Introduction to Flexible Pavement Design

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An Introduction to Flexible Pavement Design

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1. INTRODUCTION

This is an introduction to flexible pavement design for engineers. It is not intended as a definitive treatise, and it does not encompass the design of rigid pavements. Engineers are cautioned that much of pavement design is governed by codes, specifications and practices of public agencies. Engineers must always determine the requirements of the regulatory authority within whose jurisdiction specific projects fall.

1.1 Basis of Design. The prime factor influencing the structural design of a pavement is the load-carrying capacity required. The thickness of pavement necessary to provide the desired load-carrying capacity is a function of the following five principal variables:

- Vehicle wheel load or axle load.
- Configuration of vehicle wheels or tracks.
- Volume of traffic during the design life of pavement.
- Soil strength.
- Modulus of rupture (flexural strength) for concrete pavements.

The procedure presented here for design of flexible pavements is generally referred to as the California Bearing Ratio (CBR) design procedure. This procedure requires that each layer be thick enough to distribute the stresses induced by traffic so that when they reach the underlying layer they will not overstress and produce excessive shear deformation in the underlying layer. Each layer must also be compacted adequately so that traffic does not produce an intolerable amount of added compaction. Use ASTM D 1557 compaction effort procedures to design against consolidation under traffic.

1.2 Computer Aided Design. In addition to the design procedures presented herein, computer programs are available for determining pavement thickness and compaction requirements for roads, streets, and open storage areas.

2. PRELIMINARY INVESTIGATIONS

2.1 General. The subgrade provides a foundation for supporting the pavement structure. As a result, the required pavement thickness and the performance obtained from the pavement during its design life will depend largely upon the strength and uniformity of the subgrade. Therefore, insofar as is economically feasible, a thorough investigation of the sub-grade should be made so that the design and construction will ensure uniformity of support for the pavement structure and realization of the maximum strength potential for the particular sub-grade soil type. The importance of uniformity of soil and moisture conditions under the pavement cannot be over-emphasized with respect to frost action.

2.2 Investigations of Site. Characteristics of subgrade soils and peculiar features of the site must be known to predict pavement performance. Investigations should determine the general suitability of the subgrade soils based on classification of the soil, moisture-density relation, degree to which the soil can be compacted, expansion characteristics, susceptibility to pumping, and susceptibility to detrimental frost action. Factors such as groundwater, surface infiltration, soil capillarity, topography, rainfall, and drainage conditions will also affect the future support rendered by the subgrade by increasing its moisture content and thereby reducing its strength. Past performance of existing pavements over a minimum of 5 years on similar local subgrades should be used to confirm the proposed design criteria. All soils should be classified according to the Unified Soil Classification Systems (USCS) in ASTM D 2487.

2.3 Soil Conditions. Soil conditions should be investigated by a combination of a general survey of subgrade conditions, preliminary subsurface investigations, and soil borings.

2.3.1 General Survey of Subgrade Conditions. Sources of data should include the landforms, soil conditions in ditches, and cuts and tests of representative soils in the site. The survey should be augmented with existing soil and geological maps. Both natural and subsurface drainage of the subgrade must be considered.

2.3.2 Preliminary Subsurface Explorations. Preliminary subsurface explorations should be made at intervals selected to test each type of soil and topography identified in the general survey. Additional subsurface explorations should be made in those areas where the preliminary investigation indicates unusual or potentially troublesome subgrade conditions. In determining subgrade conditions, borings will be carried to the depth of frost penetration, but no less than 6 feet below the finished grade. In the design of some high fills, it may be necessary to consider settlement caused by the weight of the fill. The depth requirements stated above will usually result in the subsurface explorations reaching below the depth of maximum frost penetration. If this is not the case, they should be extended to the maximum depth of frost penetration below the design grade.

2.3.3 Soil. Soil samples from the preliminary borings should be classified and the data used to prepare soil profiles and to select representative soils for further testing. Measurements should include moisture contents which indicate soft layers in the soil.

2.4 Borrow Areas

Where material is to be borrowed from adjacent areas, subsurface explorations should be carried out in these areas 2 to 4 feet below the anticipated depth of borrow. Samples from the explorations should be classified and tested for moisture content and compactions characteristics.

3. VEHICULAR TRAFFIC

3.1 Effect on Pavement Design. Pavement thickness must be designed to withstand the anticipated traffic, categorized by type and weight of vehicles, and measured by average daily volume (ADV) of each type for the design life of the pavement. For most pavements, the magnitude of the axle load is of greater importance than the gross weight of pneumatic-tired vehicles because axle spacings are generally so large that there is little interaction between the wheel loads of one axle and the wheel loads of the other axles. Thus, for the case of pneumatic-tired vehicles having equal axle loads, the increased severity of loading imposed by conventional four or five-axle trucks as compared with that imposed by two or three-axle trucks is largely a fatigue effect resulting from an increased number of load repetitions per vehicle operation. For forklift trucks where the loading is concentrated largely on a single axle and for tracked vehicles where the loading is evenly divided between the two tracks, the severity of the vehicle loading is a function of the gross weight of the vehicle and the frequency of loading. Relations between load repetition and required rigid pavement thickness developed from accelerated traffic tests of full-scale pavements have shown that, for any given vehicle, increasing the gross weight by as little as 10 percent can be equivalent to increasing the volume of traffic by as much as 300 to 400 percent. On this basis, the magnitude of the vehicle loading must be considered as a more significant factor in the design of pavements than the number of load repetitions.

3.2 Traffic Evaluation. Procedures for the evaluation of traffic and selection of Design Index are as follows:

3.2.1 Pneumatic-tired Vehicles. To aid in evaluating vehicular traffic for the purpose of pavement design, pneumatic-tired vehicles have been divided into the following three groups —

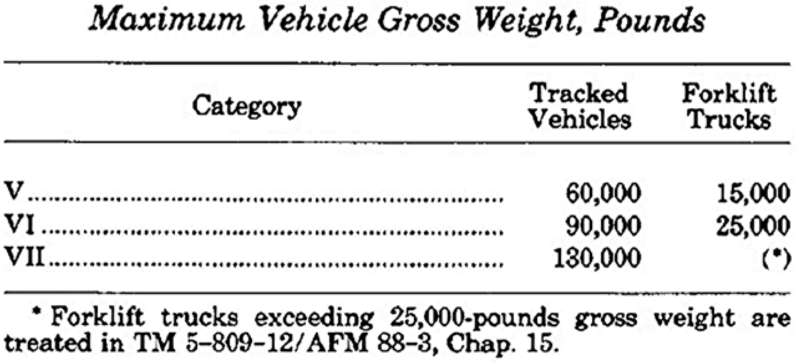
- **Group 1.** Passenger cars, panel trucks, and pickup trucks
- **Group 2.** Two-axle trucks
- **Group 3.** Three-, four-, and five-axle trucks

The design weights for various pneumatic-tired vehicles have been based on average weights, as determined from Federal Highway Administration traffic surveys made on public highways, plus one-fourth of the difference between these average group 2 and group 3 vehicles, maximum allowable weights are based on single-axle and tandem-axle loadings not exceeding 18,000 and 32,000 pounds, respectively. Since traffic rarely will be composed of vehicles from a single group, pneumatic-tired vehicular traffic has been classified into five general categories based on the distribution of vehicles from each of the three groups listed above. These traffic categories are defined as follows:

- **Category I.** Traffic composed primarily of passenger cars, panel and pickup trucks (group 1 vehicles), but containing not more than 1 percent two-axle trucks (group 2 vehicles).
- **Category II.** Traffic composed primarily of passenger cars, panel and pickup trucks (group 1 vehicles), but may contain as much as 10 percent two-axle trucks (group 2 vehicles). No trucks having three or more axles (group 3 vehicles) are permitted in this category.
- **Category III.** Traffic containing as much as 15 percent trucks, but with not more than 1 percent of the total traffic composed of trucks having three or more axles (group 3 vehicles).
- **Category IV.** Traffic containing as much as 25 percent trucks, but with not more than 10 percent of the total traffic composed of trucks having three or more axles group 3 vehicles).
- **Category IVA.** Traffic containing more than 25 percent trucks.

3.2.2 Tracked Vehicles and Forklift Trucks. Tracked vehicles having gross weights not exceeding 15,000 pounds and forklift trucks having gross weights not exceeding 6,000 pounds may be treated as two-axle trucks (group 2 vehicles) and substituted for trucks of this type in the traffic categories defined above on a one-for-one basis. Tracked vehicles having gross weights exceeding 15,000 pounds but not 40,000 pounds and forklift trucks having gross weights exceeding 6,000 pounds but not 10,000 pounds may be treated as group 3 vehicles and substituted for trucks having three or more axles in the appropriate traffic categories on an on-for-one basis.

Traffic composed of tracked vehicles exceeding 40,000 pounds gross weight and forklift trucks exceeding 10,000 pounds gross weight has been divided into the categories indicated in Table 1:



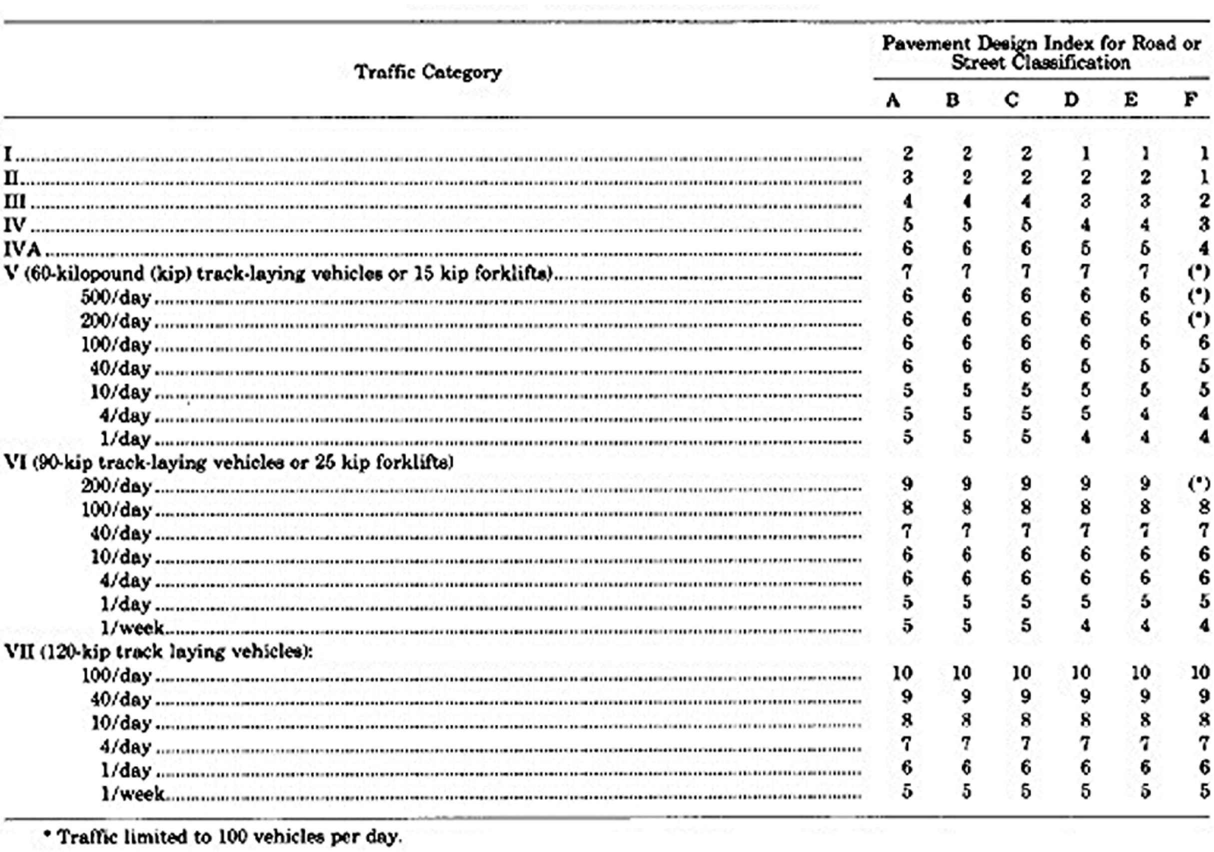
Maximum Vehicle Gross Weight, Pounds

Category	Tracked Vehicles	Forklift Trucks
V	60,000	15,000
VI	90,000	25,000
VII	130,000	(*)

* Forklift trucks exceeding 25,000-pounds gross weight are treated in TM 5-809-12/AFM 88-3, Chap. 15.

Table 1

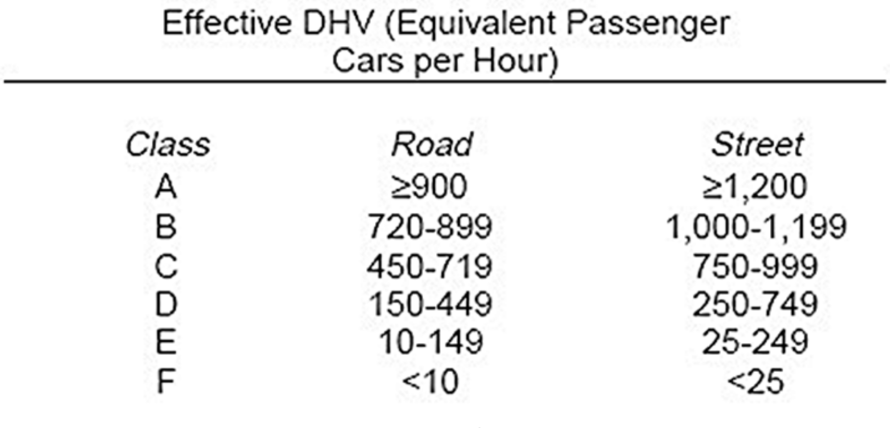
3.2.3 Selection of Design Index. The design of pavements is based on a “Design Index,” which represents the combined effect of the loads defined by the traffic categories just described and the traffic volumes associated with each of the lettered classifications of roads or streets. This index extends from one through ten with an increase in numerical value indicative of an increase in pavement design requirements. Table 2 gives the appropriate Design Index for combinations of the eight traffic categories based on distribution of traffic, vehicle type, and the six-letter classifications based on the volume of traffic. For example, suppose an average daily traffic (ADT) of 2,000 vehicles composed primarily of passenger cars, panel trucks, and pickup trucks (group 1), but including 100 two-axle trucks (group 2) is anticipated for a road in flat terrain. First the road is determined from Table 3 to be a Class E road. Second, the group 2 vehicles are 11/2000 or 5 percent of the total of groups 1 and 2, making this category II traffic. Therefore the appropriate Design Index from Table 2 is 2.



Traffic Category	Pavement Design Index for Road or Street Classification					
	A	B	C	D	E	F
I	2	2	2	1	1	1
II	3	2	2	2	2	1
III	4	4	4	3	3	2
IV	5	5	5	4	4	3
IVA	6	6	6	5	5	4
V (60-kilopound (kip) track-laying vehicles or 15 kip forklifts)	7	7	7	7	7	(*)
500/day	6	6	6	6	6	(*)
200/day	6	6	6	6	6	(*)
100/day	6	6	6	6	6	6
40/day	6	6	6	5	5	5
10/day	5	5	5	5	5	5
4/day	5	5	5	5	4	4
1/day	5	5	5	4	4	4
VI (90-kip track-laying vehicles or 25 kip forklifts)						
200/day	9	9	9	9	9	(*)
100/day	8	8	8	8	8	8
40/day	7	7	7	7	7	7
10/day	6	6	6	6	6	6
4/day	6	6	6	6	6	6
1/day	5	5	5	5	5	5
1/week	5	5	5	4	4	4
VII (120-kip track laying vehicles):						
100/day	10	10	10	10	10	10
40/day	9	9	9	9	9	9
10/day	8	8	8	8	8	8
4/day	7	7	7	7	7	7
1/day	6	6	6	6	6	6
1/week	5	5	5	5	5	5

* Traffic limited to 100 vehicles per day.

Table 2
Pavement Design Index



Effective DHV (Equivalent Passenger Cars per Hour)

Class	*Road*	*Street*
A	≥900	≥1,200
B	720-899	1,000-1,199
C	450-719	750-999
D	150-449	250-749
E	10-149	25-249
F	<10	<25

Table 3
Road and Street Classification

4. FLEXIBLE PAVEMENT SUBGRADES

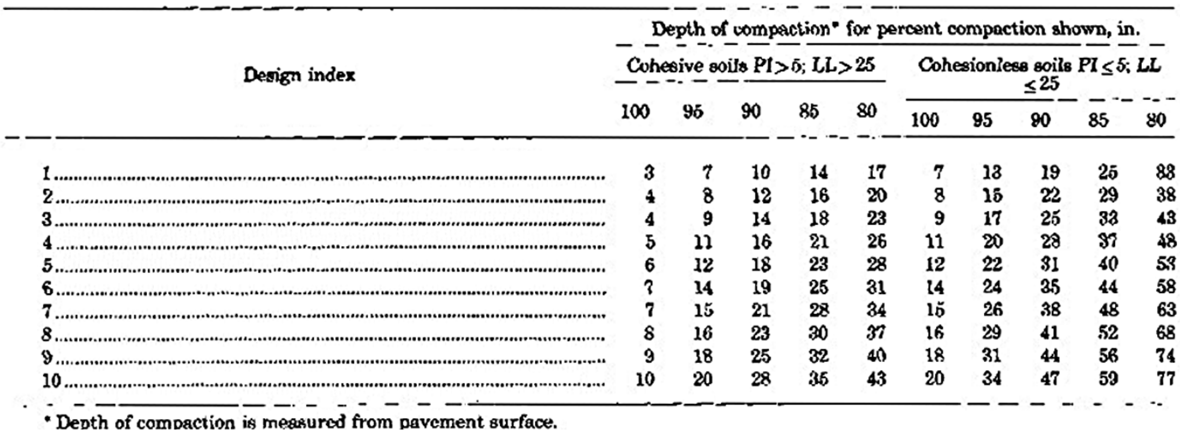
4.1 Factors to Be Considered.

The information obtained from the explorations and test previously described should be adequate to enable full consideration of all factors affecting the suitability of the subgrade and subsoil. The primary factors are as follows:

- The general characteristics of the subgrade soils such as soil classification, limits, etc.
- Depth to bed rock.
- Depth to water table (including perched water table).
- The compaction that can be attained in the subgrade and the adequacy of the existing density in the layers below the zone of compaction requirements.
- The CBR that the compacted subgrade and uncompacted subgrade will have under local environmental conditions. in-place densities are satisfactory.
- The presence of weak of soft layers in the sub-soil.
- Susceptibility to detrimental frost action.

4.2 Compaction.

The natural density of the subgrade must be sufficient to resist densification under traffic or the subgrade must be compacted during construction to a depth where the natural density will resist densification under traffic. Table 4 shows the depth, measured from the pavement surface, at which a given percent compaction is required to prevent densification under traffic. Subgrades in cuts must have natural densities equal to or greater than the values shown in Table 4. Where this is not the case, the subgrade must be compacted from the surface to meet the tabulated densities, or be removed and replaced in which case the requirements for fills apply, or 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. In fill areas, cohesionless soils will be placed at no less than 95 percent of ASTM D 1557 maximum density nor cohesive fills at less than 90 percent of ASTM D 1557 maximum density.



Design index	Depth of compaction* for percent compaction shown, in.									
	Cohesive soils $PI > 5$; $LL > 25$					Cohesionless soils $PI \leq 5$; $LL \leq 25$				
	100	95	90	85	80	100	95	90	85	80
1	3	7	10	14	17	7	13	19	25	33
2	4	8	12	16	20	8	15	22	29	38
3	4	9	14	18	23	9	17	25	33	43
4	5	11	16	21	26	11	20	28	37	48
5	6	12	18	23	28	12	22	31	40	53
6	7	14	19	25	31	14	24	35	44	58
7	7	15	21	28	34	15	26	38	48	63
8	8	16	23	30	37	16	29	41	52	68
9	9	18	25	32	40	18	31	44	56	74
10	10	20	28	35	43	20	34	47	59	77

* Depth of compaction is measured from pavement surface.

Table 4
Depth of Compaction for Select Materials and Subgrades (CBR≤20)

4.3 California Bearing Ratio (CBR)

The California Bearing Ratio (CBR) test is a simple strength test that compares the bearing capacity of a material with that of a well-graded crushed stone (thus, a high quality crushed stone material should have a CBR @ 100%). It is primarily intended for, but not limited to, evaluating the strength of cohesive materials having maximum particle sizes less than 19 mm (0.75 in.) (AASHTO, 2000). It was developed by the California Division of Highways around 1930 and was subsequently adopted by numerous states, counties, U.S. federal agencies and internationally. As a result, most agency and commercial geotechnical laboratories in the U.S. are equipped to perform CBR tests.

The basic CBR test involves applying load to a small penetration piston at a rate of 1.3 mm (0.05") per minute and recording the total load at penetrations ranging from 0.64 mm (0.025 in.) up to 7.62 mm (0.300 in.). Figure 1 is a sketch of a typical CBR sample.

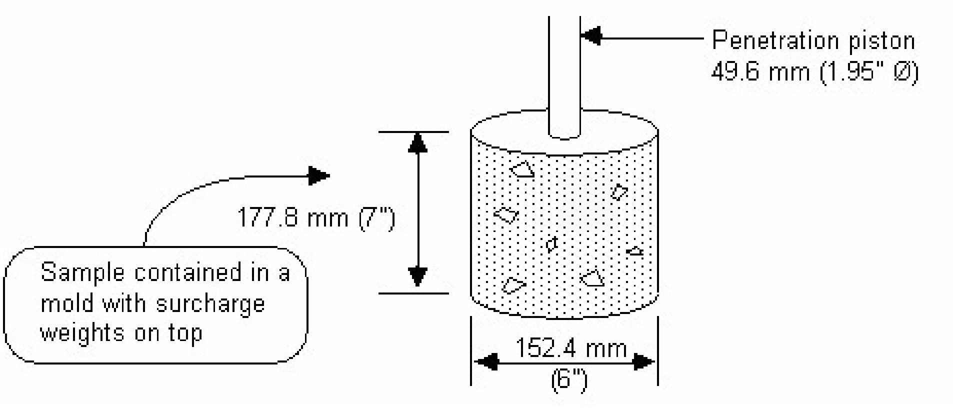


Figure 1
CBR Sample

Values obtained are inserted into the following equation to obtain a CBR value:

$$CBR\ (\%) = 100\left(\frac{x}{y}\right)$$

where: x = material resistance or the unit load on the piston (pressure) for 2.54 mm (0.1") or 5.08 mm (0.2") of penetration

y = standard unit load (pressure) for well graded crushed stone

= for 2.54 mm (0.1") penetration = 6.9 MPa (1000 psi)

= for 5.08 mm (0.2") penetration = 10.3 MPa (1500 psi)

Table 5 shows some typical CBR ranges.

General Soil Type	USC Soil Type	CBR Range
Coarse-grained soils	GW	40 - 80
	GP	30 - 60
	GM	20 - 60
	GC	20 - 40
	SW	20 - 40
	SP	10 - 40
	SM	10 - 40
	SC	5 - 20
Fine-grained soils	ML	15 or less
	CL LL < 50%	15 or less
	OL	5 or less
	MH	10 or less
	CH LL > 50%	15 or less
	OH	5 or less

Table 5
Typical CBR Ranges

Standard CBR test methods are:

- AASHTO T 193: The California Bearing Ratio
- ASTM D 1883: Bearing Ratio of Laboratory Compacted Soils

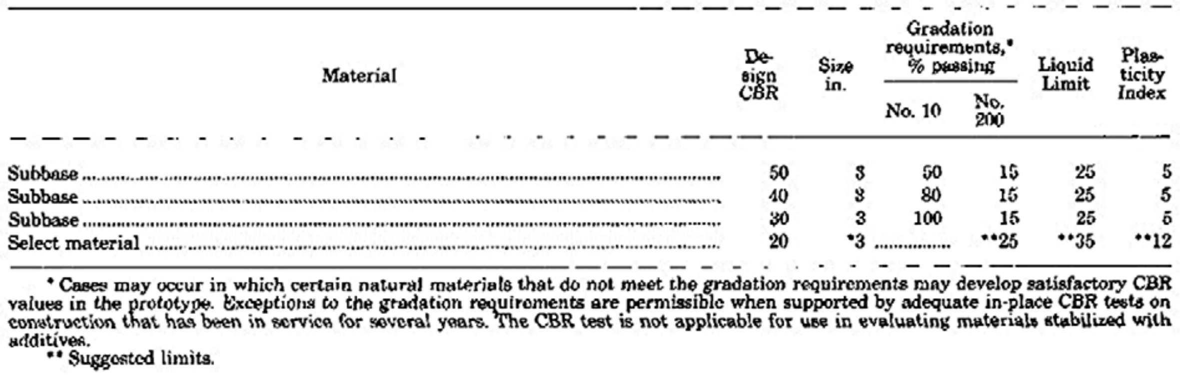
4.4 Selection of Design CBR Values. Flexible pavements may be designed using the laboratory soaked CBR, the field in-place CBR, or the CBR from undisturbed samples. For the design of flexible pavements in areas where no previous experience regarding pavement performance is available, the laboratory soaked CBR is normally used. Where an existing pavement is available at the site that has a subgrade constructed to the same standards as the job being designed, in-place tests or tests on undisturbed samples may be used in selecting the design CBR value. In-place tests are used when the subgrade material is at the maximum water content expected in the prototype. Contrarily, tests on undisturbed samples are used where the material is not at the maximum water content and thus soaking is required. Sampling involves considerably more work than in-place tests; also, "undisturbed" samples tend to be slightly disturbed; therefore, in-place tests should be used where possible. Guides for determining when in-place tests can be used are given in details of the CBR test in MIL-STD-621A, Test Method 101.

5. FLEXIBLE PAVEMENT SELECT MATERIALS AND SUBBASE COURSES

5.1 General. It is common practice in pavement design to use locally available or other readily available materials between the subgrade and base course for economy. These layers are designated as select materials or subbases. Those with design CBR values equal to or less than 20 are designated select materials, and those with CBR values above 20 are designated subbases. Minimum thicknesses of pavement and base have been established to eliminate the need for subbases with design CBR values above 50. Where the design CBR value of the subgrade without processing is in the range of 20 to 50, select materials and subbases may not be needed. However, the subgrade cannot be assigned design CBR values of 20 or higher unless it meets the gradation and plasticity requirements for subbases.

5.2 Materials. The investigations described above will be used to determine the location and characteristics of suitable soils for select material and subbase construction.

5.2.1 Select Materials. Select materials will normally be locally available coarse-grained soils (prefix G or S), although fine-grained soils in the ML and CL groups may be used in certain cases. Limerock, coral, shell, ashes, cinders, caliche, disintegrated granite, and other such materials should be considered when they are economical. Recommended plasticity requirements are listed in Table 6. A maximum aggregate size of 3 inches is suggested to aid in meeting grading requirements.



Material	Design CBR	Size in.	Gradation requirements,* % passing		Liquid Limit	Plasticity Index
			No. 10	No. 200		
Subbase	50	3	50	15	25	5
Subbase	40	3	80	15	25	5
Subbase	30	3	100	15	25	5
Select material	20	*3		**25	**35	**12

* Cases may occur in which certain natural materials that do not meet the gradation requirements may develop satisfactory CBR values in the prototype. Exceptions to the gradation requirements are permissible when supported by adequate in-place CBR tests on construction that has been in service for several years. The CBR test is not applicable for use in evaluating materials stabilized with additives.

** Suggested limits.

Table 6
Maximum Permissible Design Values for Subbases and Select Materials

5.2.2 Subbase Materials. Subbase materials may consist of naturally occurring coarse-grained soils or blended and processed soils. Materials such as limerock, coral, shell, ashes, cinders, caliche, and disintegrated granite may be used as subbases when they meet the requirements. The existing subgrade may meet the requirements for a subbase course, or it may be possible to treat the existing subgrade to produce a subbase. However, admixing native or processed materials will be done only when the unmixed subgrade meets the liquid limit and plasticity index requirements for subbases. It has been found that "cutting" plasticity in this way is not satisfactory. Material stabilized with commercial additives may be economical as a subbase. Portland cement, lime, fly ash, or bitumen and combinations thereof are commonly employed for this purpose. Also, it may be possible to decrease the plasticity of some materials by the use of lime or portland cement in sufficient amounts to make them suitable as subbases.

5.3 Compaction. These materials can be processed and compacted with normal procedures. Compaction of subbases will be 100 percent of ASTM D 1557 density except where it is known that a higher density can be obtained practically, in which case the higher density should be required. Compaction of select materials will be as shown in Table 4 except that in no case will cohesionless fill be placed at less than 95 percent or cohesive fill at less than 90 percent.

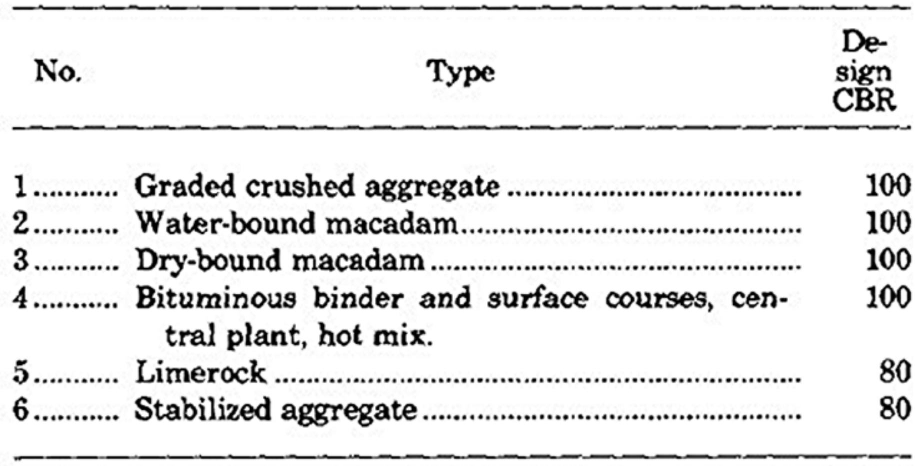
5.4 Selection of Design CBR Values. The select material or subbase will generally be uniform, and the problem of selecting a limiting condition, as described for the subgrade, does not ordinarily exist. Tests are usually made on remolded samples; however, where existing similar construction is available, CBR tests may be made in place on material when it has attained its maximum expected water content or on undisturbed soaked samples. The procedures for selecting CBR design values described for subgrades apply to select materials and subbases. CBR tests on gravelly materials in the laboratory tend to give CBR values higher than those obtained in the field. The difference is attributed to the processing necessary to test the sample in the 6-inch mold, and to the confining effect of the mold. Therefore, the CBR test is supplemented by gradation and Atterberg limits requirements for subbases, as shown in Table 6. Suggested limits for select materials are also indicated. In addition to these requirements, the material must also show in the laboratory tests a CBR equal to or higher than the CBR assigned to the material for design purposes.

6. FLEXIBLE PAVEMENT BASE COURSES

6.1 Materials. High-quality materials must be used in base courses of flexible pavements. These high-quality materials provide resistance to the high stresses that occur near the pavement surface. Guide specifications for graded crushed aggregate, limerock, and stabilized aggregate may be used without qualification for design of roads, streets, and parking areas. Guide specifications for dry and water-bound macadam base courses may be used for design of pavements only when the cost of those base courses does not exceed the cost of stabilized-aggregate base course, and the ability of probable bidders to construct pavements with dry or water-bound macadam base to the required surface smoothness and grade tolerances has been proved by experience in the area.

6-2. Compaction. Base courses placed in flexible pavements should be compacted to the maximum density practicable, generally in excess of 100 percent of ASTM D 1557 maximum density but never less than 100 percent of ASTM D 1557 maximum density.

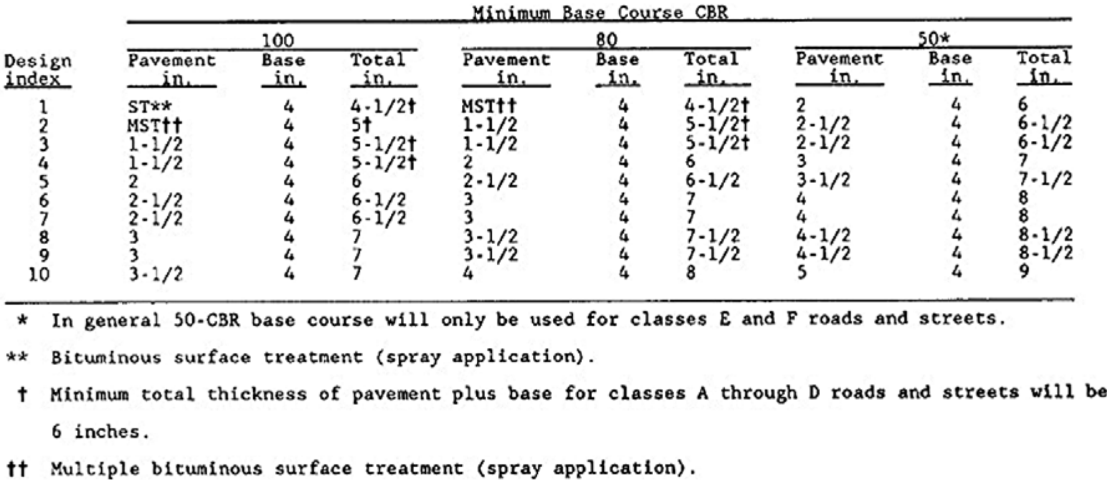
6.3 Selection of Design CBR. Because of the effects of processing samples for the laboratory CBR tests and because of the effects of the test mold, the laboratory CBR test will not be used in determining CBR values of base courses. Instead, selected CBR ratings will be assigned as shown in Table 7. These ratings have been based on service behavior records and, where pertinent, on in-place tests made on materials that had been subjected to traffic. It is imperative that the materials conform to the quality requirements given in the guide specifications so that they will develop the needed strengths.



No.	Type	Design CBR
1	Graded crushed aggregate	100
2	Water-bound macadam	100
3	Dry-bound macadam	100
4	Bituminous binder and surface courses, central plant, hot mix.	100
5	Limerock	80
6	Stabilized aggregate	80

Table 7

6.4 Minimum Thickness. The minimum allowable thickness of base course will be 4 inches as shown in Table 8, except that in no case will the total thickness of pavement plus base for class A through D roads, and streets be less than 6 inches nor less than frost design minimum when frost conditions are controlling.



	Minimum Base Course CBR								
	100			80			50*		
Design index	Pavement in.	Base in.	Total in.	Pavement in.	Base in.	Total in.	Pavement in.	Base in.	Total in.
1	ST**	4	4-1/2†	MST††	4	4-1/2†	2	4	6
2	MST††	4	5†	1-1/2	4	5-1/2†	2-1/2	4	6-1/2
3	1-1/2	4	5-1/2†	1-1/2	4	5-1/2†	2-1/2	4	6-1/2
4	1-1/2	4	5-1/2†	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
7	2-1/2	4	6-1/2	3	4	7	4	4	8
8	3	4	7	3-1/2	4	7-1/2	4-1/2	4	8-1/2
9	3	4	7	3-1/2	4	7-1/2	4-1/2	4	8-1/2
10	3-1/2	4	7	4	4	8	5	4	9

* In general 50-CBR base course will only be used for classes E and F roads and streets.

** Bituminous surface treatment (spray application).

† Minimum total thickness of pavement plus base for classes A through D roads and streets will be 6 inches.

†† Multiple bituminous surface treatment (spray application).

Table 8
Minimum Thickness of Pavement and Base Course

7. FLEXIBLE PAVEMENT DESIGN

7.1 General. 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.
- 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, non-slippery pavement.

7.2 Design Procedure.

7.2.1 Conventional Flexible Pavements. In designing conventional flexible pavement structures, the design values assigned to the various layers are applied to the curves and criteria presented herein. Generally, several designs are possible for a specific site, and the most practical and economical design is selected. Since the decision on the practicability of a particular design may be largely a matter of judgment, full particulars regarding the selection of the final design (including cost estimates) will be included in the design analysis.

7.2.2 Stabilized Soil Layers. Flexible pavements containing stabilized soil layers are designed through the use of equivalency factors. A conventional flexible pavement is first designed, and then the equivalency factors are applied to the thickness of the layer to be stabilized. When stabilized materials meeting all gradation, durability, and strength requirements are utilized in pavement structures, an appropriate equivalency factor may be applied. Soils which have been mixed with a stabilizing agent and which do not meet the requirements for a stabilized soil are considered modified and are designed as conventional pavement layers. When portland cement is used to stabilize base course materials the treatment level must be maintained below approximately 4 percent by weight to minimize shrinkage cracking which will reflect through the bituminous concrete surface course. In this case, the base course will, in most instances, be modified rather than stabilizer. In addition, when unbound granular layers are employed between two bound layers (e.g., an unbound base course between an asphalt concrete (AC) surface course and a stabilized subbase course), it is imperative that adequate drainage be provided the unbound layer to prevent entrapment of excessive moisture in the layer.

7.2.3 All-bituminous Concrete. All-bituminous concrete pavements are also designed using equivalency factors. The procedure is the same as for stabilized soil layers discussed above.

7.3 Design Index. The design of flexible pavements for roads, streets, be based on a Design Index, which is an index representing all traffic expected to use a flexible pavement during its life. See Table 2. 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. Selection of the Design Index will be accomplished as stated above. 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 exceptional use.

7.4 Thickness Criteria – Conventional Flexible Pavements. Thickness design requirements are given in Figure 2 in terms of CBR and Design Index. Minimum thickness requirements are shown in Table 8. For frost condition design, thickness requirements are not discussed in this presentation. In regions where the annual precipitation is less than 15 inches and the water table (including perched water table) will be at least 15 feet below the finished pavement surface, the danger of high moisture content in the subgrade is reduced. Where in-place tests on similar construction in these regions indicate that the water content of the subgrade will not increase above the optimum, the total pavement thickness, as determined by CBR tests on soaked samples, may be reduced by as much as 20 percent. The minimum thickness of pavement and base course must still be met; therefore the reduction will be affected in the subbase course immediately above the subgrade. when only limited rainfall records are available, or the annual precipitation is close to the 15-inch criterion, careful consideration will be given to the sensitivity of the subgrade to small increases in moisture content before any reduction in thickness is made.

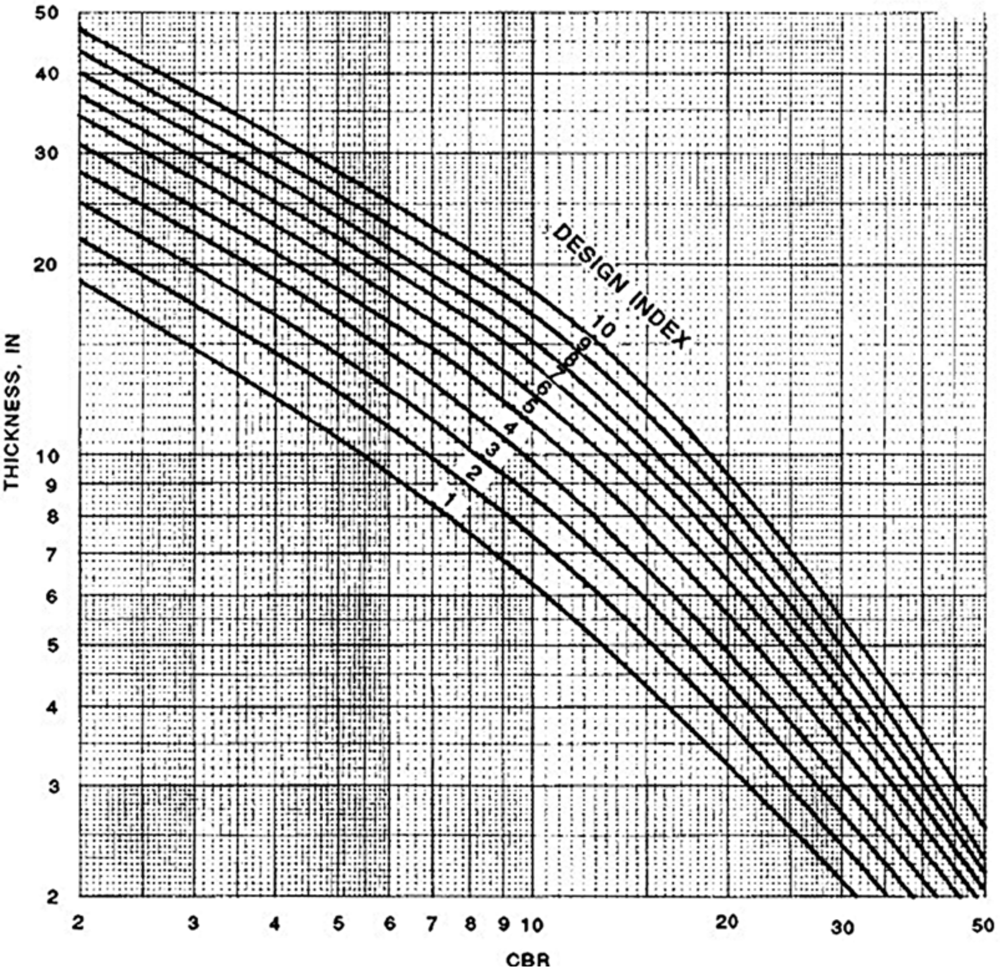


Figure 2
Flexible Pavement Design Curve for Roads and Streets

7.5 Example Thickness Design - Conventional Flexible Pavements. This example illustrates design by the CBR method when the subgrade, subbase, or base course materials are not affected by frost. 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 9 inches below the subgrade surface and that a soft layer occurs within the subgrade 24 inches below the subgrade surface. The CBR design values of the various subgrade layers and the materials available for subbase and base course construction are as shown in Table 9:

Material	Soil Classification	Design CBR
Weak layer in subgrade	CH	4
Natural subgrade	CL	7
Compacted subgrade	CL	10
1	GP	35
2	GM (limerock)	80

Table 9

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

7.5.1 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 2, the required total thickness above the compacted subgrade (CBR of 10) is 11 inches. A check must be made on the adequacy of the strength of the uncompacted subgrade and of the weak layer within the subgrade. From the curves in Figure 2, the required cover for these two layers is 14.5 and 21 inches, respectively. If the design thickness is 11 inches and the subgrade is compacted to 9 inches below the subgrade surface, the natural subgrade will be covered by a total of 20 inches of higher strength material. Similarly, the soft layer occurring 24 inches below the subgrade surface will be protected by 35 inches of total cover. Thus, the cover is adequate in both cases.

7.5.2 Minimum Base and Pavement Thicknesses. For a Design Index of 5, the minimum base thickness is 4 inches and the pavement thickness is 2½ inches as indicated in Table 8. 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.

7.5.3 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. The total thickness of subbase, base, and pavement, as determined above, is 11 inches. The thickness required above material 1 (CBR = 35), as determined from Figure 2, is 3 inches; therefore, the required thickness of material 1 is 8 inches (11 - 3 inches). The 3-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 thickness, which is a combined thickness of pavement and base of 6½ inches (2½ inches of pavement and 4 inches of base). Therefore, the section using materials 1 and 2 will consist of a 4.5- inch subbase course of material 1, a 4-inch base course of material 2, and a 2½-inch pavement.

7.6 Thickness Criteria-Stabilized Soil Layers.

7.6.1 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. An equivalency factor represents the number of inches of a conventional base or subbase which can be replaced by 1 inch of stabilized material. Equivalency factors are determined as shown in Table 10 for bituminous stabilized materials, and from Figure 3 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 3 requires that the unconfined compressive strength as determined in accordance with ASTM D 1633 be known. Equivalency factors are determined from Figure 3 for subbase materials only. The relationship established between a base and subbase is 2 to 1. Therefore, to determine an equivalency factor for a stabilized base course, divide the subbase factor from Figure 3 by 2.

Material	Equivalency Factors	
	Base	Sub-base
All-bituminous concrete	1.15	2.30
GW, GP, GM, GC	1.00	2.00
SW, SP, SM, SC	(*)	1.50

*Not used for base course material.

Table 10
Equivalency Factors for Bituminous Stabilized Materials

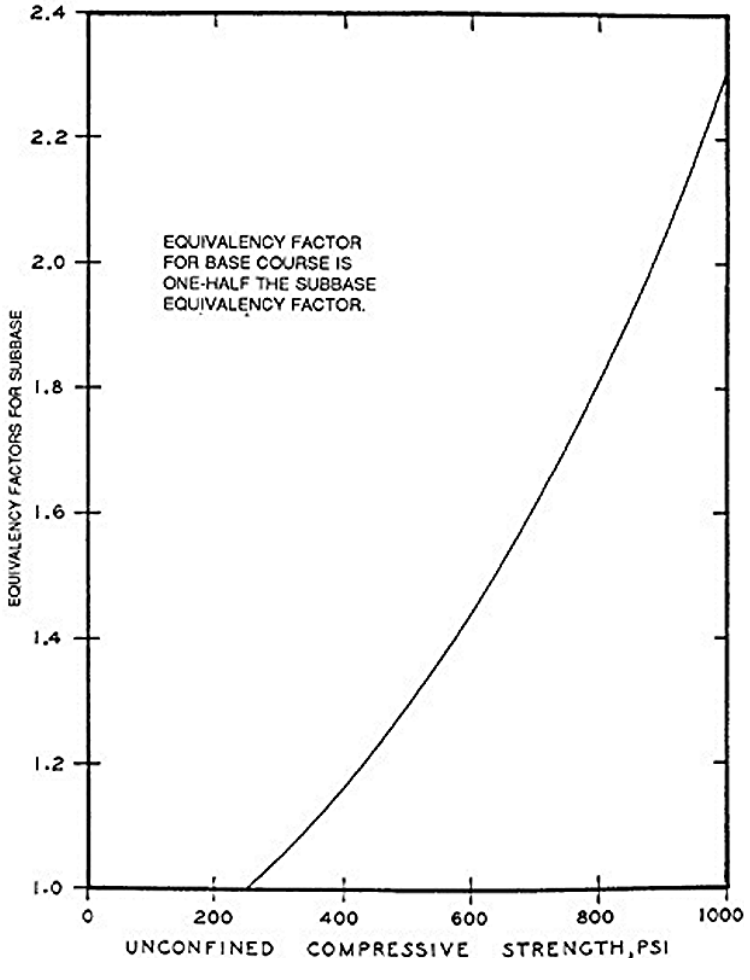


Figure 3
Equivalency Factors for Soils Stabilized with Cement, Lime, or Cement and Lime Mixed with Fly ash

7.6.2 Minimum Thickness. The minimum thickness requirements for a stabilized base or subbase is 4 inches. The minimum thickness requirements for the asphalt pavement are the same as shown for conventional pavements in Table 8.

7.7 Example Thickness Design-Stabilized Soil Layers. To use the equivalency factors requires that a conventional flexible pavement be designed to support the design load conditions. If it is desired to use a stabilized base or subbase course, the thickness of conventional base or subbase is divided by the equivalency factor for the applicable stabilized soil. Examples for the application of the equivalency factors are discussed below.

7.7.1 *Example 1.* Assume a conventional flexible pavement has been designed which requires a total thickness of 16 inches above the subgrade. The minimum thickness of AC and base is 2 and 4 inches, respectively, and the thickness of subbase is 10 inches. It is desired to replace the base and subbase with a cement-stabilized gravelly soil having an unconfined compressive strength of 890 psi. From Figure 3, the equivalency factor for a subbase having an unconfined compressive strength of 890 is 2.0. Therefore, the thickness of stabilized subbase is “10 inches ÷ 2.0 = 5.0 inches”. To calculate the thickness of stabilized base course, divide the subbase equivalency factor by 2 and then divide the unbound base course thickness by the result. Therefore, “4 inches ÷ 1.0 = 4.0 inches” of stabilized base course. The final section would be 2 inches of asphalt concrete and 9 inches of cement-stabilized gravelly soil. The base course thickness of 4.0 inches would also have been required due to the minimum thickness of stabilized base.

7.7.2 *Example* 2. Assume a conventional flexible pavement has been designed which requires 2 inches of asphalt concrete surface, 4 inches of crushed stone base, and 6 inches of subbase. It is desired to construct an all bituminous pavement (ABC). The equivalency factor from Table 8-1 for a base course is 1.15 and for a subbase is 2.30. The thickness of asphalt concrete required to replace the base is “4 inches ÷ 1.15 = 3.5 inches”, and the thickness of asphalt concrete required to replace the subbase is “6 inches ÷ 2.30 = 2.6 inches”. Therefore, the total thickness of the ABC pavement is “2 + 3.5 + 2.6 = 8.1 inches”, which would be rounded to 8.0 inches.