U.S. Department
of Transportation

Federal Aviation Administration

Advisory Circular

Subject: AIRPORT PAVEMENT DESIGN AND EVALUATION

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Change:

1. PURPOSE. This advisory circular provides guidance to the public for the design and evaluation of pavements at civil airports.

2. CANCELLATION. AC 150/5320-6C, Airport Pavement Design and Evaluation, dated December 7, 1978, is canceled.

3. APPLICATION. The guidelines contained herein are recommended by the Federal Aviation Administration for applications at airports as appropriate.

4. RELATED READING MATERIAL. The publications listed in Appendix 4 provide further guidance and detailed information on the design and evaluation of airport pavements.

5. METRIC UNITS. To promote an orderly transition to metric units, this advisory circular includes both English and metric dimensions. The metric conversions may not be the exact equivalents, and until an official changeover to metric units is effected, the English dimensions will be used.

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FOREWORD

This advisory circular is intended to provide guidance on the structural design and evaluation of airport pavements.

Although aircraft landing gears are involved in airport pavement design and evaluation, this circular is not intended to dictate any facet of landing gear design. In 1958, the FAA adopted a policy of limiting maximum Federal participation in airport pavements to a pavement section designed to serve a 350,000-pound (159 000 kg) aircraft with a DC-S-50 series landing gear configuration. In addition, the intent of the policy was to insure that future aircraft were equipped with lauding gears which would not stress Pavements more than the referenced 350,000-pound (159 000 kg) aircraft.

Aircraft manufacturers have accepted and followed the 1958 policy and have designed aircraft landing gear which conform to the policy even though aircraft gross weights have substantially exceeded 350,000 pounds (159 000 kg). This has been accomplished by increasing the number and spacing of landing gear wheels. This circular does not affect the 1958 policy with regard to landing gear design.

The pavement design guidance presented in Chapter 3 of this circular is based on methods of analysis which have resulted from experience and recent research. The change in methods was adopted to exploit these advances in pavement technology and thus provides better performing pavements and easier-to-use design curves. Generally speaking, the new design guidance will require somewhat thicker pavement sections than were required in the past.

The pavement evaluation portion of this circular is presented in Chapter 6 and is related back to the previous FAA method of design to insure continuity. An aircraft operator could be penalized unfairly if an existing facility were evaluated using a method different from that employed in the original design. A slight change in pavement thickness can have a dramatic effect on the payload or range of an aircraft. Since the new pavement design methodology generally requires slightly greater pavement thicknesses, an evaluation of an existing pavement using the new methodology would likely reduce allowable loads and penalize operators. To avoid this situation the evaluation should be based on the same methodology as was used for design.

CHAPTER 1.
AIRPORT PAVEMENTS - THEIR FUNCTION AND PURPOSES

100. GENERAL. Airport pavements are constructed to provide adequate support for the loads imposed by aircraft using an airport and to produce a firm, stable, smooth, all-year, all-weather surface free from dust or other particles that may be blown or picked up by propeller wash or jet blast. In order to satisfactorily fulfill these requirements, the pavement must be of such quality and thickness that it will not fail under the load imposed. In addition, it must possess sufficient inherent stability to withstand, without damage, the abrasive action of traffic, adverse weather conditions, and other deteriorating influences. To produce such pavements requires a coordination of many factors of design, construction, and inspection to assure the best possible combination of available materials and a high standard of workmanship.

a. Types of Pavement. Pavements discussed in this circular are flexible, rigid, hot mix asphalt overlays, and rigid overlays. Various combinations of pavement types and stabilized layers can result in complex pavements which would be classified in between flexible and rigid. The design and evaluation guidance in this circular can be adapted to any pavement type.

b. Economic Analysis and Design Selection. When properly designed and constructed, any pavement type (rigid, flexible, composite, etc.) can provide a satisfactory pavement for any civil aircraft. However, some designs may be more economical than others and still provide satisfactory performance. The engineer is required to provide a rationale for the selected design in the engineer's report (see AC 150/5300-9). Often this rationale will be based on economic factors derived from evaluating several design alternatives. Life-cycle cost analysis should be used if the design selection is based on least cost. An example of a life-cycle cost analysis of alternatives for pavement rehabilitation is shown in Appendix 1. More details on life-cycle cost analysis can be found in research report DOT/FAA/RD-81/78 (see Appendix 4). Many new developments in construction have evolved in recent times which can significantly affect pavement costs, such as, recycling. In instances where no clear cost advantage can be established in the design process, alternate bids should be taken. Design selection is not always controlled by economic factors. Operational constraints, funding limitations, future expansion, etc., can override economic factors in the design selection. These considerations should be addressed in the engineer's report.

c. Pavement Courses.

(1) Surface. Surface courses include portland cement concrete, hot mix asphalt, sand-bituminous mixture, and sprayed bituminous surface treatments.

(2) Base. Base courses consist of a variety of different materials which generally fall into two main classes, treated and untreated. The untreated bases consist of crushed or uncrushed aggregates. The treated bases normally consist of a crushed or uncrushed aggregate that has been mixed with a stabilizer such as cement, bitumen, etc.

(3) Subbase. Subbase courses consist of a granular material, a stabilized granular material, or a stabilized soil.

(4) Geotextile. Geotextiles are permeable, flexible, textile materials sometimes used to provide separation between pavement aggregate and the underlying subgrade. Geotextile needs and requirements within a pavement section are dependent upon subgrade soil and groundwater conditions and on the type of overlying pavement aggregate.

101. SPECIFICATIONS AND STANDARDS.

a. Specifications. Reference is made by Item Number throughout the text to construction material specifications contained in AC 150/5370-10, Standards for Specifying Construction of Airports.

b. Geometric Standards. Geometric standards concerning pavement lengths, widths, grades, and slopes are presented in advisory circulars listed in Appendix 4.

102. SPECIAL CONSIDERATIONS. Airport pavements should provide a surface which is not slippery and will provide good traction during any weather conditions. AC 150/5320-12, Measurement, Construction and Maintenance of Skid Resistant Airport Pavement Surfaces, presents information on skid resistant surfaces.

103. STAGE CONSTRUCTION OF AIRPORT PAVEMENTS. In some instances it may be necessary to construct the airport pavement in stages; that is, to build up the pavement profile, layer by layer, as the traffic using the facility increases in weight and number. Lateral staging, i.e., planning for future widening of pavements is sometimes advantageous to accommodate larger aircraft. If stage construction is to be undertaken, the need for sound planning cannot be overemphasized. The complete pavement should be designed prior to the start of any stage, and each stage must provide an operational surface. The planning of a stage constructed pavement should recognize a number of considerations.

a. Economics. Careful economic studies are required to determine if staged construction is warranted. Construction materials and labor costs follow inflationary trends and can be expected to increased as later stages are constructed. The costs and time involved in any pavement shutdown or diversion of traffic necessitated by the construction of any stage should be considered. The costs of mobilizing construction equipment several times should be compared with mobilizing once. The costs of maintaining an intermediate stage should be considered.

b. Adequacy of Each Stage. Each stage should be designed to adequately accommodate the traffic which will use the pavement until the next stage is constructed.

c. Drainage. The underlying layers and drainage facilities of a stage constructed pavement should be built to the standards required for the final cross section. Providing the proper foundation and drainage facilities in the first stage is mandatory as the underlying layers will not be readily accessible for upgrading in the future.

d. Communication. All parties concerned and, insofar as practicable, the general public should be informed that staged construction is planned. Staged construction sometimes draws unjust criticism when relatively new facilities are upgraded for the next stage.

CHAPTER 2. SOIL INVESTIGATIONS AND EVALUATION

200. GENERAL. The importance of accurate identification and evaluation of pavement foundations cannot be overemphasized. Although it is impossible to explore the entire field of soil mechanics in a publication such as this, the following text will highlight those aspects which are particularly important to the airport paving engineer.

a. Classification System. The Unified Soil Classification (USC) system should be used in engineering matters concerning civil airport pavements. To avoid misunderstanding, certain terms employed are defined below:

(1) Definition. For engineering purposes, and particularly as it applies to airports, soil includes all natural deposits which can be moved with earth moving equipment, without requiring blasting under unfrozen conditions. Harder materials are considered to be rock.

(2) Conditions and Properties. Soil conditions include such items as the elevation of the water table, the presence of water bearing strata, and the field properties of the soil. Field properties of the soil include the soil's density, moisture content, and frost penetration.

(3) Profile. The soil profile is the vertical arrangement of layers of soils, each of which possesses different physical properties from the adjacent layer.

(4) Subgrade. Subgrade soil is that soil which forms the foundation for the pavement. It is the soil directly beneath the pavement structure.

b. Costs. Soil conditions and the local prices of suitable construction materials are important items affecting the cost of construction of airport pavements. Earthwork and grading costs are directly related to the difficulty with which excavation can be accomplished and compaction obtained.

c. **Subgrade Support.** It should be remembered that the subgrade soil ultimately provides support for the pavement and the imposed loads. The pavement serves to distribute the imposed load to the subgrade over an area greater than that of the tire contact area. The greater the thickness of pavement, the greater is the area over which the load on the subgrade is distributed. It follows, therefore, that the more unstable the subgrade soil, the greater is the required area of load distribution and consequently the greater is the required thickness of pavement. The soils having the best engineering characteristics encountered in the grading and excavating operations should be incorporated in the upper layers of the subgrade by selective grading if economically feasible.

d. Drainage. In addition to the relationship which soil conditions bear to grading and paving operations, they determine the necessity for underdrains and materially influence the amount of surface runoff. Thus, they have a resulting effect on the size and extent of other drainage structures and facilities. (See FAA publication, AC 150/5320-5, Airport Drainage.)

201. SOIL INVESTIGATIONS.

a. Distribution and Properties. To provide essential information on the various types of soils, investigations should be made to determine their distribution and physical properties. This information combined with data on site topography and area climatic records, provides basic planning material essential to the logical and effective development of the airport. An investigation of soil conditions at an airport site will include:

(1) Survey. A soil survey to determine the arrangement of different layers of the soil profile with relation to the proposed subgrade elevation.

(2) Sampling. Collection of representative samples of the layers of soil.

(3) Testing. Testing of samples to determine the physical properties of the various soil materials with respect to in-place density and subgrade support.

(4) **Availability.** A survey to determine the availability of materials for use in construction of the subgrade and pavement.

b. **Procedures.** With respect to sampling and surveying procedures and techniques, ASTM D 420, Investigating and Sampling Soils and Rock for Engineering Purposes, is one of the most frequently used. This method is based entirely on the soil profile. In the field, ASTM D 2488, Description of Soils (Visual-Manual Procedures) is commonly used to identify soils by such characteristics as color, texture, structure, consistency, compactness, cementation, and to varying degrees, chemical composition.

(1) **Maps.** The use of Department of Agriculture soils maps, United States Geodetic Survey (USGS) geologic maps, and USGS engineering geology maps can prove valuable aids in the study of soils at and in the vicinity of the airport. Although the pedological classification, determined from these maps, does not treat soil as an engineering or construction material, data so obtained are extremely useful to the agronomist in connection with the development of turf areas on airports and to the engineer concerned with preliminary investigations of site selection, development costs, and alignment.

(2) **Aerial Photography.** The practice of determining data on soils by use of aerial photographs is established and commonly acceptable. Relief, drainage, and soil patterns may be determined from the photographs, and an experienced photo interpreter can define differences in characteristics of soils. By employing this method of investigation, it is possible to expedite soil studies and reduce the amount of effort required to gather data.

202. SURVEYING AND SAMPLING.

a. **Soil Borings.** The initial step in an investigation of soil conditions is a soil survey to determine the quantity and extent of the different types of soil, the arrangement of soil layers, and the depth of any subsurface water. These profile borings are usually obtained with a soil auger or similar device. Washed borings are not recommended due to inaccuracies of depth determinations. The intent of the borings is to determine the soil or rock profile and its lateral extent. Inasmuch as each location presents its particular problems and variations, the spacing of borings cannot always be definitely specified by rule or preconceived plan. Suggested criteria for the location, depth, and number of borings are given in Table 2-1. Wide variations in these criteria can be expected due to local conditions.

TABLE 2-1. RECOMMENDED SOIL BORING SPACINGS AND DEPTHS

AREA	SPACING	DEPTH
Runways and Taxiways	Random across pavement at 200 foot (68 m) intervals	Cut Areas - 10' (3.5 m) Below Finished Grade Fill Areas - 10' (3.5 m) Below Existing Ground'
Other Areas of Pavement	1 Boring per 10,000 Square Feet (930 sq m) of Area	Cut Areas - 10' (3.5 m) Below Finished Grade Fill Areas - 10' (3.5 m) Below Existing Ground'
Borrow Areas	Sufficient Tests to Clearly Define the Borrow Material	To Depth of Borrow Excavation

'For deep fills, boring depths shall be sufficient to determine the extent of consolidation and/or slippage the fill may cause.

b. **Number of Borings, Locations, and Depths.** Obviously, the locations, depths, and numbers of borings must be such that all important soil variations can be determined and mapped. Whenever past experience at the location in question has indicated that settlement or stability in deep fill areas may be a problem or, if in the opinion of the engineer, additional investigations are warranted, more or deeper borings may be required in order that the proper design, location, and construction procedures may be determined. Cdnversely, where uniform soil conditions are encountered, fewer borings may be acceptable.

c. **Boring Log.** A graphic log of soil conditions can be of great value in assessing subgrade conditions. It is recommended that the graphic log be developed which summarizes the results of the soil explorations. A typical graphic log is included as Figure 2-1. The graphic log should include:

(1) **Location**

(2) **Date Performed**

(3) **Type of exploration**

(4) **Surface elevation**

(5) **Depth of materials**

(6) **Sample identification numbers**

(7) **Classification**

(8) **Water table**

d. **Soil Survey Areas.** The soil survey is not confined to soils encountered in grading or necessarily to the area within the boundaries of the airport site. Possible sources of locally available material that may be used as borrow areas or aggregate sources should be investigated.

e. **Undisturbed Samples.** Samples representative of the different layers of the various soils encountered and various construction material discovered should be obtained and tested in the laboratory to determine their physical and engineering properties. In-situ properties such as in-place density, shear strength, consolidation characteristics, etc. may necessitate obtaining "undisturbed" core samples. ASTM D 1587, Thin Walled Tube Sampling of Soils, describes a method of obtaining "undisturbed" soil samples. Because the results of a test can only be as good as the sampling, it is of utmost importance that each sample be representative of a particular type of soil material and not be a careless and indiscriminate mixture of several materials.

f. **Inplace Testing.** Pits, open cuts, or both may be required for making inplace bearing tests, for the taking of undisturbed samples, for charting variable soil strata, etc. This type of supplemental soil investigation is recommended for situations which warrant a high degree of accuracy or when in situ conditions are complex and require extensive investigation,

203. **SOIL TESTS.**

a. **Physical Soil Properties.** To determine the physical properties of a soil and to provide an estimate of its behavior under various conditions, it is necessary to conduct certain soil tests. A number of field and laboratory tests have been developed and standardized. Detailed methods of pet forming soil tests are completely covered in publications of the American Society for Testing and Materials (ASTM).

b. **Testing Requirements.** Soil tests are usually identified by terms indicating the soil characteristics which the tests will reveal. Terms which identify the tests considered to be the minimum or basic requirement for airport pavement, with their ASTM designations and brief explanations, follow:

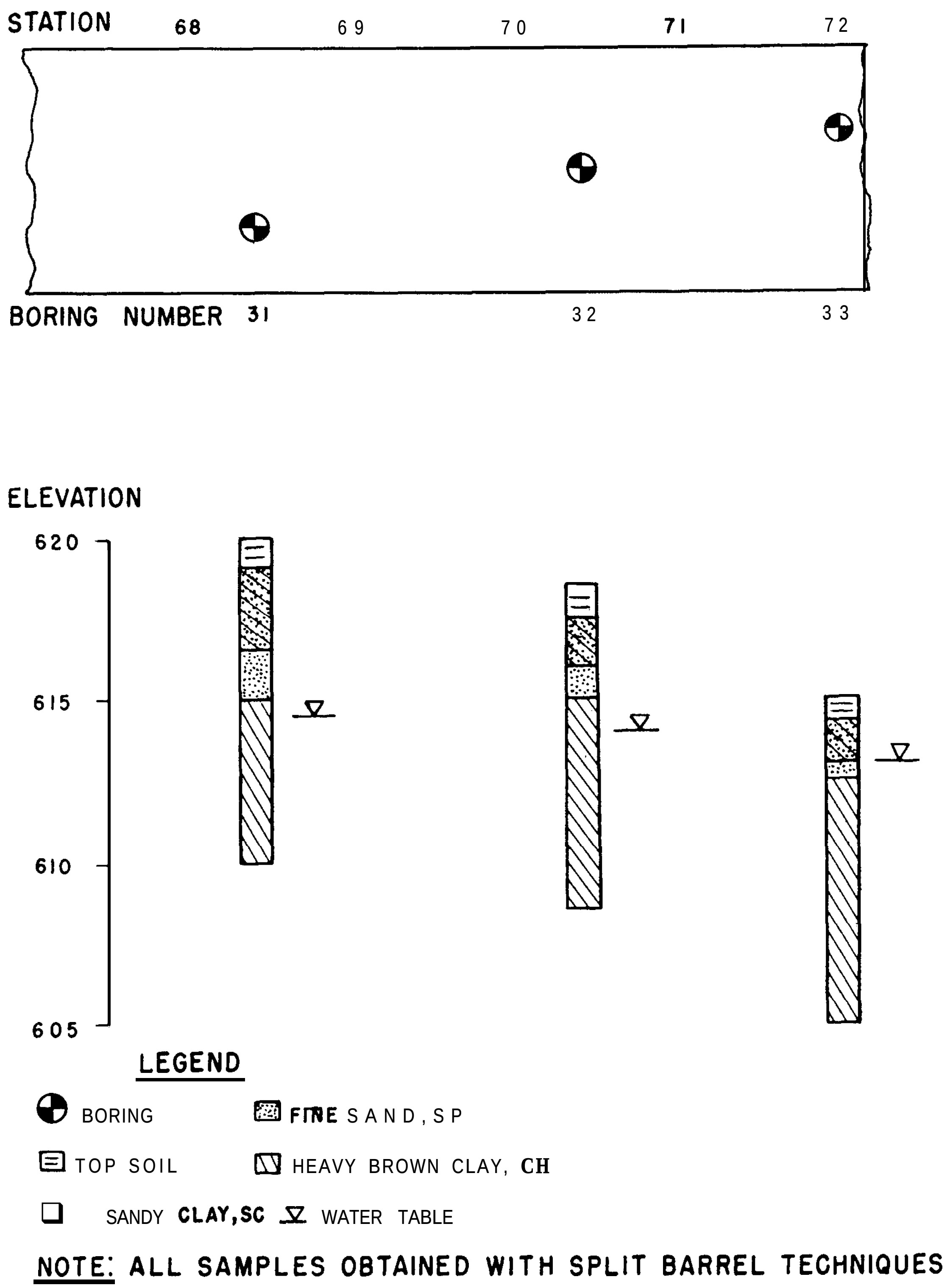


FIGURE 2-1 TYPICAL BORING LOG

(1) **Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants (ASTM D 421) or Wet Preparation of Soil Samples for Grain-Size Analysis and Determination of Soil Constants (ASTM D 2217).** The dry method (D-421) should be used only for clean, cohesionless granular materials. The wet method (D-2217) should be used for all cohesive or borderline materials. In case of doubt, the wet method should be used.

(2) **Particle-Size Analysis of Soils (ASTM** C 422). This analysis provides a quantitative determination of the distribution of particle sizes in soils.

(3) **Liquid Limit, Plastic Limit and Plasticity Index of Soils (ASTM D 4318).** The plastic and liquid limits of soil define in a standard manner the lowest moisture contents at which a soil will change from a semi-solid to a plastic state and at which a solid passes from a plastic to a liquid state, respectively. The plasticity index is the numerical difference between the plastic limit and the liquid limit. It indicates the range in moisture content over which a soil remains in a plastic state prior to changing into a liquid. The plastic limit, liquid limit and plasticity index of soils are used in engineering classification in accordance with the Unified Soil Classification System (ASTM D 2487). In conjunction with particle size analysis, natural moisture content and other soil properties or conditions, the limits may be used to estimate engineering properties or behavior of soils such as shrink/swell potential, consolidation characteristics, construction/stabilization characteristics, permeability, and strength characteristics.

(4) **Moisture-Density Relations of Soils (ASTM D** 698, **D 1557).** For purposes of compaction control during construction, tests to determine the moisture-density relations of the different types of soils should be performed.

(i) **Heavy Load Pavements.** For pavements designed to serve aircraft weighing 30,000 pounds (13 000 kg) or more, use ASTM Method D 1557.

(ii) **Light Load Pavements.** For pavements designed to serve aircraft weighing less than 30,000 pounds (13 000 kg), use ASTM Method D 698.

(5) **Bearing Ratio of Laboratory-Compacted Soils (ASTM D 1883).** This test is used to assign a California Bearing Ratio (CBR) value to subgrade soils for use in the design of flexible pavements.

(6) **Modulus of Soil Reaction (AASHTO T** 222). This test is used to determine the modulus of soil reaction, K, for use in the design of rigid pavements.

c. **Supplemental Tests.** In many cases additional soil tests will be required over those listed in paragraph 203b above. It is not possible to cover all the additional tests which may be required; however, a few examples are presented below. This list should not be considered all inclusive.

(1) **Shrinkage Factors of Soils (ASTM D** 427). This test may be required in areas where swelling soils might be encountered.

(2) **Permeability of Granular Soils (ASTM D** 2434). This test may be needed to assist in the design of subsurface drainage.

(3) **Determination of Organic Material in Soils by Wet Combustion (AASHTO T-194).** This test may be needed in areas where deep pockets of organic material are encountered or suspected.

(4) **California Bearing Ratio, Field In-place Tests (Mil-Std 621, Method 101).** Field bearing tests can be performed when the in site conditions satisfy density and moisture conditions which will exist under the pavement being designed. The method is also described in Manual Series No. 10, Soils Manual, The Asphalt Institute, College Park, MD.

204. UNIFIED SOIL CLASSIFICATION SYSTEM.

a. Purpose. The standard method of classifying soils for engineering purposes is ASTM D 2487, commonly called the Unified system. The primary purpose in determining the soil classification is to enable the engineer to predict probable field behavior of soils. The soil constants in themselves also provide some guidance on which to base performance predictions. The Unified system classifies soils first on the basis of grain size, then further subgroups soils on the plasticity constants. Table 2-2 presents the classification of soils by the Unified system.

b. Initial Division. As indicated in Table 2-2, the initial division of soils is based on the separation of coarse-and fine-grained soils and highly organic soils. The distinction between coarse and fine grained is determined by the amount of material retained on the No. 200 sieve. Coarse-grained soils are further subdivided into gravels and sands on the basis of the amount of material retained on the No. 4 sieve. Gravels and sands are then classed according to whether or not fine material is present. Fine-grained soils are subdivided into two groups on the basis of liquid limit. A separate division of highly organic soils is established for materials which are not generally suitable for construction purposes.

TABLE 2-2. CLASSIFICATION OF SOILS FOR AIRPORT PAVEMENT APPLICATIONS

	MAJOR DIVISIONS		GROUP SYMBOLS
Coarse-grained Soils more than 50% retained on No. 200 sieve'	Gravels 50% or more of coarse fraction retained on No. 4 sieve	Clean Gravels	GW GP
		Gravels with Fines	GM GC
	Sands less than 50% of coarse fraction retained on No. 4 sieve	Clean Sands	SW SP
		Sands with Fines	SM SC
Fine-grained Soils 50 % or less retained on No. 200 sieve'	Silts and Clays Liquid Limit 50% or less		ML CL OL
	Silts and Clays Liquid Limit Greater than 50%		MH CH OH
Highly Organic Soils			PT

'Based on the material passing the 3-in (75-mm) sieve.

c. Soil Groups. Soils are further subdivided into 15 different groupings. The group symbols and a brief description of each is given below:

(1) **GW** Well-graded gravels and gravel-sand mixtures, little or no fines.
(2) **GP** Poorly graded gravels and gravel-sand mixtures, little or no fines.
(3) **GM** Silty gravels, gravel-sand-silt mixtures.
(4) **GC** Clayey gravels, gravel-sand-clay mixtures.
(5) **SW** Well-graded sands and gravelly sands, little or no fines.
(6) **SP** Poorly graded sands and gravelly sands, little or no tines.
(7) **SM** Silty sands, sand-silt mixtures.
(8) **SC** Clayey sands, sand-clay mixtures.
(9) **ML** Inorganic silts, very fine sands, rock flour, silty or clayey fine sands.
(10) **CL** Inorganic clays of low to medium plasticity, gravelly clays, silty clays, lean clays.
(11) **OL** Organic silts and organic silty clays of low plasticity.
(12) **MH** Inorganic silts, micaceous or diatomaceous fine sands or silts, plastic silts.

(13) **CH** Inorganic clays or high plasticity, fat clays.
(14) **OH** Organic clays of medium to high plasticity.
(15) **PT** Peat, muck and other highly organic soils.

d. **Final Classification.** Determination of the final classification group requires other criteria in addition to that given in Table 2-2. These additional criteria are presented in Figure 2-2 and have application to both coarse and tine grained soils.

e. **Flow Chart.** A flow chart which outlines the soil classification process has been developed and is included as Figure 2-3. This flow chart indicates the steps necessary to classify soils in accordance with ASTM D 2487.

f. **Field Identification.** ASTM D 2488, Description of Soils (Visual-Manual Procedure), presents a simple, rapid method of field identification of soils. This procedure provides techniques for classifying soils rather accurately with a minimum of time and equipment.

g. **Characteristics as Pavement Foundations.** A table of pertinent characteristics of soils used for pavement foundations is presented in Table 2-3. These characteristics are to be considered as approximate, and the values listed are generalizations which should not be used in lieu of testing.

205. **EXAMPLES.** The following examples illustrate the classification of soils by the Unified system. The classification process progresses through the flow chart shown in Figure 2-3.

a. **Example 1.** Assume a soil sample has the following properties and is to be classified in accordance with the Unified system.

(1) **Fines.** Percent passing No. 200 sieve = 98%.

(2) **Liquid Limit.** Liquid limit on minus 40 material 30%.

(3) **Plastic Limit.** Plastic limit on minus 40 material 10%.

(4) **Plasticity Chart.** Above "A" line, see Figure 2-2. The soil would be classified as CL, lean clay of low to medium plasticity. Table 2-3 indicates the material would be of fair to poor value as a foundation when not subject to frost action. The potential for frost action is medium to high.

b. **Example** 2. Assume a soil sample with the following properties is to be classified by the Unified system.

(1) **Fines.** Percent passing No. 200 sieve = 48%.

CLASSIFICATION CRITERIA		
Classification on basis of percentage of fines Less than 5% Pass No. 200 sieve GW, GP, SW, SP More than 12% Pass No. 200 sieve GM, GC, SM, SC 5% to 12% Pass No. 200 sieve Borderline Classification requiring use of dual symbols	$C_u = D_{60}/D_{10}$ Greater than 4 $C_z = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
	Not meeting both criteria for GW	
	Atterberg limits plot below "A" line or plasticity index less than 4	Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols
	Atterberg limits plot above "A" line and plasticity index greater than 7	
	$C_u = D_{60}/D_{10}$ Greater than 6 $C_z = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
	Not meeting both criteria for SW	
	Atterberg limits plot below "A" line or plasticity index less than 4	Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols
	Atterberg limits plot above "A" line and plasticity index greater than 7	

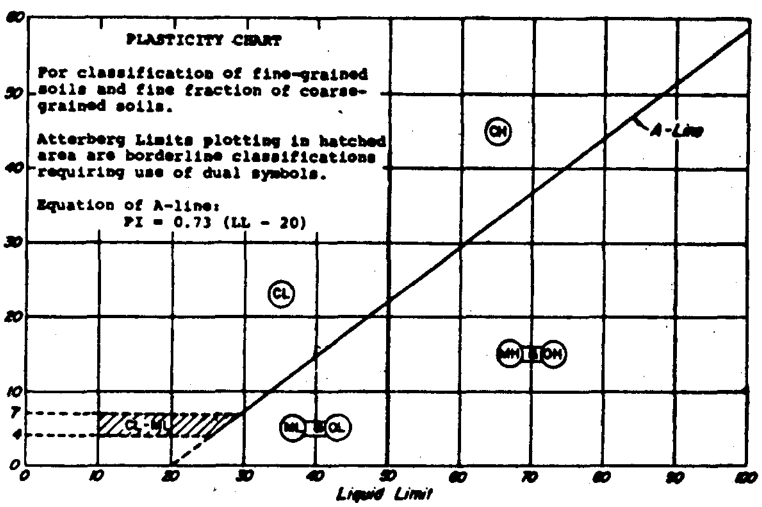
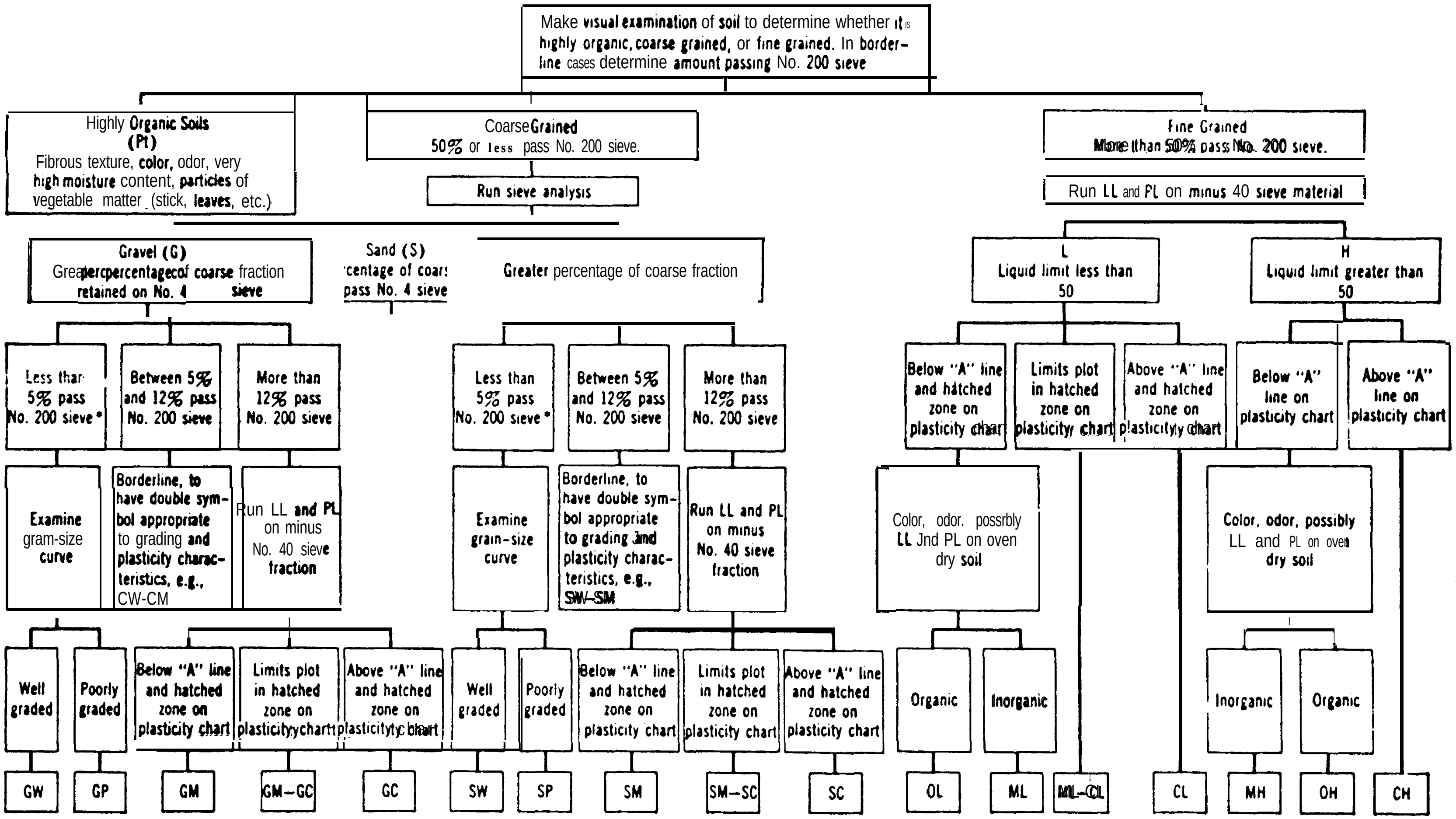


FIGURE 2-2 SOIL CLASSIFICATION CRITERIA



Note: Sieve sizes are U.S. Standard.

- If fines interfere with free-draining properties use double symbol such as GW-GM, etc.

Figure 2-3. Flow chart for Unified Soil Classification System

TABLE 2-3. Soil Characteristics Pertinent to Pavement Foundations

Major Divisions (1)	(2)	Letter (3)	Name (4)	Value as Foundation When Not Subject to Frost Action (5)	Value as Base Directly under Wearing Surface (6)	Potential Frost Action (7)	Compressibility and Expanston (8)	Drainage Characteristics (9)	Compaction Equipment (10)	Unit Dry Weight (pcf) (11)	Field CBR (12)	Subgrade Modulus k (pci) (13)
Coarse-grained soils	Gravel and gravelly soils	GW	Gravel or sandy gravel. well graded	Excellent	Good	None to very slight	Ahnost none	Excellent	Crawler-type tractor. rubber-tired equipment. steel-wheeled roller	125-140	60-80	300 or more
		GP	Gravel or sandy gravel, poorly graded	Good to excellent	Poor to fair	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment. steel-wheeled roller	120-130	35-60	300 or more
		GU	Gravel or sandy gravel, uniformly graded	Good	Poor	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	115-125	25-50	300 or more
		GM	Silty gravel or silty sandy gravel	Good to excellent	Fair to good	Slight to medium	Very slight	Fair to poor	Rubber-tired equipment, sheepsfoot roller, close control of moisture	130-145	40-80	3tJtJ or more
		GC	Clayey gravel or clayey sandy gravel	Good	Poor	Slight to medium	Slight	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	120-140	20-40	200-300
	Sand and sandy soils	SW	Sand or gravelly sand, well graded	Good	Poor	None to very slight	Almost noue	Excellent	Crawler-type tractor. rubber-tired equipmeut	I IO-130	20-40	200-300
		SP	Sand or gravelly sand. poorly graded	Fair to good	Poor to not suitable	None to very slight	Almost none .	Excellent	Crawler-type tractor. rubber-tired equipment	105-120	15-25	200-300
		SU	Sand or gravelly sand, uniformly graded	Fair to good	Not suitable	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	100-115	IO-20	200-300
		SM	Silty sand or silty gravelly sand	Good	Poor	Slight to high	Very slight	Fair to poor	Rubber-tired equipment, sheepsfoot roller. close control of moisture	120-135	20-40	200-300
		SC	Clayey sand or clayey gravelly sand	Fair to good	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired quipment. sheepsfoot roller	105-130	JO-20	200-300
Fine-grained Soils	Low compressibility LL < 50	ML	Silts, sandy silts, gravelly silts, or diatomaceous soils	Fair to good	Not suitable	Medium to very high	Slight to medium	Fair to poor	Rubber-tired equipment, sheepsfoot roller, close control of moisture	100-125	5-15	IOO-200
		CL	Lean clays, sandy clays, or gravelly clays	Fair to good	Not suitable	Medium to high	Medium	Practically impervious	Rubber-tired equipment, sheepsfoot roller	It-IO-125	5-15	100-200
		OL	Organic silts or lean organic clays	Poor	Not suitable	Medium to high	Medium to high	Poor	Rubber-tired quipmeut. sheepsfoot roller	90-105	4-8	IOO-200
	High compressibility LL > 50	MH	Micaceous clays or diatomaceous soils	Poor	Not suitable	Medium to very high	ffigh	Fair to poor	Rubber-tired quipment, sheepsfoot roller	80-100	4-g	IOO-200
		CH	Fat clays	Poor to very poor	Not suitable	Medium	ffigh	Practically impervious	Rubber-tired equipment. sheepsfoot roller	90-I IO	3-5	50-100
		OH	Fat organic clays	Poor to very poor	Not suitable	Medium	High	Practically impervious	Rubber-tired quipmeut, sheepsfoot roller	SO-105	3-5	50-100
Peat and other fibrous organic soils		Pt	Peat, humus and other	Not suitable	Not suitable	Slight	Very high	Fair to poor	Compaction not practical			

(2) **Gravel.** Percent of coarse fraction retained on No. 4 sieve = 70%.

(3) **Liquid Limit.** Liquid limit on minus 40 fraction = 60%.

(4) **Plastic Limit.** Plastic limit on minus 40 fraction = 20%.

(5) **Plasticity Index.** Compute Plasticity Index LL-PL = 40%.

(6) **Plasticity Chart.** Above "A" line, see Figure 2-2.

(7) **Classification.** This sample is classified as GC, clayey gravel. Table 2-3 indicates the material is good for use as a pavement foundation when not subject to frost action. The potential for frost action is slight to medium.

206. SOIL STRENGTH TESTS. Soil classification for engineering purposes provides an indication of the probable behavior of the soil as a pavement subgrade. This indication of behavior is, however, approximate. Performance different from that expected can occur due to a variety of reasons such as degree of compaction, degree of saturation, height of overburden, etc. The possibility of incorrectly predicting subgrade behavior can be largely eliminated by measuring soil strength. The strength of materials intended for use in flexible pavement structures is measured by the California Bearing Ratio (CBR) tests. Materials intended for use in rigid pavement structures are tested by the plate bearing method of test. Each of these tests is discussed in greater detail in the subsequent paragraphs.

a. California Bearing Ratio. The CBR test is basically a penetration test conducted at a uniform rate of strain. The force required to produce a given penetration in the material under test is compared to the force required to produce the same penetration in a standard crushed limestone. The result is expressed as a ratio of the two forces. Thus a material with a CBR value of 15 means the material in question offers 15% of the resistance to penetration that the standard crushed stone offers. Laboratory CBR tests should be performed in accordance with ASTM D 1883, Bearing Ratio of Laboratory-Compacted Soils. Field CBR tests should be conducted in accordance with the ASTM D 4429, Standard Test Method for Bearing Ratio of Soils in Place.

(1) **Laboratory.** Laboratory CBR tests are conducted on materials which have been obtained from the site and remolded to the density which will be obtained during construction. Specimens are soaked for 4 days to allow the material to reach saturation. A saturated CBR test is used to simulate the conditions likely to occur in a pavement which has been in service for some time. Pavement foundations tend to reach nearly complete saturation after about 3 years. Seasonal moisture changes also dictate the use of a saturated CBR design value since traffic must be supported during periods of high moisture such as spring seasons.

(2) **Field.** Field CBR tests can provide valuable information on foundations which have been in place for several years. The materials should have been in place for a sufficient time to allow for the moisture to reach an equilibrium condition. An example of this condition is a fill which has been constructed and surcharged for a long period of time prior to pavement construction.

(3) **Gravelly Materials.** CBR tests on gravelly materials are difficult to interpret. Laboratory CBR tests on gravel often yield CBR results which are too high due to the confining effects of the mold. The assignment of CBR values to gravelly subgrade materials may be based on judgment and experience. The information given in Table 2-3 may provide helpful guidance in selecting a design CBR value for a gravelly soil. Table 2-3 should not, however be used indiscriminately as a sole source of data. It is recommended that the maximum CBR for unstabilized grave1 subgrade be 50.

(4) **Number of Tests.** The number of CBR tests needed to properly establish a design value cannot be simply stated. Variability of the soil conditions encountered at the site will have the greatest influence on the number of tests needed. As an approximate "rule of thumb" three CBR tests on each different major soil type should be considered. The preliminary soil survey will reveal how many different soil types will be encountered. The design CBR value should be conservatively selected. Common paving engineering practice is to select a value which is one standard

deviation below the mean. As a rule, a design CBR value of 3 the lowest practical value which should be assigned. In instances where the subgrade strength is lower than CBR = 3, the subgrade should be improved through stabilization or other means to raise the design CBR value.

(5) Lime Rock Ratio. Some areas of the country use the lime rock ratio, LBR, to express soil strength. To convert LBR to CBR, multiply LBR by 0.8.

b. Plate Bearing Test. As the name indicates, the plate bearing test measures the bearing capacity of the pavement foundation. The result, k value, can be envisioned as the pressure required to produce a unit deflection of the pavement foundation. The plate bearing test result, k value, has the units of pounds per cubic inch (Mega-Newtons per cubic meter). Plate bearing tests should be performed in accordance with the procedures contained in AASHTO T 222.

(1) Sensitivity. Rigid pavement design is not too sensitive to the k value. An error in establishing a k value will not have a drastic impact on the design thickness of the rigid pavement. Plate bearing tests must be conducted in the field and are best performed on test sections which are constructed to the design compaction and moisture conditions. A correction to the k value for saturation is required to simulate the moisture conditions likely to be encountered by the in-service pavement.

(2) Number of Tests. Plate bearing tests are relatively expensive to perform and thus the number of tests which can be conducted to establish a design value is limited. Generally only 2 or 3 tests can be performed for each pavement feature. The design k value should be conservatively selected.

(3) Plate Size. The rigid pavement design and evaluation curves presented in this circular are based on a k value determined by a static plate load test using a 30-inch (762 mm) diameter plate. Use of a plate of smaller diameter will result in a higher k value than is represented in the design and evaluation curves.

(4) Subbase Effects. It is recommended that plate bearing tests be conducted on the subgrade and the results adjusted to account for the effect of subbase. Figure 2-4 shows the increase in k value for various thicknesses of subbase over a given subgrade k. Plate bearing tests conducted on top of subbase courses can sometimes yield erroneous results since the depth of influence beneath a 30” inch (762 mm) bearing plate is not as great as the depth of influence beneath a slab loaded with an aircraft landing gear assembly. In this instance a subbase layer can influence the response of a bearing plate more than the response of a loaded pavement.

(5) Stabilized Subbase. The determination of k value for stabilized layers is a difficult problem. The k value normally has to be estimated. It is recommended that the k value be estimated as follows. The thickness of the stabilized layer should be multiplied by a factor ranging from 1.2 to 1.6 to determine the equivalent thickness of well-graded crushed aggregate. The actual value in the 1.2 - 1.6 range should be based on the quality of the stabilized layer and the thickness of the slab relative to the thickness of the stabilized layer. High quality materials which are stabilized with high percentages of stabilizers should be assigned an equivalency factor which is higher than a lower quality stabilized material. For a given rigid pavement thickness, a thicker stabilized layer will influence pavement performance more than a thin stabilized layer and should thus be assigned a higher equivalency factor.

(6) Maximum k Value. It is recommended that a design k value of 500 lbs/in^3 (136 MN/m^3) not be exceeded for any foundation. The information presented in Table 2-3 gives general guidance as to probable k values for various soil types.

c. Additional Soil Strength Tests. Where stability of the underlying section is questionable, additional soil strength tests may be necessary. Direct shear tests (ASTM D 3080) or field vane tests (ASTM D 2573) may be required to adequately design the pavement structure.

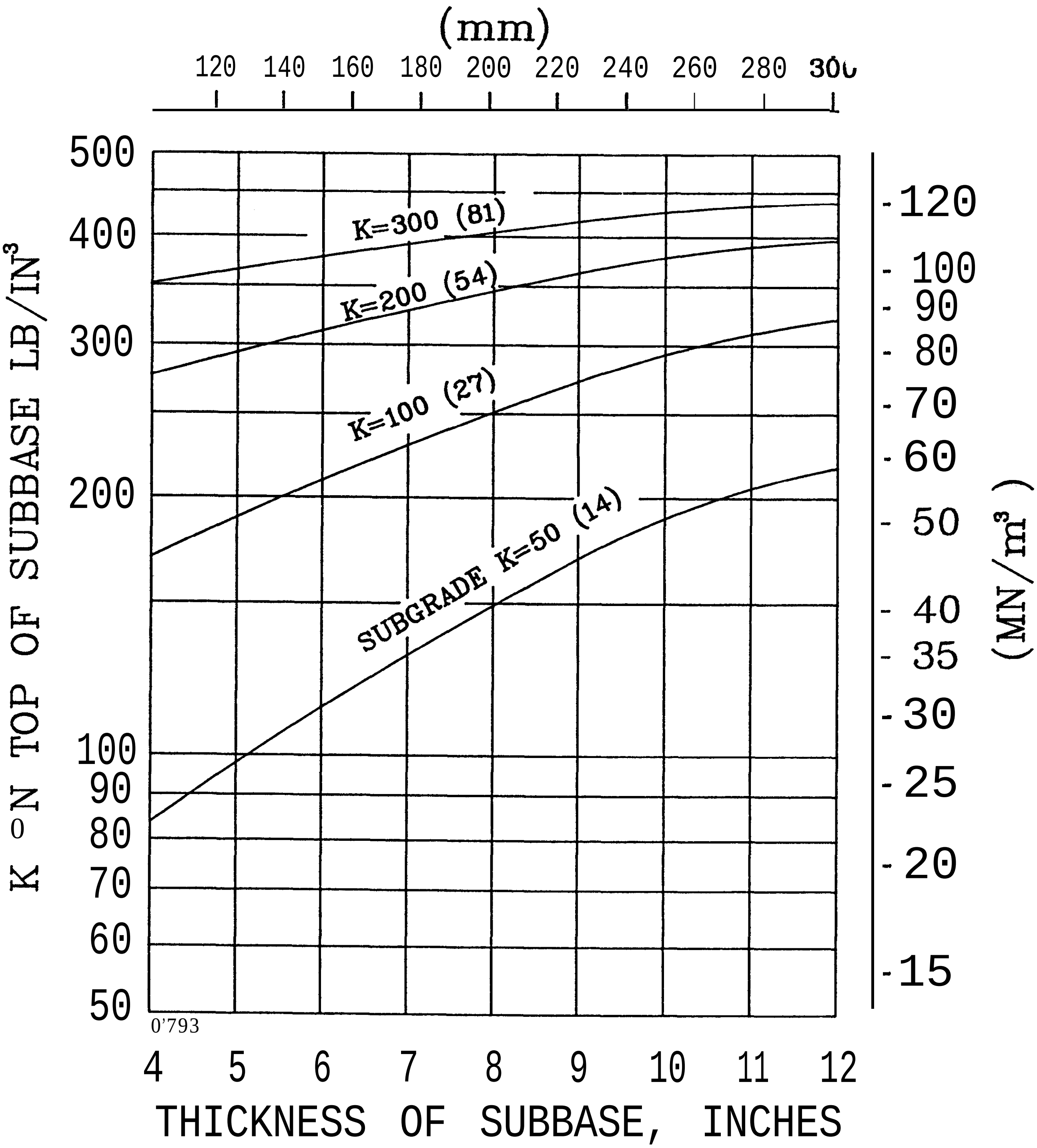


FIGURE 2-4. EFFECT OF SUBBASE ON MODULUS OF SUBGRADE REACTION

207. SUBGRADE STABILIZATION. Subgrade stabilization should be considered if one or more of the following conditions exist: poor drainage, adverse surface drainage, frost, or need for a stable working platform. Subgrade stabilization can be accomplished through the addition of chemical agents or by mechanical methods.

a. Chemical Stabilization. Different soil types require different stabilizing agents for best results. The following publications are recommended to determine the appropriate type and amount of chemical stabilization for subgrade soils. US Army, Corps of Engineers, Technical Manual TM 5-818-2/AFM 88-6 Chapter 6 ; Technical Manual 5-825.2/AFM 88-6 Chapter 2; Technical Manual 5-824-3/AFM 88-6, Chapter 3; Soil Cement Handbook, Portland Cement Association; and The Asphalt Institute Manual Series MS-19, A Basic Asphalt Emulsion Manual.

b. Mechanical Stabilization. In some instances subgrades cannot be adequately stabilized through the use of chemical additives. The underlying soils may be so soft that stabilized materials cannot be mixed and compacted over the underlying soils without failing the soft soils. Extremely soft soils may require bridging in order to construct the pavement section. Bridging can be accomplished with the use of thick layers of shot rock or cobbles. Thick layers of lean, porous concrete have also been used to bridge extremely soft soils. Geotextiles should be considered as mechanical stabilization over soft, fine-grained soils. Geotextiles can facilitate site access over soft soils and aid in reducing subgrade soil disturbance due to construction traffic. The geotextile will also function as a separation material to limit long-term weakening of pavement aggregate associated with contamination of the aggregate with underlying fine-grained soils. More information regarding construction over soft soils using geotextiles is provided in FHWA-KI-90-001 (see Appendix 4).

208. SEASONAL FROST. The design of pavements in areas subject to seasonal frost action requires special consideration. The detrimental effects of frost action may be manifested by nonuniform heave and in loss of soil strength during frost melting. Other related detrimental effects include: possible loss of compaction, development of pavement roughness, restriction of drainage, and cracking and deterioration of the pavement surface. Detrimental frost action requires three conditions be met simultaneously: first, the soil must be frost susceptible; secondly, freezing temperatures must penetrate into the frost susceptible soil; thirdly, free moisture must be available in sufficient quantities to form ice lenses.

a. Frost Susceptibility. The frost susceptibility of soils is dependent to a large extent on the size and distribution of voids in the soil mass. Voids must be of a certain critical size for the development of ice lenses. Empirical relationships have been developed correlating the degree of frost susceptibility with the soil classification and the amount of material finer than 0.02 mm by weight. Soils are categorized into four groups for frost design purposes, Frost Group 1 (FG-l), FG-2, FG-3, and FG-4. The higher the frost group number the more susceptible the soil, i.e., soils in frost group 4 are more frost susceptible than soils in frost groups 1, 2, or 3. Table 2-4 defines the frost groups.

b. Depth of Frost Penetration. The depth of frost penetration is a function of the thermal properties of the pavement and soil mass, the surface temperature, and the temperature of the pavement and soil mass at the start of the freezing season. Several methods are available to calculate the depth of frost penetration and subsurface temperatures. The method presented here is a simplification of a method based on the modified Berggren equation. This method requires the use of the air freezing index and the dry unit weight of the soil.

(1) Air Freezing Index. The air freezing index is a measure of the combined duration and magnitude of below freezing temperatures occurring during any given freezing season. the average daily temperature is used in the calculation of freezing index. For example, assume the average daily temperature is 10 degrees below freezing for 10 days. The freezing index would be calculated as follows, 10 degrees X IO days = 100 degree days. Ideally, air freezing indices should be based on actual data obtained from a meteorological station located in close proximity to the construction site. The air freezing index used for design (design air freezing index) should be based on the average of the 3 coldest winters in a 30 year period, if available, or the coldest winter observed in a 10 year period. Figures 2-6 and 2-7 show the approximate design air freezing indices for the lower United States and Alaska, respectively. The values shown in Figures 2-6 and 2-7 do not show local variation which may be substantial, especially in mountainous areas.

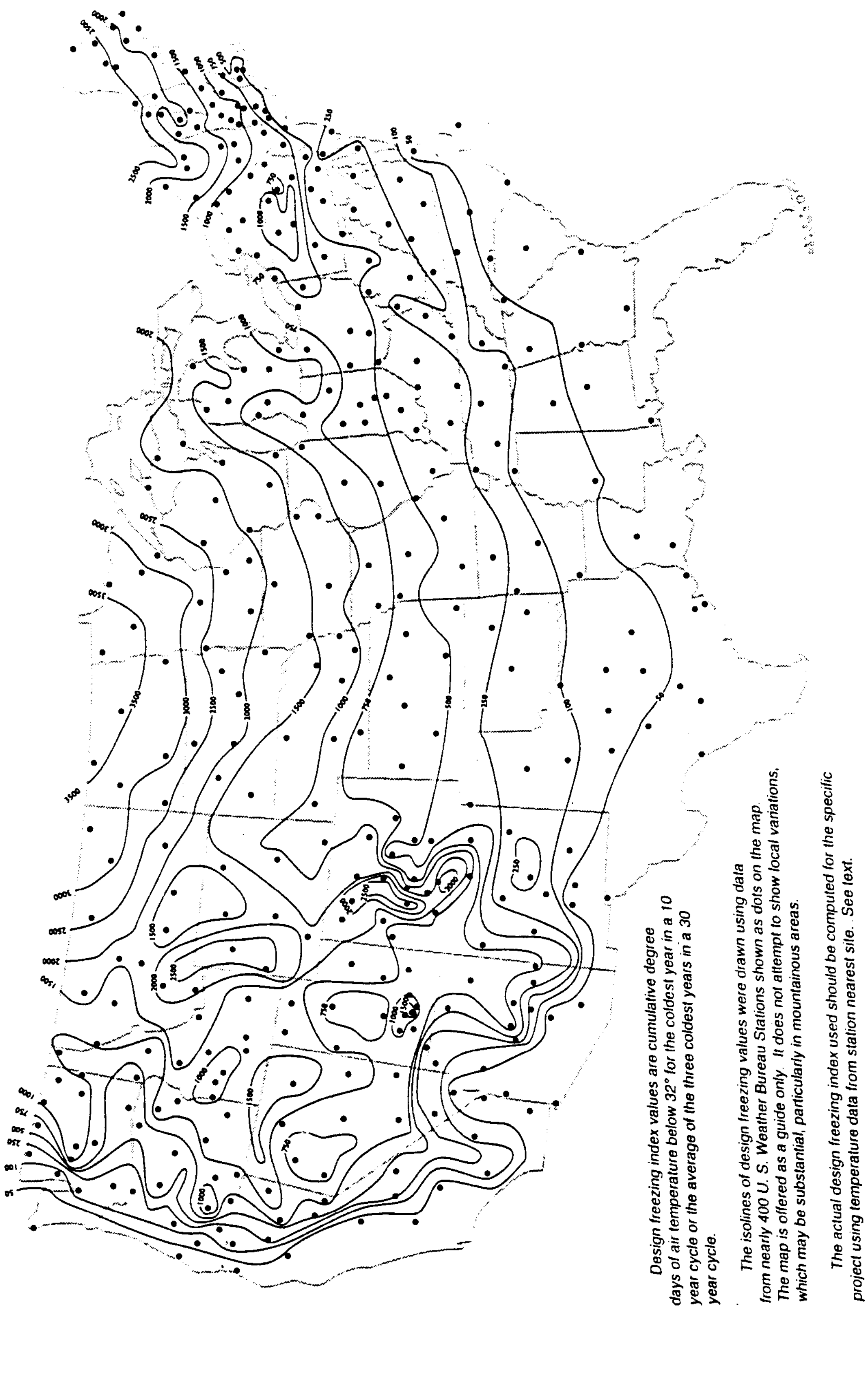


FIGURE 2-5. DISTRIBUTION OF DESIGN AIR FREEZING INDEXES IN THE CONTINENTAL U.S.

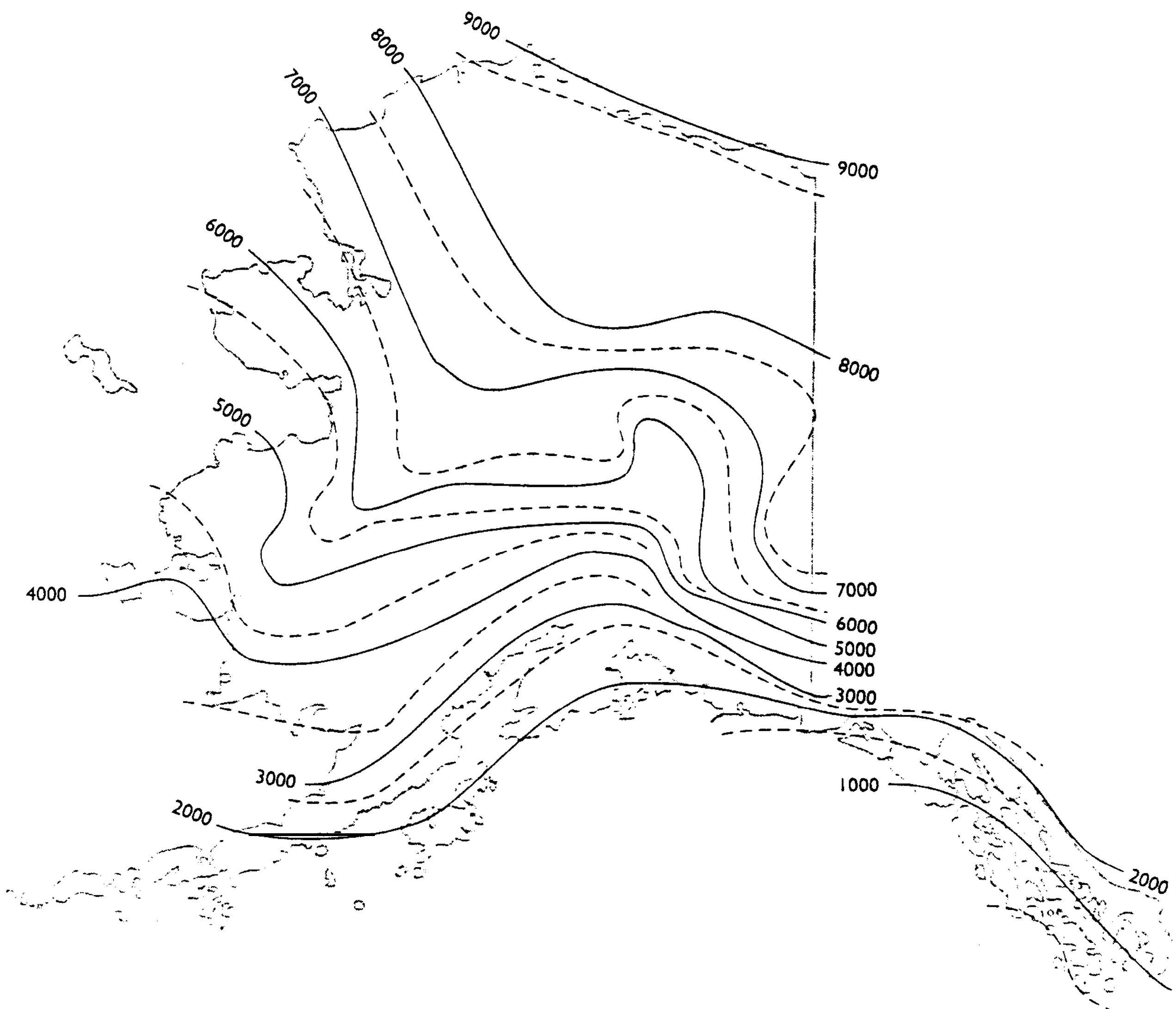


FIGURE 2-6. DISTRIBUTION OF DESIGN AIR FREEZING INDEX VALUES IN ALASKA

(2) Depth of Frost Penetration. The relationship between air freezing index and depth of frost penetration is shown in Figure 2-8. The thermal properties of the soil mass are reflected by differences in the dry unit weight of the subgrade soil. In the development of this method, the pavement is assumed to be either a 12 inch (300 mm) thick rigid pavement or a 20 inch (510 mm) thick flexible pavement. The depths of frost penetration shown on Figure 2-8 are measured from the pavement surface downward.

TABLE 2-4. SOIL FROST GROUPS

Frost Group	Kind of Soil	Percentage finer than 0.02 mm by weight	Soil Classification
FG-1	Gravelly Soils	3to 10	GW, GP, GW-GM, GP-GM
FG-2	Gravelly Soils	10 to 20	GM, GW-GM, GP-GM,
	Sands	3to 15	SW, SP, SM, SW-SM SP-SM
FG-3	Gravelly Soils	Over 20	GM, GC
	Sands, except very fine silty sands	Over 15	SM, SC
	Clays, PI above 12		CL, CH
FG-4	Very fine silty sands	Over 15	SM
	All Silts		ML, MH
	Clays, PI = 12 or less		CL, CL-ML
	Varied Clays and other fine prained banded sediments.	-	CL, CH, ML, SM

c. Free Water. The availability of free water in the soil mass to freeze and form ice lenses is the third consideration which must be present for detrimental frost action to occur. Water may be drawn from considerable depths by capillary action, by infiltration from the surface or sides, or by condensation of atmospheric water vapor. Generally speaking, if the degree of saturation of the soil is 70% or greater, frost heave will probably occur. For all practical purposes, the designer should assume that sufficient water to cause detrimental frost action will be present.

d. Frost Design. The design of pavements to offset seasonal frost effects is presented in Chapter 3. A more detailed and rigorous discussion of frost action and its effects can be found in Research Report No. FAA/RD/74/30, see Appendix 3.

209. PERMAFROST. In arctic regions soils are often frozen at considerable depths year round. Seasonal thawing and refreezing of the upper layer of permafrost can lead to severe loss of bearing capacity and/or differential heave. In areas with continuous high-ice-content permafrost at shallow depths, satisfactory pavements are best ensured by restricting seasonal thawing to the pavement and to a non-frost susceptible base course. This approach is intended to prevent degradation (thawing) of the permafrost layer.

a. Susceptibility. The frost susceptibility of soils in permafrost areas is classified the same as given above in paragraph 206.

b. Depth of Thaw Penetration. Pavement design for permafrost areas must consider the depth of seasonal thaw penetration, The depth to which thawing temperatures penetrate into permafrost may be estimated using Figure 2-9. Use of Figure 2-9 requires inputs air thawing index, average wind speed during the thaw period, pavement type, and density of the permafrost layer. The air thawing index is expressed in degree days and is the difference between average daily temperature and 32 degrees Fahrenheit (0 degrees Celsius) multiplied by the number of days the temperature exceeds freezing. The thawing index used for design (design thawing index) should be based on the 3 warmest summers in the last 30 years of record. If 30 year records are not available, data from the warmest summer in the latest 10 year period may be used.

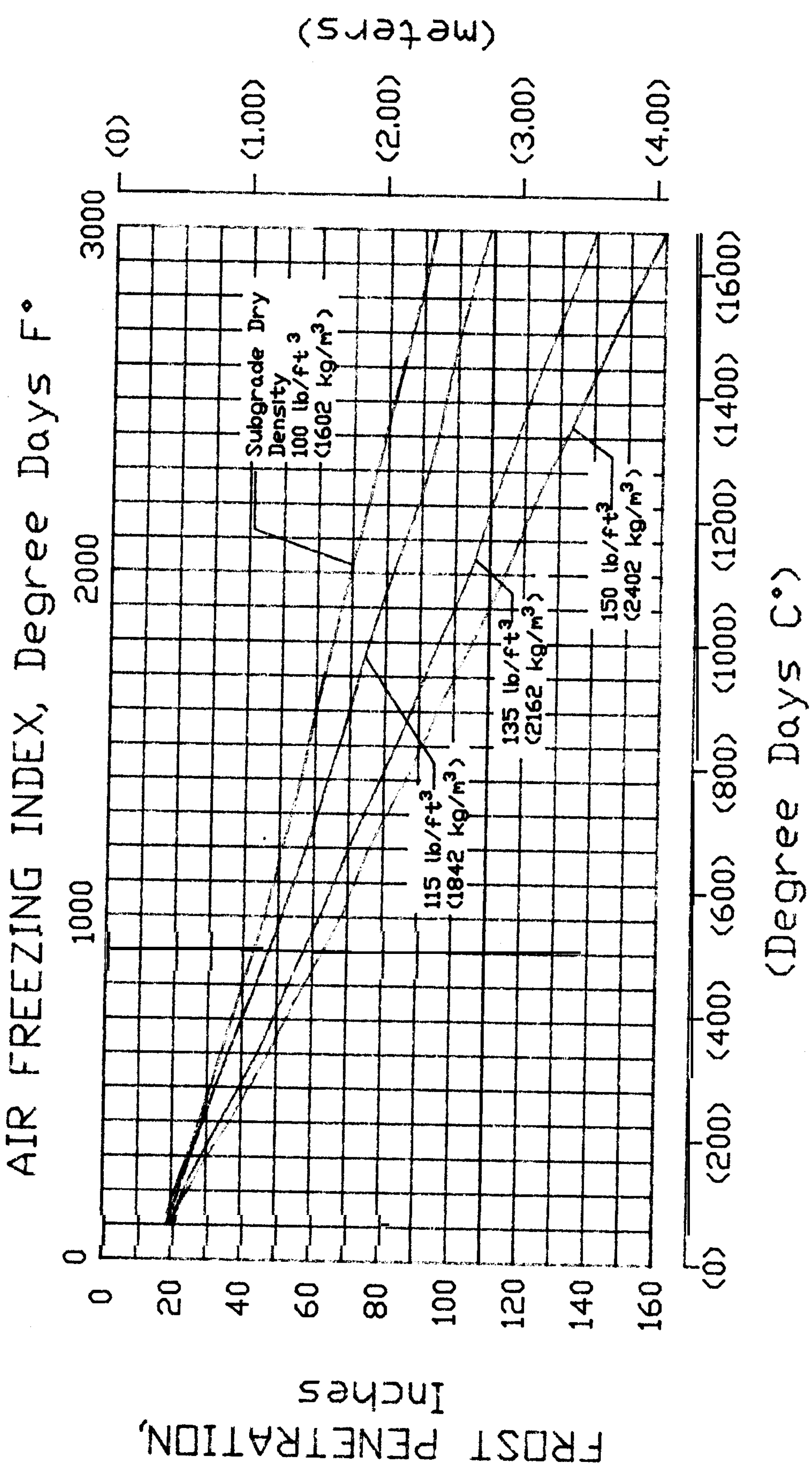
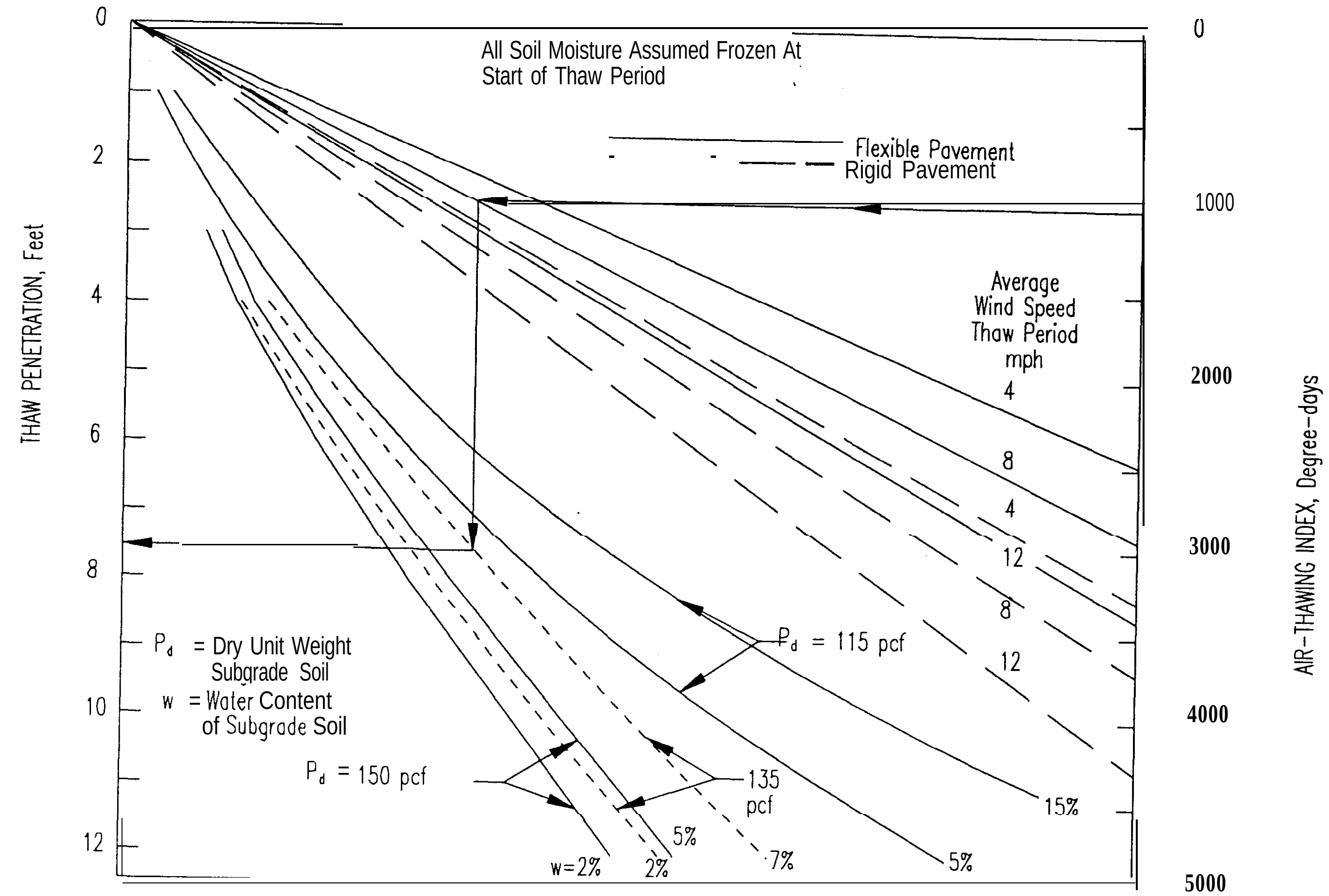


FIGURE 2-7. DEPTH OF FROST PENETRATION



RELATIONSHIP BETWEEN AIR THAWING INDEX AND THAW

Note:
1 foot = 0.3048 m
1 pcf = 16.02 kg/m^3
1 mph = 1.609 km/h

FIGURE 2-8. RELATIONSHIP BETWEEN AIR THAWING INDEX AND THAW PENETRATION INTO GRANULAR, NON-FROST SUSCEPTABLE SUBGRADE SOIL