB NO:		PROJECT: TYPICAL MIX	DATE:

STOCKPILE SAMPLES — DRY GRADATION

SAMPLE NO. Crushed Coarse Aggregate				SAMPLE NO. Crushed Fine Aggregate			
U.S. STAND. SIEVE NO.	WEIGHT RETAINED	% RETAINED	% PASS	U.S. STAND. SIEVE NO.	WEIGHT RETAINED	% RETAINED	% PASS
3/4			100	3/4			
1/2	225.9	30.0	70.0	1/2			100
3/8	267.3	35.5	34.5	3/8	1.1	0.2	99.8
NO. 4	237.2	31.5	3.0	NO. 4	53.9	9.8	90.0
NO. 8	22.6	3.0		NO. 8	104.6	19.0	71.0
NO. 16				NO. 16	104.6	19.0	52.0
NO. 30				NO. 30	96.3	17.5	34.5
NO. 50				NO. 50	82.5	15.0	19.5
NO. 100				NO. 100	60.5	11.0	8.5
NO. 200				NO. 200	30.3	5.5	3.0
-200			/////	-200	16.5	3.0	/////
TOTAL	753.0	/////		TOTAL	550.3	/////	
WEIGHT ORIGINAL SAMPLE				WEIGHT ORIGINAL SAMPLE			

WASHED GRADATION

SAMPLE NO. Natural Sand				SAMPLE NO. Limestone Filler			
U.S. STAND. SIEVE NO.	WEIGHT RETAINED	% RETAINED	% PASS	U.S. STAND. SIEVE NO.	WEIGHT RETAINED	% RETAINED	% PASS
3/4				3/4			
1/2				1/2			
3/8				3/8			
NO. 4				NO. 4			
NO. 8				NO. 8			
NO. 16				NO. 16			
NO. 30			100	NO. 30			
NO. 50	9.4	4.5	95.5	NO. 50			100
NO. 100	54.6	26.0	69.5	NO. 100	2.3	2.0	98.0
NO. 200	124.9	59.5	10.0	NO. 200	9.4	8.0	90.0
-200 (T)	21.0	10.0	/////	-200 (T)	105.3	90.0	/////
TOTAL	209.9	/////		TOTAL	117.0	/////	

(A) WEIGHT ORIGINAL SAMPLE	209.2 GM	(A) WEIGHT ORIGINAL SAMPLE	117.4 GM
(B) WEIGHT AFTER WASHED	193.7 GM	(B) WEIGHT AFTER WASHED	18.9 GM
(C) WASH LOSS (A - B)	15.5 GM	(C) WASH LOSS (A - B)	98.5 GM
(S) -200 FROM SIEVING	5.5 GM	(S) -200 FROM SIEVING	6.8 GM
(T) TOTAL -200 C + S	21.0 GM	(T) TOTAL -2000 C + S	105.3 GM
USE "T" TO CALCULATE PERCENTAGES		USE "T" TO CALCULATE PERCENTAGES	

TESTED BY:	COMPUTED BY:	CHECKED BY:

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FIGURE A-1. SIEVE ANAYSIS

SPECIFIC GRAVITY OF BITUMINOUS MIX COMPONENTS		DATE		
PROJECT	**JOB**	**TYPICAL MIX**		
COURSE AGGREGATE				

MATERIAL PASSING 3/4" SIEVE AND RETAINED ON 3/8" SIEVE	UNITS			
SAMPLE NUMBER Coarse aggregate				
1. WEIGHT OF OVEN - DRY AGGREGATE	GM.	378.3		
2. WEIGHT OF SATURATED AGGREGATE IN WATER	GM.	241.0		
3. DIFFERENCE (1.-2.)	GM.	137.3		
APPARENT SPECIFIC GRAVITY, $G = \frac{(1.)}{(3.)}$	2.755			

FINE AGGREGATE				
MATERIAL PASSING NUMBER 3/8" SIEVE	UNITS			
SAMPLE NUMBER Natural sand				
4. WEIGHT OF OVEN - DRY MATERIAL	GM.	478.8		
5. WEIGHT OF FLASK FILLED WITH WATER AT 20°C	GM.	678.6		
6. SUM (4.+5.)	GM.	1157.4		
7. WEIGHT OF FLASK + AGGREGATE + WATER AT 20°C,	GM.	977.4		
8. DIFFERENCE (6.-7.)	GM.	180.0		
APPARENT SPECIFIC GRAVITY, $G = \left(\frac{4.}{8.}\right)$	2.660			

FILLER	UNITS			
SAMPLE NUMBER Limestone Filler				
9. WEIGHT OF OVEN - DRY MATERIAL	GM.	466.5		
10. WEIGHT OF FLASK FILLED WITH WATER AT 20°C,	GM.	676.1		
11. SUM (9.+10.)	GM.	1142.6		
12. WEIGHT OF FLASK + AGGREGATE + WATER AT 20°C,	GM.	973.8		
13. DIFFERENCE (11.-12.)	GM.	168.8		
APPARENT SPECIFIC GRAVITY, $G = \left(\frac{9.}{13.}\right)$	2.764			

BINDER	UNITS			
SAMPLE NUMBER 6873				
14. WEIGHT OF PYCNOMETER FILLED WITH WATER	GM.	61.9595		
15. WEIGHT OF EMPTY PYCNOMETER	GM.	37.9215		
16. WEIGHT OF WATER (14.-15.)	GM.	24.0380		
17. WEIGHT OF PYCNOMETER + BINDER	GM.	47.8617		
18. WEIGHT OF BINDER (17.-15.)	GM.	9.9402		
19. WEIGHT OF PYCNOMETER + BINDER + WATER TO FILL PYCNOMETER	GM.	62.1568		
20. WEIGHT OF WATER TO FILL PYCNOMETER (19.-17.)	GM.	47.8617		
21. WEIGHT OF WATER DISPLACED BY BINDER	GM.	9.7429		
APPARENT SPECIFIC GRAVITY, $G = \left(\frac{18.}{20.}\right)$	1.020			

REMARKS

TECHNICIAN (Signature)	COMPUTED BY (Signature)	CHECKED BY (Signature)

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FIGURE A-2. SPECIFIC GRAVITY OF BITUMINOUS MIX COMPONENTS

f. Selection of materials for mix design. The first step in the design of a paving mix is the tentative selection of materials. The bitumen used in the laboratory tests will be the same as that used in field construction. The selection of aggregates and mineral filler for the paving mix is more involved than the selection of the bitumen. Aggregates and mineral fillers that do not meet the requirements of the specifications should be eliminated from further consideration. The remaining aggregates and filler then must be examined from technical and economical viewpoints. The final objective is to determine the most economical blend of aggregates and mineral filler that will produce a pavement meeting the engineering requirements set forth in this manual. The mix design gradation (i.e., job-mix formula) plus or minus specification tolerances must fall within the specified gradation band. The job-mix formula will be allowed the tolerances specified in the guide specification.

(1) Aggregates and mineral filler. Generally, it is necessary to combine aggregates from two or more sources for paving mixes. The addition of mineral filler is sometimes required, depending on the amount of filler naturally present in the aggregate. Mathematical equations are available for making such combinations, but they are not presented herein because they are lengthy and normally it is easier to use trial-and-error procedures. The gradation of the aggregate must fall within the limits of the gradations chosen from table A-1 for the project and will present a smooth curve when plotted with sieve size versus percent passing.

Table A-1. Aggregate Gradations for Plant-Mix
Cold-Laid Bituminous Pavements

Sieve Size	Percent Passing, by Weight	
	1/2-Inch Maximum	3/8-Inch Maximum
1/2 inch	100	
3/8 inch	86 $\pm$ 9	100
No. 4	66 $\pm$ 9	85 $\pm$ 9
No. 8	53 $\pm$ 9	71 $\pm$ 9
No. 16	41 $\pm$ 9	57 $\pm$ 9
No. 30	31 $\pm$ 9	43 $\pm$ 9
No. 50	21 $\pm$ 8	31 $\pm$ 8
No. 100	13 $\pm$ 6	19 $\pm$ 6
No. 200	4.5 $\pm$ 1.5	6 $\pm$ 3

(2) Bituminous materials. Plant-mix cold-laid pavements may be made with asphalt cement and liquefier, liquid asphalts, emulsified asphalts, or tar. The asphalt-cement-and-liquefier type is recommended because the wetting action of the liquefier insures good adhesion of the asphalt to the aggregate, the amount of liquefier can be adjusted to give any desired shelf life before the mix is to be placed, the

amount of residual asphalt from design is actually measured into the
mix, and the penetration grade of the residual asphalt can be easily
varied. Asphalt emulsions are advantageous in that no heat is required
in the mixing process, and the emulsions can be added to damp
aggregates. However, mixes made with asphalt emulsions cannot be
stockpiled unless the emulsion has been specifically formulated for
stockpiling purposes. Liquid asphalts can be contained in a single
tank and only the standard pipelines and spray bar are necessary,
whereas additional equipment is necessary for handling the liquefier
for the asphalt cement and liquefier type. The choice of type of
bituminous material would depend primarily on the most economical
available type and on the type of equipment to be used, although the
best results can probably be obtained with the asphalt-cement-and-
liquefier-type binder. Table A-2 is provided as a guide to selection
of the proper grade of bituminous material. The table is given in two
parts, one for bitumen for mixes to be used immediately and the other
for the bitumen in mixes for stockpiling for later use.

Table A-2. Selection of Bitumen

Bituminous Material	Climatic Conditions		
	Cold	Moderate	Hot
		Immediate Construction	
Asphalt cement penetration	120-150	85-100	85-100
Liquefier kerosene gal per ton mix	2.0	1.7	1.5
Liquid asphalts	RC-70 – RC-250	RC-250 – RC-800	RC-800 – RC-3,000
Emulsified asphalts	MS-2h	MS-2 – MS-2h	MS-2
	SS-1h	SS-1 – SS-1h	SS-1
Tar	RT-7 – RT-9	RT-7 – RT-9	RT-7 – RT-9
		Stockpile Material	
Asphalt cement, penetration	120-150	85-100	85-100
Liquefier, gal per ton mix	4.5	3.7	3.0
Liquid asphalts	MC-70 – MC-250	MC-250 – MC-800	MC-800 – MC-3,000
Tar	RT-5 – RT-7	RT-5 – RT-7	RT-5 – RT-7
Emulsified asphalts (a)	MS-2h	MS-2 – MS-2h	MS-2
	SS-1h	SS-1 – SS-1h	SS-1

_____

(a) Specifically formulated for stockpile use.

g. Mix design. Several equations based on the surface area of the aggregate are available for calculating the optimum amount of bituminous material in the mix. Although these equations give an approximation of the binder content, they do not properly account for porosity of the aggregate or the compaction characteristics of the mix and, therefore, can be misleading. The following procedure is recommended for determination of the amount of bituminous material to be used in the paving mix for plant-mixed cold-laid pavements. The design procedure described subsequently for plant-mix cold-laid mixes is similar to the method for designing plant-mix hot-laid mixes for roads and streets. The laboratory equipment and test procedures are to be in accordance with MIL-STD-620, Methods 100 and 101.

(1) Bitumen contents for specimens. The quantity of bitumen required for a particular aggregate is the most important factor in the design of a paving mixture. An estimate for the optimum amount of bitumen for the aggregate to be tested must be made in order to start the laboratory tests. Laboratory tests normally are conducted for a minimum of five bitumen contents: two above, two below, and one at the estimated optimum content. One percent incremental changes of bitumen may be used for preliminary work; however, increments of 1/2 percent generally are used where the approximate optimum bitumen content is known and for final designs. The bitumen content will be determined using asphalt cement except that paving grade tar will be used in the test procedures when tar is to be the binder medium of the pavement being designed. Tar generally requires about the same volume of bitumen, but since tar is heavier than asphalt, the percentage by weight is generally higher.

(2) Proportioning of aggregates. As a preliminary step in mixture design and manufacture, it is necessary to determine the approximate proportions of the different available stockpiled materials required to produce the desired gradation of aggregate. This is necessary in order to determine whether a suitable blend can be produced and if so, the approximate proportion of aggregates to be fed from the cold feed into the dryer. Sieve analyses are run on material from each of the stockpiles. After a suitable blend has been prepared from the available materials, then samples of these materials can be processed for use in the laboratory design tests in accordance with MIL-STD-620.

h. Determination of optimum bitumen content. The optimum bitumen content will be taken as the average of the asphalt contents corresponding to the mix properties in table A-3.

Table A-3. Optimum Bitumen Content

Mix Property	Value for Determining Optimum Bitumen Content
Unit weight of mix	Peak of curve
Percent voids total mix	4 ± 1
Percent voids filled with bitumen	75 ± 5

The optimum bitumen content will be the amount of asphalt cement or tar that will be incorporated into the mix. The percent of liquid asphalts and emulsified asphalts will be corrected to give a residual asphalt content equal to the optimum asphalt content determined by the tests. When the asphalt cement-liquefier-type mix is to be used, the desired amount of liquefier will be added to the actual paving mix in addition to the optimum asphalt content determined from the laboratory design. When tar is to be used in the mix, the amount of tar will be the same as optimum value determined by the laboratory tests.

A-3. Plant control.

    a. Plant operation. Three typical types of mixing plants are illustrated in appendix A of EM 1110-3-141. Typical plants include batch, continuous-mix, and dryer drum. It is generally necessary, during the operation of a bituminous paving plant, to combine aggregates from two or more sources to produce an aggregate mixture having the desired gradation. Aggregates from the different sources are fed into the aggregate dryer in the proportions required to produce the desired gradation. This initial proportioning generally is accomplished by means of a hopper-type mechanical feeder on one or more bins that feeds the aggregates into a cold elevator, which, in turn, delivers them to the dryer. The mechanical feeder is generally loaded by a clam shell or other suitable means in the proportions of aggregates desired. The aggregates pass through the dryer where the moisture is driven off and the aggregates are heated to the desired temperature. In the dryer drum mix plant the binder is added to the aggregate during drying and leaves the dryer as mixed pavement material ready for truck loading. Upon leaving the dryer of batch and continuous-mix plants, the aggregates pass over vibrating screens where they are separated according to size. When using emulsified asphalt as the binder, the dryer operation is omitted. The usual screening equipment for a three-bin plant consists of a rejection screen for eliminating oversize material and screens for dividing the coarse aggregate into two separate bins with the fine aggregate going to the third bin. When the aggregate is not dried, the fine bin screen size shall not be smaller than 3/8 inch. An additional screen is provided for further separation of the coarse aggregate in a four-bin plant. When additional mineral filler is required, usually it is stored and weighed or proportioned into the mix separately. Plant screens vary in size of opening, and the size employed is largely dependent upon the

type of mixture being produced. In some cases, it may be necessary to change the size of screens to obtain a proper balance of aggregate sizes in each bin.

(1) Feeding. The aggregates must be fed through the plant uniformly, preferably by a mechanical feeder, in order to obtain efficient plant operation and to produce a mixture conforming to the desired gradation. The proper proportion of aggregates to be fed into the dryer may be determined approximately from the laboratory design. However, it is usually necessary to make some adjustments in these proportions because (a) a sieve analysis of the stockpile aggregates generally will not exactly duplicate the sieve analysis of the aggregate samples obtained for laboratory design use; (b) fines may be lost while passing through the dryer unless the equipment includes an effective dust collector; (c) aggregate may degrade in the dryer; and (d) the plant screens are not 100-percent efficient in separating of the aggregate and some fines are carried over into the coarser bins.

(2) Batch plant. The batch-type plant proportions, mixes, and dumps successive batches of the bituminous mix. These plants handle batches generally ranging in weight from about 2,000 to 6,000 pounds, with capacities varying from 40 to 300 tons per hour. Usually, the batch proportions are measured by actually weighing the prescribed quantities of the various aggregate fractions and bituminous materials into each batch. However, in some of the automatically operated plants, although the actual calibration is based on weights, the operational proportioning is accomplished by measuring the volumes of the several materials required to give these weights.

(3) Continuous-mix plant. The continuous-mix plant takes its name from the operating procedure. The ingredients are fed into the mixer, mixed, and discharged continuously at a constant rate. A small storage bin at the discharge end of the mixer holds the plant output while a loaded truck is being moved away from the discharge chute and an empty truck is being brought into position. Although the calibration of the continuous-mix plant is based on weights of the various materials going into the mix, the actual proportioning is based on the volumes of materials coming from the different feeders. The devices feeding each aggregate and the bituminous materials are interlocked to automatically maintain the proper proportions continuously. The capacities of continuous-mix plants are about the same as for batch plants.

(4) Dryer-drum mix plant. The dryer-drum type plant is a continuous-mix process but differs from the continuous-mix plant in that the aggregate and bituminous binder are mixed and dried in one operation. Aggregate gradation control is achieved in the crushing and stockpiling operation. Accurately controlled feeders proportion the aggregate from the cold bins which is conveyed to the drum. Belt scales continuously weigh the aggregate and proportion the asphalt pump

to maintain a constant aggregate-to-asphalt ratio entering the drum. The mix leaving the dryer-drum passes through a scalping screen before being conveyed to a surge bin for truck loading.

(5) Operation variables. The plant operation varies with the type of bituminous material used in the mix. For mixes with asphalt-cement-liquefier bitumen, the liquefier and asphalt cement must be introduced onto the aggregate at different times. Drying of aggregate is not necessary with asphalt emulsions, but aggregates should be heated to between 200 and 250 degrees F. prior to mixing with the other liquid types of bituminous materials. Aggregates should not be hotter than 200 degrees F. when mixed with rapid curing liquid asphalts, and not more than 250 degrees F. for mixing with the medium curing grades or asphalt cement and kerosene. The bituminous materials should be in the temperature ranges given in table A-4 when introduced into the pugmill.

Table A-4. Mixing Temperatures

| Bituminous Material | | Temperature |
Type	Grade	Range, Degrees F.
Emulsified asphalts	MS-2	100-160
	MS-2h	100-160
	SS-1	75-130
	SS-1h	75-130
Liquid asphalts	RC-70	100-135
	RC-250	135-175
	RC-800	170-205
	MC-70	100-135
	MC-250	135-175
	MC-800	170-205
Tar	RT-5	80-150
	RT-6	80-150
	RT-7	150-225
	RT-8	150-225
	RT-9	150-225

b. Plant laboratory. A plant laboratory is necessary to insure that the aggregate is of the proper gradation and that the mix contains the prescribed percentage of bituminous material. The plant laboratory should contain the following major equipment:

(1) Sieve shaker: One hand- or power-driven mechanical sieve shaker with a capacity of not less than eight full-height 8-inch-diameter sieves.

(2) Sieves: One full-height 8-inch-diameter sieve for each of the following sieve openings: 1/2 and 3/8 inch, and Nos. 4, 8, 30, 100, and 200. The sieves should have square openings and meet the ASTM E-11 requirements of sieves for testing purposes.

(3) Extractor: One extractor suitable for obtaining bitumen content within close tolerances.

(4) Balance: One balance having capacity of 2 kilograms and sensitive to 0.1 gram.

(a) Plant calibration. The first step in starting operation of either a batch-type or continuous-mix plant is calibration of the cold feeds. This is accomplished by setting the cold feeder gate at a specific opening, operating the feeder for a given length of time or number of revolutions, catching the discharge, and determining the dry weight of the discharge. This process is repeated to develop a calibration curve for a specific feeder for a given aggregate. The procedure is repeated for each feeder and then the feeders are adjusted for the proper percentage by weight of each aggregate to be used in the mix and for the desired output of the plant in tons per hour.

(b) Selection of screens. The next step is selection of screens for the hot bins. For this it is necessary to know the capacities of the hot bins so that screens may be used that will divide the aggregate into the hot bins in proportion to the capacity of the bins. This is accomplished by taking the gradation of the combined aggregate from the cold feeder and dividing it according to the bin capacities. Generally, a slightly larger screen is used over the fine-aggregate bin than the maximum size desired in the bin. The reason for this is that the fine screens tend to clog and override into the bin of the next larger size. The plant is started in operation and aggregate is allowed to run long enough to allow the hot bins to fill to about one-half total capacity. This dry run consists of firing the dryer and allowing it to heat and starting the cold feeder, cold elevator, hot elevator, and screening unit so that hot, dry aggregates go into the hot bins. The batch-type plant is then calibrated from gradation analyses made on samples from each hot bin. The plant scales are set to weigh the correct percentages of aggregates from each hot bin and the correct amount of bituminous material to meet the job-mix formula. For the continuous-mix plant, each hot bin has an apron-type feeder that is calibrated in the same manner as the cold feeder. The apron feeder is always calibrated in terms of the revolutions of a gear shaft, which has a revolution counter attached. Also attached to this shaft is a metering pump for the bitumen. This is a positive displacement pump that delivers a constant amount of bitumen for each revolution of the pump. The speed of the pump can be varied by using different sprocket sizes. To calibrate the metering pump, the pump is run for a number of revolutions and the discharge from the pump is collected and weighed. Since the bitumen is measured by volume through

the pump, a change in temperature from the desired production temperature will affect the weight per unit value. When the output of the feeders from each hot bin and the output of the bitumen pump per revolution are known, the plant is set by letting the output of the bitumen equal the desired bitumen content. The apron feeders for each hot bin are then set to produce the desired percentages of bitumen and aggregate sizes to meet the job-mix formula.

(c) Gradation control, sieve analysis. All sieve analyses are to be conducted in accordance with ASTM C 136. The gradation of the aggregates going into the paving mix must fall within the tolerances of the job-mix formula as given in the appropriate guide specification.

c. Controlling plant production. In order to insure that the plant remains in calibration and that the proper bituminous mix is produced, the following control procedures should be followed:

(1) Extraction tests. Representative samples of paving mixture are obtained twice daily for extraction tests to determine the percentage of bitumen in the mix and the gradation of the extracted aggregates. Extraction tests are made in accordance with ASTM D 2172 using trichloroethylene as the extraction solvent. Sieve analyses of recovered aggregates will be tested with procedures specified previously.

(2) Hot-bin gradations. Hot-bin gradation tests are determined on the aggregate in the fine bin at 2-hour intervals during operation. Hot-bin gradations are determined on all bins in conjunction with sampling of the pavement mixture. Washed sieve analyses are determined initially and when gradations vary to establish a correction factor to be applied to unwashed (dry) gradations. Dry sieve analyses must be conducted frequently to maintain control.

(3) Adjusting mix proportions. Mix proportions are to be adjusted whenever the above tests indicate that specified tolerances are not being met. In the case of batch plants, faulty scales and failure of operator to weigh accurately the required proportions of materials are common causes for paving-mixture deficiencies. The total weight of each load of mixture produced should not vary more than plus or minus 2 percent from the total of the batch weights dumped into the truck. Improper weighing or faulty scales may be detected readily and corrective measures taken by maintaining close check of load weights. Other probable causes of paving-mixture deficiencies due to improper plant operations are given in figure A-3.

Types Of Mix Trouble

Types Of Deficiencies That May Be Encountered In Producing Plant Mix Paving Mixtures

Columns (Types Of Mix Trouble):
- Bitumen content fails to check job-mix formula
- Gradation fails to check job-mix formula
- Poorly mixed loads
- Fat, rich mixtures
- lean or burned mixtures
- Mixture temperature fails to check job mix
- Smoking loads
- Steaming loads
- Overweight or underweight loads
- Lack of uniformity of mixtures in loads

Probable Causes Of Deficiencies In Plant Mix Paving Mixtures

Rows (Probable Causes):
1. Aggregate scales out of adjustment
2. Bitumen scales out of adjustment
3. Lack of proper aggregate in bin
4. Bridging of hot aggregate in bin
5. Faulty pug mill weighing by operator
6. Bitumen pug mill dump gate by operator
7. Drum feed temperature gate not uniform
8. Improper dryer operation
9. Too little bitumen
10. Too much bitumen
11. Sampling method not uniform
12. Excessive moisture content of aggregate
13. Bin overflow pipes not functioning
14. Leaky bins
15. Segregation content of aggregate
16. Mixing time not uniform
17. Mineral filler feed not uniform in bins
18. Aggregate filler temperature not uniform
19. Temperature feed not uniform
20. Improper temperature too high
21. Overrated feed of aggregate mechanism too uniform
22. Overrated dryer capacity to dryer
23. Faulty screen capacity to dryer
24. Overload pug mill operation
25. Improper pug mill set on dryer
26. Bitumen set on pug mill
27. Bitumen pump and aggregate feed out of adjustment
28. Not sufficient hot aggregate
    Aggregate gates not properly set in storage bins

Items 1 to 5 incl. and items 24 to 28 incl. are applicable to all types of plants. Items 6 to 23 incl. are applicable to batch plants and volumetric plants respectively.

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FIGURE A-3. TYPES OF PAVING MIXTURE DEFICIENCIES AND PROBABLE CAUSES

APPENDIX B

DESIGN EXAMPLES

B-1. General. Both magnitude and repetitions of loading are
significant parameters in pavement design. Highway designers have long
been plagued with these parameters, further complicated by the variety
of loadings to be accommodated. However, means have now been developed
for expressing the relative effect of any particular loading in terms
of operations of a basic loading. This permits integration of the
gross effect of any array of loadings in terms of equivalent operations
of a basic loading, which in turn permits treatment of traffic
intensities directly. Typical arrays of traffic for a range of maximum
loadings and of intensities of use have been treated, in the manner
indicated above, to reduce them to an equivalent in terms of
repetitions of a basic 18,000-pound, single-axle, dual-tire load.
These have in turn been reduced to the design-index values tabulated in
table 5-1, paragraph 5-2.c. To illustrate the selection of a design
index, assume that the design index is desired for a Class B street to
support traffic including about 10 percent three-, four-, and five-axle
trucks. This is a Category IV loading according to the criteria
established in paragraph 5-2.b., and using the Class B designation, a
design-index value of 5 is obtained from table 5-1, paragraph 5-2.c.
To illustrate selection of a design index when tracked vehicles are
involved, assume that the street in the example above must, in addition
to the traffic indicated, sustain the operation of tanks having a gross
weight of 80,000 pounds. Paragraph 5-2.c. shows that this is provided
for by design index of 6.

B-2. Compaction requirements. An example of the application of the
compaction requirements shown in figure 3-1 is given here. Assume a
design is required for a design index of 5.

   a. Base course. Materials meeting the specifications for base
course can usually be compacted to more than 100 percent of maximum
density. Assume that previous experience or a test section showed that
while maximum density for the processed sample was approximately 143
pcf, field densities on total samples were all more than 150 pcf when
compacted with eight coverages of a heavy rubber-tired roller. In this
case, the requirement should be specified as 105 percent maximum
density.

   b. Subbase. Subbase compaction requirement would be specified
as 100 percent of maximum density unless the subbase is a sandy
gravel, gravel, or rock, in which case it is probable that 100
percent would be obtained with relatively little field compaction.
In this case, a higher value, based on previous experience or a
test section, should be specified. For the remainder of the
example, two subgrades are used to illustrate the application of
the data.

c. Cohesionless (PI≤5; LL≥25) subgrade. Assume a clean cohesionless sand and a design CBR of 20, with a natural in-place density of 90 percent of maximum density to beyond the depth of exploration (6 feet). A minimum of 100 percent of maximum density is required at the top of this material unless, as explained in the preceding paragraph for subbase, a higher value is readily obtainable. From figure 3-1, it is found that this 100 percent must extend to a depth of 11.5 inches below the pavement surface. Below this depth, fill sections must be compacted to 95 percent maximum density throughout, and cut sections to 95 percent of maximum density to a depth of 20 inches below the pavement surface. The designer must decide from previous experience or from test-section data whether or not these percentages of compaction in cut sections can be obtained from the top of the subgrade. If they cannot, a part of the subgrade must be removed, the underlying layer compacted, and the material replaced, or the thickness of select material or subbase must be so increased that the densities in the uncompacted subgrade will be adequate.

d. Cohesive (PI>5; LL>25) subgrade. Assume a lean clay, a design CBR of 7, and a natural in-place density of 80 percent of maximum density extending below the depth of exploration (6 feet). For this example it is assumed that with the soils involved and the type of equipment available, compaction of the subgrade from the surface would be impracticable beyond the 6- to 8-inch depth that could be processed; therefore, the minimum depth of cut would be limited by the in-place density. From figure 3-1, it is found that the 80 percent in-place natural density would be satisfactory below depths of about 26.5 inches from the pavement surface. From CBR design curves (explained subsequently), the top of the subgrade will be 13 inches below the pavement surface; therefore, a zone 13.5 inches thick below the top of the subgrade requires treatment. The bottom 6 to 8 inches of this can be processed in place; so about 6 inches of material must be removed and replaced. Compaction to 95 percent of maximum density is required for all cohesive material that lies within 13 inches of the pavement surface. Since the subgrade does not fall within this zone, compaction requirements in the replaced material and in the layer processed in place should be 90 percent of maximum density to conform to fill requirements. Compaction requirements for the subgrade will therefore be 90 percent for the top 13 inches, the first lift of which can be processed in place.

B-3. Thickness design by CBR method. To illustrate the analysis of design by the CBR method when the subgrade, subbase, or base course materials are not affected by frost, or when detrimental settlement or conditions requiring special treatment are not the principal consideration in design, assume that a design is to be prepared for a road that will require a design index of 5. Further assume that compaction requirements will necessitate an increase in subgrade density to a depth of 7 inches below the subgrade surface and that a

soft layer occurs within the subgrade 21 inches below the subgrade
surface. The CBR design values of the various subgrade layers and the
materials available for subbase and base course construction determined
by the methods described in previous paragraphs and shown in table B-1
are as follows:

Table B-1. CBR Design Values

Material	Soil Group Unified Soils Classification System	Design CBR
Weak layer in subgrade	CH	3
Natural subgrade	CL	5
Compacted subgrade	CL	7
1	GP	35
2	GM (Limerock)	80

The total thickness and thicknesses of the various subbase and base
layers are determined as follows.

    a. Total thickness. The total thickness of subbase, base, and
pavement will be governed by the CBR of the compacted subgrade. From
the flexible-pavement design curves shown in figure 5-1, the required
total thickness above the compacted subgrade (CBR of 7) is 13.5 inches.
Next, a check must be made of the adequacy of the strength of the
uncompacted subgrade and of the weak layer within the subgrade. From
the curves in figure 5-1, the required cover for these two layers is
found to be 17.0 and 23.5 inches, respectively. If the design
thickness is 13.5 inches and the subgrade is compacted to 7.0 inches
below the subgrade surface, the natural subgrade will be covered by a
total of 21.5 inches of higher strength material. Similarly, the soft
layer occurring 21.0 inches below the subgrade surface will be
protected by 34.5 inches of total cover. Thus, the cover is adequate
in both cases.

    b. Minimum base and pavement thickness. For a design index of 5
the minimum base thickness is 4.0 inches and the pavement thickness is
2.5 inches as indicated in table 3-1. If, however, the CBR of the base
material had been 100 rather than 80, a minimum pavement thickness of 2
inches would have been required.

    c. Thickness of subbase and base courses. The design thickness of
each layer of materials 1 and 2 will depend upon the CBR design value
of each material. Figure B-1 herein shows two combinations chosen to
illustrate the design procedures. Final selection of the section to be
used will be based on the economics of its construction. Figure B-1(a)
shows a design using both materials. The total thickness of subbase,
base, and pavement, as determined in a above, is 13.5 inches. The
thickness required above material 1 (CBR = 35), as determined from
figure 5-1, is 3.5 inches; therefore, the required thickness of

material 1 is 10.0 inches (13.5 - 3.5 inches). The 3.5-inch layer
required above material 1 will be composed of material 2 and pavement;
however, adjustments must be made in the thicknesses of material 2 and
the pavement to conform with minimum base and pavement thicknesses
given above, which is a combined thickness of pavement and base of 6.5
inches (2.5 inches of pavement and 4.0 inches of base). Therefore, the
section using materials 1 and 2 will consist of a 7.0-inch subbase
course of material 1, a 4.0-inch base course of material 2, and a
2.5-inch pavement, as shown in figure B-1(a). Figure B-1(b)
illustrates a simple design using material 2 only. The total thickness
of 13.5 inches is composed of 2-1/2 inches of pavement and 11.0 inches
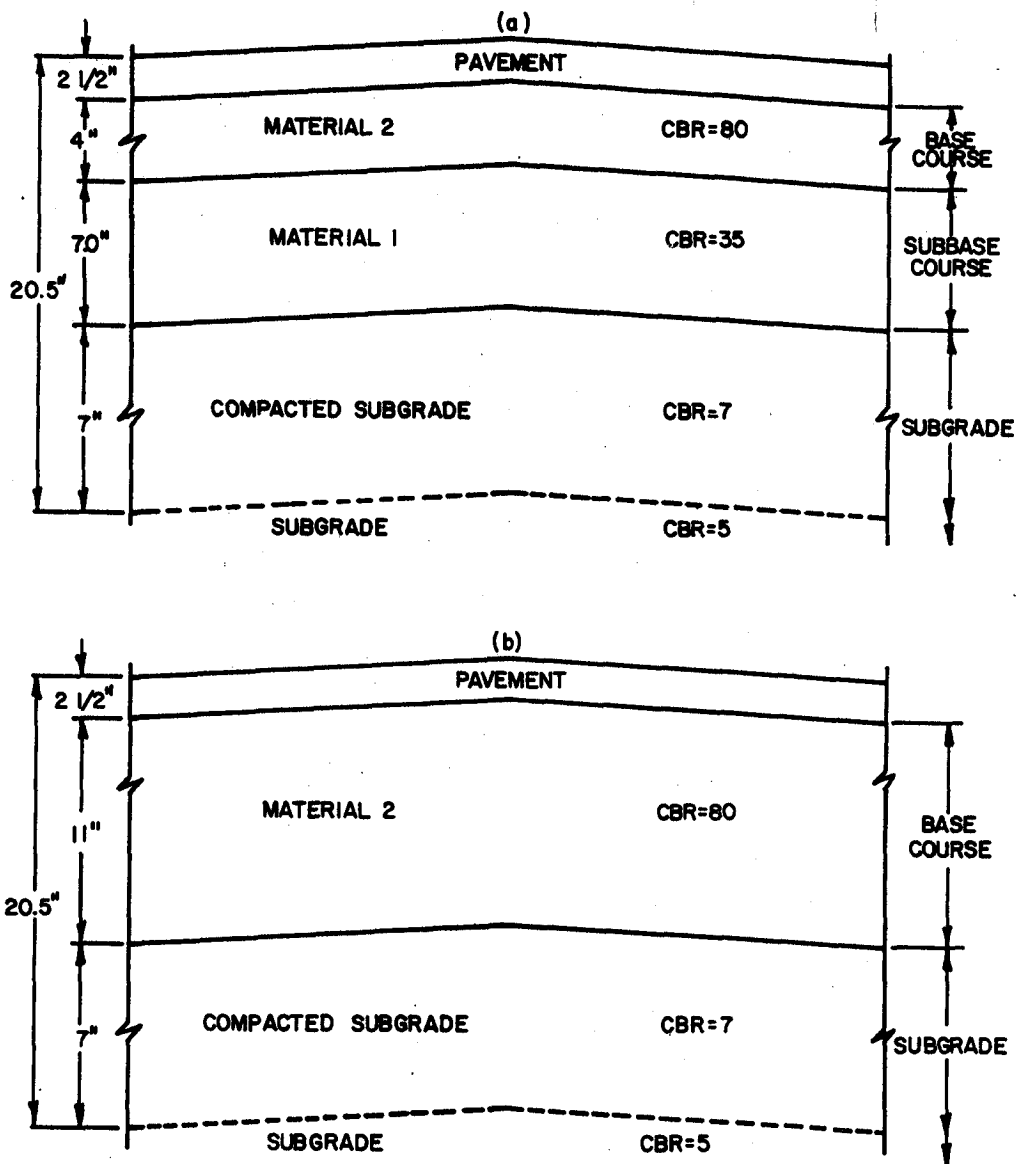of material 2.

   d. Cost comparison. A careful cost comparison would be needed to
establish whether the design shown in figure B-1(a) is more economical
than that shown in figure B-1(b) since the cost of material 1 would
rarely approach the cost of material 2. These examples show that CBR
method of design allows rapid investigation of the possibilities of
economizing by using locally available materials.

B-4. Determination of subbase CBR values. For an example, suppose
that five types of material are available for subbase course
construction at a particular site and the CBR design value to be used
for each of these materials is desired. Assume also that the necessary
testing has been performed on each of these materials with the results
shown in table B-2.

<div align="center">Table B-2. Material Types and Design Values</div>

Test	Caliche	Silty Sand	Gravelly Sand	Sandy Gravel	Gravel
CBR (laboratory)	100	14	35	45	65
Maximum size, inches	1.5	0.06	0.5	1.0	2
Percentage passing No. 10 sieve	42	100	85	35	20
Percentage passing No. 200 sieve	10	20	14	6	3
Liquid limit	31	14	12	11	10
Plasticity index	10	2	3	NP	NP
CBR design value	20	14	30	45	50

The CBR design value for the caliche is 20 because the liquid limit and
plasticity index are higher than those allowed (see table 2-1) for
greater CBR design values. The CBR design value for the silty sand is
14 because this is the value determined by the CBR penetration test and
no other limitations apply. If the laboratory CBR value had been
greater than 20, the CBR design value would have been restricted to 20
because 15 percent is the maximum amount of material passing the No.
200 sieve permitted for higher CBR values and this material had 20

(a)

PAVEMENT

2 1/2"

MATERIAL 2   CBR=80   BASE COURSE

4"

70"

MATERIAL 1   CBR=35   SUBBASE COURSE

20.5"

7"

COMPACTED SUBGRADE   CBR=7   SUBGRADE

SUBGRADE   CBR=5

(b)

PAVEMENT

2 1/2"

MATERIAL 2   CBR=80   BASE COURSE

11"

20.5"

7"

COMPACTED SUBGRADE   CBR=7   SUBGRADE

SUBGRADE   CBR=5

U. S. Army Corps of Engineers

FIGURE B-1.   DESIGN EXAMPLE, CLASS B STREET CATEGORY IV, LOADING DESIGN INDEX 5

percent passing. The CBR design value for the gravelly sand is 30, because 80 percent is the maximum amount of material passing the No. 10 sieve permitted for higher CBR values and this material had 85 percent passing. The CBR design value for the sandy gravel can be a maximum of 50 since it meets all the requirements of the limiting specifications, and it is therefore 45 as determined by the CBR penetration test. The CBR design value for the gravel is 50 since it meets all specification limitations for subbase and cannot qualify as a base course material.

APPENDIX C

REFERENCES

Government Publications.

Department of Defense, Military Standards.

MIL-STD-620A   Test Methods for Bituminous
& Notice 1   Paving Materials.

MIL-STD-621A   Test Methods for Pavement,
& Notice 1,2   Subgrade, Subbase, and
                               Base-Course Material.

Department of the Army.

EM 1110-3-130   Geometrics for Roads, Streets,
                               Walks, and Open Storage Areas.

EM 1110-3-136   Drainage and Erosion Control.

EM 1110-3-137   Soil Stabilization for Pavements.

EM 1110-3-138   Pavement Criteria for Seasonal Frost
                               Conditions.

EM 1110-3-141   Airfield Flexible Pavement.

Nongovernment Publications.

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

C 131-81   Resistance to Degradation of
                               Small-Size Coarse Aggregate by
                               Abrasion and Impact in the
                               Los Angeles Machine.

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                               Aggregates.

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D 1633-63   Compressive Strength of Molded
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E 11-70   Wire-Cloth Sieves for Testing Purposes.
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