SUBGRADES AND BASE COURSES

CHAPTER 5

This chapter discusses the functions of the subgrade, subbase, and base courses and covers the selections of materials and construction procedures. Chapters 8 and 9 of this manual discuss the determination of the base- and surface-course thickness for roads. Chapters 11 and 12 of FM 5-430-00-2/AFPAM 32-8013, Vol 2, include similar information for all classes of airfields and heliports as well as all commonly used types OJ surface materials. Additional information on soils, compaction, and California Bearing Ratio (CBR) requirements is contained in Chapters 2, 6, and 10 of FM 5-410 and in Chapter 2 of FM 5-530.

DESIGN CONSIDERATIONS

Pavement structures may be rigid or flexible. In rigid pavements, the wearing surface is made of portland cement concrete. A rigid pavement made of concrete will have great flexural strength, permitting it to act as a beam and allowing it to bridge over minor irregularities that may occur in the base or the subgrade upon which it rests.

All other types of pavements are classified as flexible. In a flexible pavement, any distortion or displacement occurring in the subgrade is reflected in the base course and continues upward into the surface course. Flexible denotes the tendency of all courses in ibis type of structure to conform to the same shape under traffic.

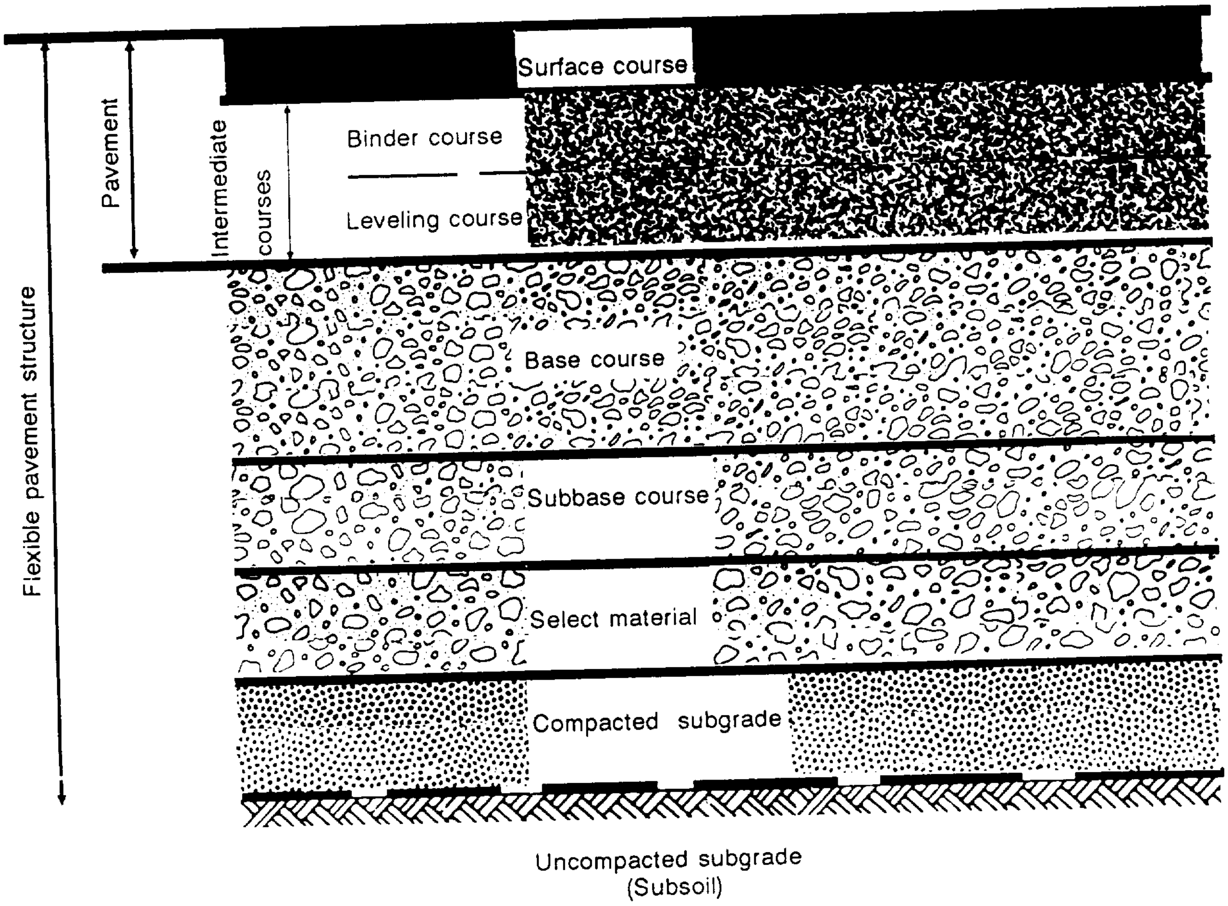
Flexible pavements are used almost exclusively in the TO for road and rear area airfield construction. They are adaptable to almost any situation, and they fall within the construction capabilities of the combat heavy engineer battalion and its support units. Rigid pavements are generally not suited to TO construction requirements (unless the materials are more readily available) and are not discussed in detail in this chapter.

FLEXIBLE-PAVEMENT STRUCTURE

A typical flexible-pavement structure is shown in Figure 5-1, page 5-2. It illustrates the terms used in this manual that refer to the various layers. All the layers shown in Figure 5-1 are not present in every flexible pavement. For example, a flexible-pavement structure may consist only of an asphaltic-concrete surface, a base course, and the subgrade. The design of flexible pavements must include a thorough investigation of the subgrade conditions; borrow areas; and sources of select, subbase, and base materials.

TESTS

Engineers should classify soils according to Chapter 2 of FM 5-410, and then select representative samples for detailed tests. Detailed tests determine compaction characteristics, CBR values, and other properties



NOTE: 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 between the intermediate courses and under the surface course. A prime coat may be required between the highest aggregate surface and the first layer of asphalt.

Figure 5-1. Typical flexible-pavement section

needed for designing the flexible-pavement structure. Subbase-and base-course materials are tested for compliance with specification requirements for gradation, liquid limit (LL), plasticity index (PI). and CBR values. When tests arc completed, limiting conditions in the subgrade and subsoil must be determined. Materials are selected for each layer based on their characteristics (gradation, LL, PI. and CBR values).

DISTRIBUTION OF LOADS

Flexible-pavement design is based on the principle that the magnitude of stress induced by a wheel load decreases with depth below the surface. Consequently, the stresses induced on a given subgrade material can be decreased by increasing the thickness of the overlying layers (subbase, base, and surface courses). Figure 5-2 shows the distribution of a single-wheel load on two

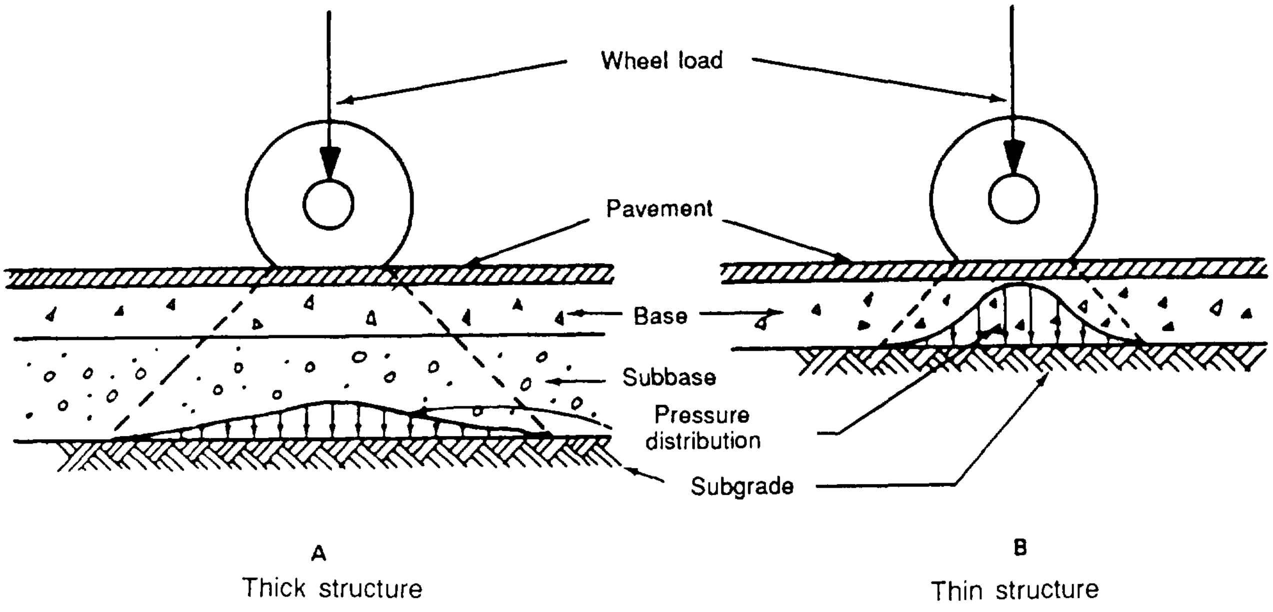


Figure 5-2. Distribution of pressures under single-wheel loads

sections of flexible pavement. one with a thick and one with a thin flexible-pavement structure. In both cases, the subgrade is the found ation that eventually carries any load applied at the surface. Figure 5-2 demonstrates that the magnitude of the stresses on the subgrade decreases as the flexible-pavement structure is thickened. In the left diagram in Figure 5-2, the flexible-pavement structure is thick, the load at the subgrade level is spread over a wide area, and the stresses on the subgrade arc low. In the right diagram the structure is thin, the load at the subgrade level is confined to a much smaller area, and the stresses on the subgrade level are significantly higher. The pattern of decreasing stresses with increasing depth is the basis of the conventional flexible-pavement design in which subgrade materials of low-bearing capacity arc covered with thick flexible-pavement structures.

The distribution of pressures under a multiple-wheel assembly is shown in Figure 5-3, page 5-4. Multiple-wheel assemblies are beneficial because the stress distributions produced by the tires do not overlap to a large degree at shallow depths. This is illustrated at line A-A in Figure 5-3. Therefore, multiple-wheel assemblies are beneficial on thin, flexible- pavement structures constructed on subgrades with high-bearing capacity.

The intensity of stress at a given point in a flexible pavement is affected by the tire-contact area and tire pressure. The major difference in stress intensities caused by variation in tire pressure occurs near the surface. Consequently, the surface course (pavement or a well-graded crushed aggregate) and base course arc the most seriously affected by high tire pressures.

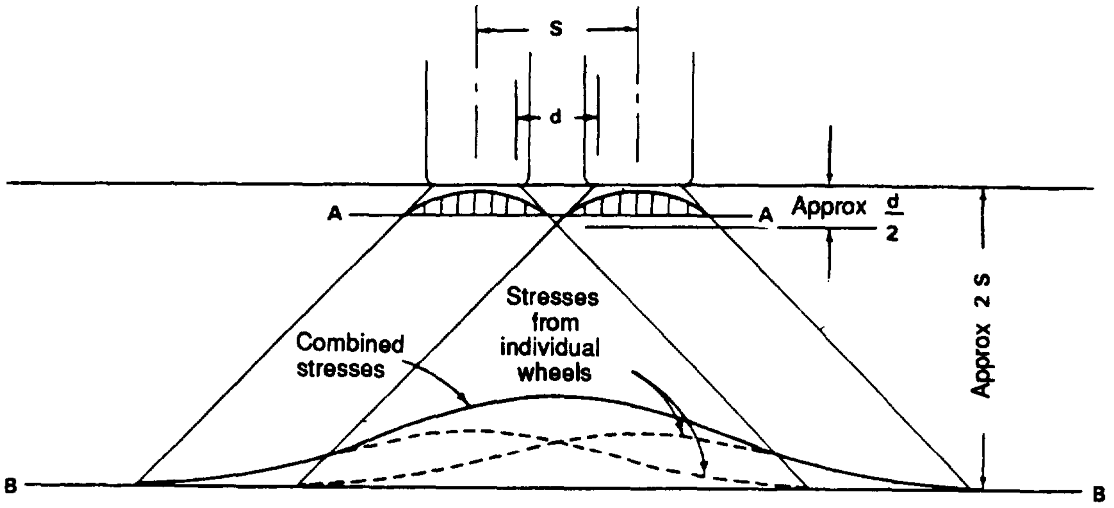


Figure 5-3. Distribution of pressures produced by muitiple-wheel assemblies

SUBGRADES

Using information from a deliberate soil survey as outlined in Chapter 2 of FM 5-530, consider the following factors when determining the suitability of a subgrade:

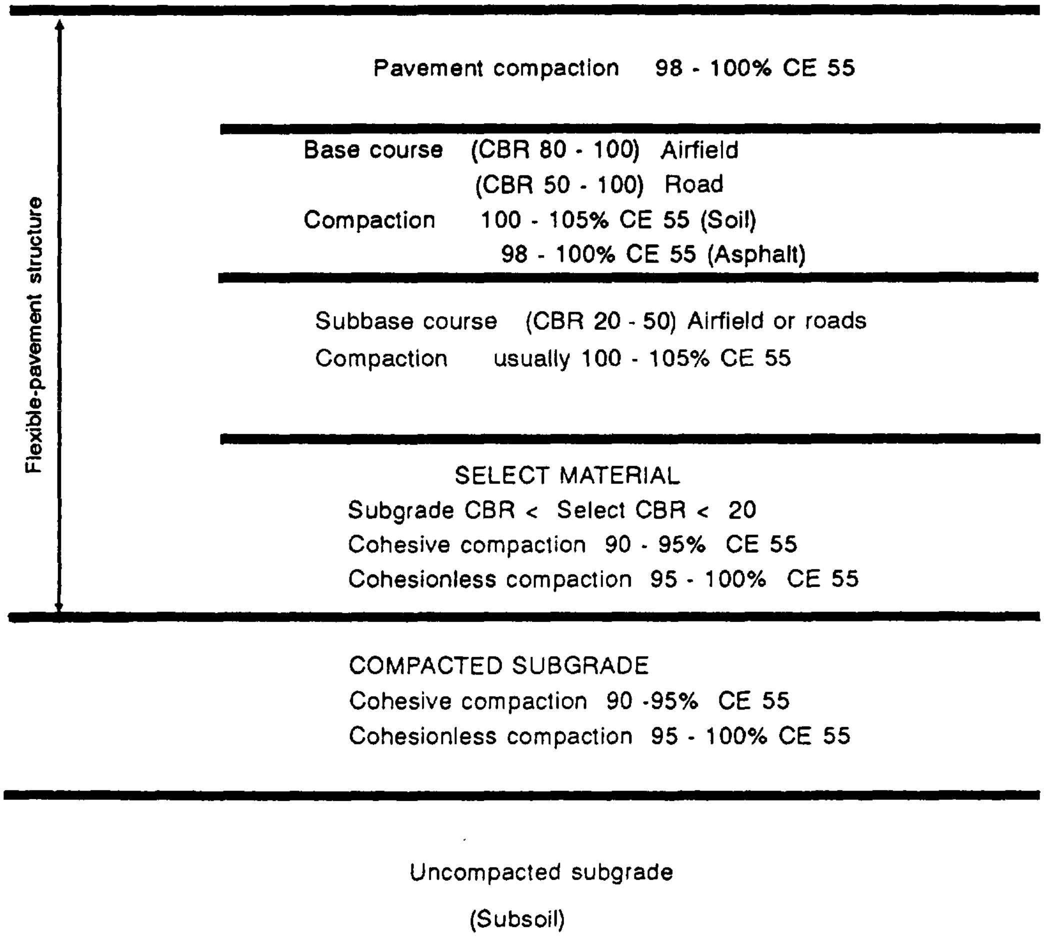
- General characteristics of the subgrade soils.
- Depth to bedrock.
- Depth to the water table.
- Compaction that can be attained in the subgrade.
- CBR values of uncompacted and compacted subgrades.
- Presence of weak or soft layers or organics in the subsoil.
- Susceptibility to detrimental frost action or excessive swell.

GRADE LINE

Classify the subgrade soil in accordance with the Unified Soil Classification System (USCS) (as described in FM 5-410) and consider the previously listed factors to determine the suitability of a subgrade material. When locating the grade line of a road or airfield, consider the suitability of the subgrade, the depth to the water table, and the depth to bedrock. Generally, the grade line should be established to obtain the best possible subgrade material consistent with the design parameters. However, simplicity of construction must also be considered.

COMPACTION

Compaction normally increases the strength of subgrade soils, The normal procedure is to specify compaction according to the requirements in Figure 5-4. A specification block should be used to determine limits for density and moisture content.



NOTES:
1. A cohesive soil is one with PI > 5.
2. A cohesionless soil is one with a PI ≤ 5.
3. Percent compaction is a percent of the maximum density at CE 55.
4. Each layer shown will not necessarily be used in the final design.
5. The minimum compacted layer thicknesses are 4" for a road and 6" for an airfield.

Figure 5-4. Recommended compaction requirements for rear areas

Compaction is relatively simple in fill sections because all the layers are subjected to construction processes and can be compacted during construction. Compaction is more difficult in cut sections. Compaction must be obtained during construction to a depth at which the natural density of the material will resist further consolidation under traffic.

Specific requirements for minimum depth of subgrade compaction for both cohesive and cohesionless soils for road designs are described in Chapter 9 of this FM. This same information for airfield designs is described in Chapter 12 of FM 5-430-00-2/AFPAM 32-8013, Vol 2.

SUBGRADE COMPACTION—NORMAL CASES

Cohesionless soils (except silts) can be compacted from the surface with heavy rollers or very heavy vibratory compactors. Cohesive soils [including silts) cannot be compacted in thick layers. In cut areas consisting of cohesive soils, it may be necessary to remove the subgrade material and replace it with sequential lifts capable of being compacted to the required density. As a rule of thumb, initially replace material in 6-inch lifts, then adjust the lift thickness up or down, as necessary, to determine the minimum compactive effort. Compaction of cohesive soil is best achieved with penetrating rollers such as tamping or sheepsfoot.

Compare the subsoil with compaction requirements for the subgrade (as described in Chapter 9 of this FM and Chapter 12 of FM 5-430-00-2/AFPAM 32-8013, Vol 2) to determine if consolidation of the subsoil is likely to occur under the design traffic load. If such consolidation is likely to occur, provide a means for compacting the subsoil or design a thicker flexible-pavement structure to prevent subsoil consolidation.

Cohesive materials, including those of relatively low plasticity showing little swell, should be compacted at the optimum moisture content determined from the density-moisture curves developed for that soil using the 55-blows-per-layer compactive effort (CE 55) test. CE 55 may also be designated for ASTM 1557, the American Society of Testing and Materials code for density-moisture curves. Cohesionless, free-draining materials should be compacted at moisture contents approaching saturation.

SUBGRADE COMPACTION—SPECIAL CASES

Although compaction normally increases the strength of soils, some soils lose stability when scarified and rolled. Some soils shrink excessively during dry periods and expand excessively when they absorb moisture. Special treatment is required when these soils are encountered. The following paragraphs describe the soils in which these conditions may occur and suggested methods of treatment.

Soils That Lose Strength

The types of soils that decrease in strength when remolded are generally in the USCS CH, MH, and OH groups. They are soils that have been consolidated to a very high degree, either under an overburdened load by alternate cycles of wetting and drying or by other means, and they have developed a definite structure. They have attained a high strength in the undisturbed state. Scarifying, reworking, and rolling these soils in cut areas may reduce the soil's load-bearing capacity.

When these soils are encountered, obtain CBR values for the soil in both the undisturbed and disturbed conditions. Compact the soil that is removed to the design density at the design moisture content. Other samples should be compacted to the design density across the range of specified moisture contents. If the undisturbed value is higher than the laboratory test results, no compaction should be attempted and construction operations should be conducted to produce the least possible soil disturbance. Since compaction should be avoided in these cases, the total thickness design above the subgrade may be governed by the required depth of compaction rather than the CBR method. (See Chapter 3 of TM 5-825-2.)

Silts

The bearing capacity of silts, very fine sands, and rock flour (predominantly USCS ML and SC groups) is reasonably good if properly compacted within the specified moisture range. Compaction of deposits of silt, very fine sand, and rock flour located in areas with a high water table can pump water to the surface. The material becomes quick or spongy and practically loses all load-bearing capacity. This condition can also develop when silts and poorly draining, very fine sands are compacted at a high moisture content. Compaction reduces the air voids so that the available water fills the void space. Therefore, it is difficult to obtain the desired compaction in these silts and very fine sands at moisture contents greater than optimum.

Water from a wet, spongy silt subgrade often enters the subbase and base during compaction through capillary action. This additional moisture may have detrimental effects on bearing capacity and frost susceptibility. If the source of water can be removed, it is usually not difficult to dry these deposits. These soils usually crumble easily and scarify readily. If the soils can be dried, normal compaction effort should be applied. However, removing the source of the water is often very difficult and, in some cases, impossible in the allotted construction period.

In areas with a high water table, drying is not possible until the water table is sufficiently lowered. Compaction operations will continue to cause water to be pumped to the surface. Areas of this nature are best treated by replacing the soil with subbase and base materials or with a dry soil that is not adversely affected by water.

Do not disturb the subgrade where drainage is not feasible or a high water table cannot be lowered. Also, do not disturb the subgrade in cases where soils become saturated from sources other than high water tables and cannot be dried (as in construction during wet seasons). Compaction of lifts during wet periods can cause fines from the subgrade to contaminate upper layers of the flexible-pavement structure.

The pumping and detrimental actions previously described should be anticipated whenever silts or very-fine-sand subgrades are located in areas with a high water table. Pumping action limits the ability to obtain the desired compaction in the immediate overlying material.

Swelling soils

Soils are characterized as swelling if they display a significant increase in volume with the addition of moisture. These soils can cause trouble in any region where construction is accomplished during a dry season and the soils absorb moisture during a subsequent wet season. If the moisture content of the compacted soil increases after compaction, the soil will swell and produce large, uplift pressures. This action may result in unacceptable differential heaving of flexible pavements. For military construction, swelling soils are placed at moisture contents that will not result in more than a 3-percent change in volume if soil moisture is later increased.

Preswelling is a common method for treating subgrade soils with expansive characteristics. The soil should be compacted at a moisture content at which a 3-percent or greater swelling has already occurred. This reduces the impact of future expansion. Proper control of moisture content is the most important item to remember for swelling soils.

SELECTION OF SUBGRADE AND SUBSOIL DESIGN CBR VALUES

The CBR test described in FM 5-530 includes procedures for conducting tests on samples compacted in test molds (design density and soaked for four days) and for taking in-place CBR tests on undisturbed samples. These tests are used to estimate the CBR that will develop in the prototype structure. Where the design CBR is above 20, the subgrade must also meet the gradation and Atterberg limit requirements for a subbase given in Table 5-1.

SUBGRADE STABILIZATION

Subgrades can be stabilized mechanically (by adding granular materials), chemically (by adding chemical admixtures), or with a stabilization expedient (sand-grid, matting, or geosythetics). Stabilization with chemical admixtures (lime, port-land cement, fly ash, and such) is generally costly but may prove to be economically feasible, depending on the availability of the chemical stabilization agent in comparison with the availability of granular material. Chemically stabilized layers should be designed according to the criteria presented in Chapter 9 of FM 5-410.

Table 5-1. Recommended maximum permissible value of gradation and Atterberg limit requirements in subbases and select materials for roads and airfields

Maximum Permissible Value						
	Maximum design CBR	Size in inches	Gradation requirements % passing No. 10	No. 200	Atterberg Limits LL*	PI*
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

*Determination of these values will be made according to ASTM D4318.

If mechanical stabilization is used and the stabilized material meets the gradation and Atterberg limit requirements in Table 5-1, it can be assigned a subbase CBR rating. If it does not meet the requirements for a subbase, the material must be considered a select material.

A stabilization expedient may provide significant time and cost savings as a substitute to other means of stabilization or low strength fill. The most popular of the man-made stabilizers are sand grid, roll-matting, and various types of geosynthetics, especially geotextiles. Matting and sand grid are expedient methods of stabilizing cohesionless soils such as sand for unsurfaced road construction. Geotextiles and other geosynthetics are primarily used to reinforce weak subgrades, maintain the separation of soil layers, and control drainage through the road or airfield design. The availability of these materials must be weighed with the considerable time savings for use of expedients in combat construction.

FROST SUSCEPTIBILITY OF SUBGRADE

In areas subjected to seasonal freezing and thawing, subgrade materials may exhibit frost heave and thaw weakening. Table 5-2 lists the frost-susceptibility ratings of soils. Those materials with the F3 and F4 classifications are extremely frost-susceptible, especially if the water table is less than 5 feet below the top of the subgrade. Silty soils are particularly susceptible and their CBR value may be less than 1 during thawing periods. The thaw period and resulting degraded soil strength may last from one to four weeks. Emphasis must be placed on reducing traffic loads during this period to help reduce the possibility of damage.

SELECT MATERIALS AND SUBBASE COURSES

When designing flexible pavements, locally available or other inexpensive materials may be used between the subgrade and base course. These layers are designated in this manual as select materials or subbases. Those with design CBR values less than or equal to 20 are called select materials, and those with CBR values greater than 20 are called subbases.

Where the CBR value of the subgrade, without processing, is in the range of 20 to 50,

Table 5-2. Frost-design soil classification

Frost Group	Type of Soil	% By Weight < 0.02 mm	Typical Soil Types Under the USCS
NFS	(a) Gravels (e ≥ 0.25)	0 - 3	GW, GP
	Crushed stone	0 - 3	GW, GP
	Crushed rock	0 - 3	GW, GP
	(b) Sands (e ≤ 0.30)	0 - 3	SW, SP
	(c) Sands (e > 0.30)	3 - 10	SP
S1	(a) Gravels (e < 0.25)	0 - 3	GW, GP
	Crushed stone	0 - 3	GW, GP
	Crushed rock	0 - 3	GW, GP
	(b) Gravelly soils	3 - 6	GW, GP, GW-GM, GP-GM, GW-GC, GP-GC
S2	Sandy soils (e ≤ 0.30)	3 - 6	SW, SP, SW-SM, SP-SM, SW-SC, SP-SC
F1	Gravelly soils	6 - 10	GW-GM, GP-GM, GW-GC, GP-GC
F2	(a) Gravelly soils	10 - 20	GM, GC, GM-GC
	(b) Sands	6 - 15	SM, SC, SW-SM, SP-SM, SW-SC, SP-SC, SM-SC
F3	(a) Gravelly soils	> 20	GM, GC, GM-GC
	(b) Sands, except very fine silty sands	> 15	SM, SC, SM-SC
	(c) Clays (PI > 12)	-	CL, CH, ML-CL
F4	(a) Silts	-	ML, MH, ML-CL
	(b) Very fine sands	> 15	SM, SC, SM-SC
	(c) Clays (PI < 12)	-	CL, ML-CL
	(d) Varved clays and other fine-grained, banded sediments	-	CL or CH layered with ML, MH, SM, SC, SM-SC, or ML-CL

NOTE: e = void ratio.

select materials and subbases may not be needed. However, the subgrade cannot be assigned a design CBR value greater than 20 unless it meets the gradation and plasticity requirements for subbases.

Where subgrade materials meet plasticity requirements but are deficient in grading requirements, it may be possible to treat an existing subgrade by blending in stone, lime rock, sand, or similar materials to produce an acceptable subbase and raise the design CBR value.

MATERIALS

Select Materials

Select materials will normally be locally available, coarse-grained soils (classified G or S), although fine-grained soils in the ML and CL groups may be used in certain cases. Consider lime rock, coral, shell, ashes, cinders, caliche, and disintegrated granite when evaluating sources of select material. To qualify as a select material, a material must meet the gradation and Atterberg limit requirements established in Table 5-1. A **maximum** aggregate size of 3 inches will aid in meeting aggregate gradations.

Subbase Materials

Subbase materials may consist of naturally occurring, coarse-grained soils or blended and processed soils. Lime rock, coral, shell, ashes, cinders, caliche, and disintegrated granite may be used as subbases when they meet the requirements in Table 5-1, page 5-8. 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. Do not admix native or processed materials unless the unmixed subgrade meets the LL and PI requirements for subbases.

A suitable subbase may be formed using material stabilized with commercial admixtures. Portland cement. hydrated lime, fly ash, and bituminous materials are commonly used for this purpose. The plasticity of some materials can be decreased by adding lime or portland cement, enabling them to be used as subbases.

COMPACTION

Select and subbase materials can be processed and compacted using normal compaction procedures. Specify compaction according to the criteria described in Figure 5-4, page 5-5.

SELECTION OF DESIGN CBR

CBR tests are usually conducted on remolded samples. However, where existing similar construction is available, conduct CBR tests on material in place when it has attained its maximum expected water content or on undisturbed, soaked samples. The procedures for selecting test values described in the section on subgrades also applies to select and subbase materials. In order to be used as a select or subbase, the material must comply with the requirements indicated in Table 5-1, including CBR value, gradation, and Atterberg limits. If a material meets the requirements for gradation and Atterberg limits for the next higher design CBR category, but the material's CBR value does not meet the maximum design CBR for that category, assign the material design a CBR value equal to the measured CBR results. For example, a material with a measured CBR value of 37, which meets the gradation and Atterberg limit requirements for a CBR 40 subbase, should be used as a CBR 37 subbase. Conversely, if the material failed to meet the CBR 40 subbase requirements (gradation and Atterberg limits) but met the CBR 30 subbase requirements, it would be used as a CBR 30 subbase rather than a CBR 37.

Some natural materials develop satisfactory CBR values but do not meet the gradation requirements in Table 5-1. These materials may be used as select or subbase materials, as appropriate, if supported by adequate in-place CBR tests on construction projects using the materials that have been in service for several years.

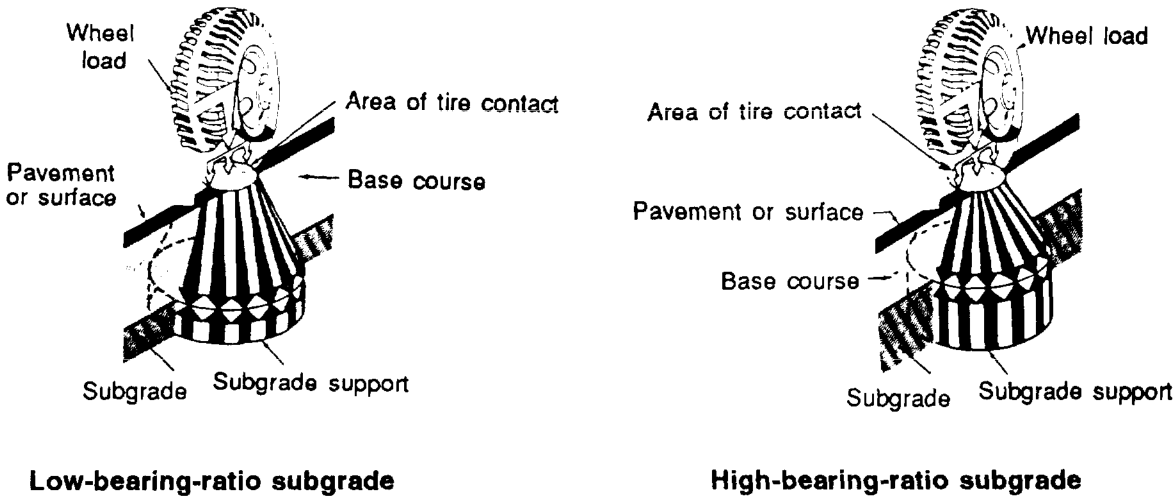
The CBR test is not applicable for use in evaluating materials stabilized with chemical admixtures. These chemically stabilized soils must be assigned an equipment CBR value based on the type of admixture and method of application. (See Chapter 9 of FM 5-410.) Ratings as high as 100 can be assigned to these materials when proper construction procedures are followed.

POTENTIAL FOR FROST ACTION

Select and subbase materials which are subjected to freezing and thawing may exhibit detrimental frost effects. Although these materials generally are not affected by excessive frost heave, they may lose up to 50 percent of their strength during thawing conditions. This is especially true of materials which have more than 20 percent fines (particles passing the Number (No.) 200 sieve). If possible, materials listed in Table 5-2, page 5-9, as NFS, S1, S2, F1, or F2 should be used as subbase and select materials in seasonal frost and permafrost areas.

BASE COURSE

The purpose of a base course is to distribute the induced stresses from the wheel load so that it will not exceed the strength of the underlying soil layers. Figure 5-5 shows the distribution of stress through two base courses. When the subgrade strength is low, the stress must be reduced to a low value and a thick base is needed.



Fjgure 5-5. Distribution of stress in base courses and affects of subgrade strength on basecourse thickness

When the subgrade strength is higher, a thinner base course will provide adequate stress distribution. Because the stresses in the base course are always higher than in the subgrade (Figure 5-5), the base course must have higher strength.

The base course is normally the highest-quality structural material used in a flexible-pavement structure, having CBR values near the CBR standard material (crushed limestone). Base courses are always cohesionless materials and are normally processed to obtain the proper gradation.

REQUIREMENTS

Give careful attention to the selection of materials for base courses. The materials should be dense and uniformly graded so that no differential settlement occurs. For continuous stability, base courses must meet gradation and plasticity requirements.

Gradation

Normally, a material used as a base course must meet the gradation requirements outlined in Tables 5-3, 5-4 and 5-5, page 5-12 (depending on the type of material). Determine gradation of the proposed material using mechanical analysis. If strict adherence to gradation requirements is not feasible, a safe rule of thumb is to avoid using materials which have more than 15 percent fines (particles passing the No. 200 sieve).

Plasticity Index and Liquid Limit

In addition to the gradation requirement, a base-course material must meet the same PI and LL requirements for a subbase material as indicated in Table 5-1, page 5-8. Material with a LL greater than 25 or a PI greater than 5 should not be used as a base course.

Compaction

Base-course material must be capable of being compacted to meet the requirements given in Figure 5-4, page 5-5. When constructing a base course, lift thickness must be based on the ability to attain the required density. Lift thickness is dependent on the type of material, the compaction equipment used, and the method of construction.

The CBR of the finished base course must conform to that used in the design. The total compacted thickness must equal that obtained from the flexible-pavement design curves, Table 5-6, page 5-13 lists nine types of materials commonly used as base

Table 5-3. Generally suitable base course materials

	Rock Type	Use as an Aggregate: Concrete	Use as an Aggregate: Asphalt	Use as a Base Course or Subbase
IGNEOUS	Granite	Fair to Good	Fair to Good**	Good
	Gabbro-Diorite	Excellent	Excellent	Excellent
	Basalt	Excellent	Excellent	Excellent
	Felsite	Poor*	Fair	Fair to Good
SEDIMENTARY	Conglomerate Breccia	Poor	Poor	Poor
	Sandstone	Poor to Fair	Poor to Fair	Fair to Good
	Shale	Poor	Poor	Poor
	Limestone	Fair to Good	Good	Good
	Dolomite	Good	Good	Good
	Chert	Poor*	Poor**	Poor-Fair
METAMORPHIC	Gneiss (nice)	Good	Good	Good
	Schist	Poor to Fair	Poor to Fair	Poor to Fair
	Slate	Poor	Poor	Poor
	Quartzite	Good	Fair to Good**	Fair to Good
	Marble	Fair	Fair	Fair

*Reacts (alkali aggregate)
**Antistripping agents should be used

Table 5-4. Desirable gradation for crushed rock or slag, and uncrushed sand and gravel aggregates for nonmacadam base courses

Sieve Designations	Percent Passing Each Sieve (Square Openings) by Weight — Maximum Aggregate Size: 2 inch	1 1/2 inch	1 inch	1-inch sand clay
2 inch	100			
1 1/2 inch	70-100	100		
1 inch	55-85	75-100	100	100
3/4 inch	50-80	60-90	70-100	
3/8 inch	30-60	45-75	50-80	
No. 4	20-50	30-60	35-65	
No. 10	15-40	20-50	20-50	65-90
No. 40	5-25	10-30	15-30	33-70
No. 200	0-10	5-15	5-15	8-25

Table 5-5. Desirable gradation for crushed rock, gravel, or slag aggregates for macadam base courses

Sieve Designations	Percent Passing Each Sieve (Square Openings) by Weight — Maximum Aggregate Size: 2 inch	1 1/2 inch	1 inch
2 inch	100		
1 1/2 inch	70-100	100	
1 inch	45-80		100
1/2 inch	30-60		
No. 4	30-50	20-40	25-45
No. 10	15-40		
No. 40	5-25		
No. 200	<10	<10	<10

Table 5-6. Assigned CBR ratings for base-course materials

Type	Design CBR
Graded, crushed aggregate	100
Water-bound macadam	100
Dry-bound macadam	100
Bituminous base course, central plant, hot mix	100
Lime rock	80
Bituminous macadam	80
*Stabilized aggregate (mechanically)	80
Soil cement	80
Sand shell or shell	80

*It is recommended that stabilized-aggregate base-course material not be used for tire pressures in excess of 100 psi.

courses for roads and airfields. A typical design CBR is given for each type of material. Laboratory CBR tests to determine design CBR are not necessary.

MATERIALS

Natural, processed, and other materials are used for base courses. Descriptions of these materials follow.

Natural Materials

A wide variety of gravels; sands: gravelly and sandy soils; and other natural materials such as lime rock, coral, shells, and some caliches can be used alone or blended as a suitable base course. Sometimes natural materials require crushing or removal of oversize material to maintain gradation limits. Some natural materials may be suitable for use as a base course by mixing or blending them with other materials.

Sand and Gravel. Many natural deposits of sandy and gravelly materials make satisfactory base-course materials, Gravel deposits differ widely in the relative proportions of coarse- and fine-grained material and in the character of the rock fragments. Satisfactory base materials can often be produced by blending materials from two or more deposits. Uncrushed, clean, washed gravel is normally not suitable for a base course because not enough fines are present. Fines act as a binder and fill the voids between coarser particles.

Sand and Clay. Natural mixtures of sand and clay are often located in alluvial deposits of varying thicknesses. Often there are great variations in the proportions of sand and clay from the top to the bottom of the deposit. Depending on the proportions of sand and clay, these deposits may also provide suitable base-course materials. With proper proportioning and construction methods, satisfactory results can be obtained with sand-clay soils.

Deposits of partly disintegrated rock that consist of fragments of rock, clay, and mica flakes should not be confused with sand-clay soils. The mica flakes make the deposit unsuitable for use as a base course. Mistaking these deposits for a sand-clay soil may result in base-course failure.

Processed Materials

Processed materials are made by crushing and screening rock, gravel, or slag. A properly graded, crushed rock base-course material produced from sound, durable rock makes the highest-quality base material. Existing quarries; ledge rock; cobbles and gravel: talus deposits; coarse mine tailings; and similar hard, durable rock fragments are the sources of processed materials. Table 5-3 shows the common rock types that are generally suitable for base-course material. Generally, rock which is hard enough to require blasting during excavation makes suitable base-course material.

Base courses made from processed materials can be divided into three general types: stabilized, coarse-graded, and macadam.

Stabilized. In a stabilized base course, material ranging from coarse to fine is mixed to meet the gradation requirement given in Table 5-4. The mixing process can be accomplished in advance (at a processing plant) or during the placing operation. Because the aggregates produced in crushing operations or obtained from deposits are often deficient in fines, it may be necessary to blend in selected fines to get a suitable gradation. Screenings, crusher-run fines, or natural clav-free soil may be added for this purpose.

Coarse-Graded. A coarse-graded type of base course is composed of crushed rock, gravel, or slag, When gravel is used. 50 percent of the material by weight must have two or more freshly fractured faces, with the area of each face equal to at least 75 percent of the smallest midsectional area of the piece.

Macadam. The term *macadam* is usually applied to construction in which a coarse, crushed aggregate is placed in a relatively thin layer and rolled into place. Fine aggregate or screenings are placed on the surface of the coarse-aggregate layer and rolled and broomed into the coarse rock until it is thoroughly keyed in place. Water may be Used in the compacting and keying process. When water is used, the base is termed a *water-bound macadam*. The crushed rock used for macadam base courses should consist of clean, angular, durable particles free of clay, organic matter. and other unwanted material or coating, Any hard, durable, crushed aggregate can be used, provided the coarse aggregate is one size and the fine aggregate will key into the coarse aggregate. Aggregates for macadam-type construction should meet the gradation requirements given in Table 5-5, page 5-12.

Other Materials

In some TO areas, deposits of natural sand and gravel and sources of crushed rock are not available. This has led to the development of base courses from materials that normally would not be considered. These include caliche, lime rock, shells, cinders, coral, iron ore, rubble, and other similar materials. Some of these materials arc weak rock that crush or degrade under construction traffice to produce composite base materials similar to those described in the preceding paragraphs. Others develop a cementing action that results in a satisfactory base.

These materials cannot be judged on the basis of the gradation limits used for other materials. Rather, they arc judged on the basis of service behavior. Strength tests on laboratory samples arc not satisfactory because the method of preparing the sample seldom replicates the characteristics of the material in place. The PI is a reasonably good criterion for determining the suitability of these materials as base courses. As a general rule, a low PI(≤ 5) is a necessity. However, observation of these types of base materials in existing roads and pavements is the most reliable indicator of whether or not they will be satisfactory.

Coral. Coral is commonly found along the coastlines of the Pacific Ocean and the Caribbean Sea. Coral is normally very angular and, as such, its greatest assets as a construction material are its bonding properties. These properties vary, based on the amount of volcanic impurities, the proportion of fine and coarse material, and the age and length of exposure to the elements. Proper moisture control, drainage, and compaction arc essential to obtain satisfactory results. Avoid variations of more than 1 percent from optimum moisture content. Uncompacted and poorly drained coral is susceptible to high capillary rise, resulting in too much moisture and loss of stability. Sprinkling with sea water or sodium chloride in solution promotes bonding when rollers are used. As a rule of thumb, coral should cure for a minimum of 72 hours after compaction is completed.

Caliche. Caliche is a by-product of chemical weathering processes. It is composed of limestones, silts, and clays cemented together by lime, iron oxide, or salt. Caliche has been used extensively in arid regions as a base material because of its ability to recement when saturated with water, compacted, and given a setting period. Caliche varies in content (limestone, silt, and clay) and in degree of cementation. It is important that caliche of good, uniform quality be obtained from deposits and that it be compacted within a specified moisture range.

After caliches have been air-dried for 72 hours, the LL of the material passing the No. 40 sieve should not exceed 35, and the PI should not exceed 10. For base-course material, caliches should be crushed to meet the following gradations:

Percent passing 2-inch sieve	100
Percent passing No. 40 sieve	15-35
Percent passing No. 200 sieve	0-20

Stripping should be used to remove undesirable material from surface deposits of caliche.

Tuff. Tuff and other cement-like materials of volcanic origin may be used for base courses. Tuff bases are constructed in the same manner as other base courses except that the oversize pieces are broken and the base is compacted with sheepsfoot rollers after the tuff is dumped and spread. The surface is then graded and final compaction and finishing are accomplished.

Rubble. The debris or rubble of destroyed buildings may be used in constructing base courses. Jagged pieces of metal and similar objects must be removed: large pieces of rubble should be broken into 3-inch pieces or smaller. Caution should be exercised when using rubble in a tactical environment to avoid mines or booby traps.

Bituminous Base. In general, a bituminous base course may be considered equal, on an inch-for-inch basis, to other types of high-quality base courses. Bituminous mixtures are frequently used as base courses beneath high-use bituminous pavements, particularly for rear-area airfields carrying heavy traffic, Bituminous bases may be advantageous when locally available aggregates are relatively weak and of poor quality, when mixing-plant and bituminous materials are readily available, or when a relatively thick structure is required for the traffic.

When a bituminous base course is used, it is placed in lifts no more than 3 1/2 inches thick. If a bituminous base is used, the binder and leveling courses may be omitted and the surface course may be laid directly on the base course.

SELECTION OF BASE COURSE

Selection of the type of base-course construction depends on the materials and equipment available and the anticipated weather conditions during construction. A complete investigation should be made to determine the location and characteristics of all natural materials suitable for base-course construction. Base courses of untreated natural materials are less affected by adverse weather and normally require less technical control. Untreated bases are relatively easy and fast to build and are preferable to bituminous or cement-stabilized types. This is true even where suitable admixture materials for such construction are readily available, which is not true in many areas of the world.

SPECIAL CONSIDERATIONS FOR SEASONAL FROST AND PERMAFROST CONDITIONS

Since base-course materials are near the surface of the road or airfield, the amount of strength loss during thawing periods will have a strong influence on the life of the facility. If possible, materials listed in Table 5-2, page 5-9, as nonfrost susceptible (NFS), or possibly frost susceptible (S1 or S2) should be used as base courses in seasonal frost and permafrost areas.

CONSTRUCTION OPERATIONS

Construction operations for roads and airfields include the following tasks which are organized according to the construction schedule and quality control plan for the project.

Fine Grading

The subgrade is fine graded to achieve the desired cross section established by final grade stakes. Before placing select material, subbase, and base course, the subgrade should be compacted to attain the required density, and ruts and other soft spots should be corrected.

Hauling, Placing, and Spreading

Placing and spreading material on the prepared subgrade may begin at the point nearest the borrow source or at the point farthest from the source. The advantage of working from the point nearest the source is that the haul vehicles can be routed over the spread material, which compacts the base and avoids damage to the subgrade. An advantage of working from the point farthest from the source is that hauling equipment will further compact the subgrade. Also, this practice will not overwork the base course, which can cause unwanted segregation. This method also reveals any weak spots in the subgrade so that they can be corrected prior to placement of the base courses, and interferes less with spreading and compaction equipment.

The self-propelled aggregate spreader is the preferred piece of equipment for placing a base course. If a self-propelled spreader is not available, base-course material can be spread using towed spreaders, scrapers, or dump trucks. If equipment capable of spreading the aggregate in even lifts is not available, the material can be initially dumped in long windrows and subsequently spread with graders, dozers, or front-end loaders.

Lift thickness should be based on the ability to compact the material to the required density. A good rule of thumb is to initially place the base course in 6-inch lifts. After testing the compacted density, increase or decrease the lift thickness as necessary to meet the project requirements.

Blending and Mixing

Materials to be blended and mixed should be spread on the road, runway, or taxiway in correct proportions, with the finer material on top. Fold the fine material into the coarser aggregate with the grader blade. If available, dry-mix the material using blades, disks, harrows, or rototillers, leaving the material in windrows. When a grader is used, thoroughly mix the materials by blading the windrows of materials from one side of the area to the other, with the blade of the grader set to give a rolling action to the material. The coarse and fine aggregates can also be mixed in mechanical plants (mobile or stationary) or on a paved area with graders and bucket loaders. Proportionally distribute the coarse and fine aggregates by weight or volume in quantities so that the specified gradation, LL, and PI requirements are attained after the base has been placed and compacted. Mixing operations should produce uniform blending.

When mechanical mixing is used, place the coarse and fine aggregates in separate stockpiles or adjacent windrows to permit easy proportioning. When bucket loaders are used, place the fine- and coarse-aggregate portions in adjacent windrows on a paved area. Blade the windrows together to meet the requirements specified for the project.

Watering Base Materials

As in subgrade-compaction operations, obtaining the specified compacted density requires that the material be placed and compacted at a moisture content inside the specification block. The moisture content of the base material at the site can be obtained by a nucIear densometer, a speedy moisture tester, or by expedient methods. Given the on-site moisture content, the engineer in charge can calculate exactly how much water is to be added or if the base needs to be aerated to achieve the specified moisture content range.

Controlled watering can be done with a truck-mounted waler distributor. Asphalt distributors should not be used because the pump lubrication system is not designed for water. Any container capable of movement and gravity discharge of water may be used as an expedient water distributor.

Compacting

Base-course compacting must produce a uniformly dense layer that conforms to the specification block. Compact base-course material with vibratory or heavy.

rubber-tired rollers. Maintain moisture content during the compaction procedure within the specified moisture-content range. Compact each Iayer through the full depth to the required density. Measure field densities on the total sample. Use a *test strip* to determine which rollers are most effective and how many roller passes are necessary to achieve the desired compaction. The care and judgment used when constructing the base course will directly reflect on the quality of the finished flexible pavement. Base-course layers that contain gravel and soil-binder material may be compacted initially with a sheepsfoot roller and rubber -tired rollers. Rubber-tired rollers are particularly effective in compacting base materials if a kneading motion is required to adjust and pack the particles. Base courses of crushed rock, lime rock, and shell are compacted with vibratory, steel-wheeled, or rubber -tired rollers. Select the equipment and methods on each job to suit the characteristics of the base material. When using rollers, begin compaction on the outside edges and work inward, overlapping passes by one-half of a roller width.

Finishing

Finishing operations must closely follow compaction to furnish a crowned, light, water-shedding surface free of ruts and depressions that would inhibit runoff. Use the grader for finishing compacted aggregate bases. Blade the material from one side of the runway, taxiway, or road to the middle and back to the edge until the required lines and grades are obtained. Before final rolling, the bladed material must be within the specified moisture-content range so it will consolidate with the underlying material to form a dense, unyielding mass. If this is not done, thin layers of the material will not be bound to the base, and peeling and scabbing may result. Final rolling is done with rubber-tired and steel-wheeled rollers.

SPECIAL PROCEDURE FOR MACADAM BASES

Construction of macadam base courses requires the procedures that follow.

Preparing Subgrade

If a macadam base course is constructed on a material with high plasticity, there may be base infiltration. This can be prevented with a blanket course of fine material such as crusher screenings or 3 to 4 inches of sand. The blanket course should be lightly moistened and rolled to a smooth surface before spreading the coarse macadam aggregate. A membrane or a geotextile fabric may be used in lieu of the blanket course.

Spreading

Macadam aggregate must be placed and spread carefully to ensure that hauling vehicles do not add objectionable material to the aggregate. Care is particularly necessary when placing the aggregate at the point nearest to the source and routing hauling vehicles over the spread material. If the compacted thickness of the lift is 4 inches or less, spread the loose macadam aggregate in a uniform layer of sufficient depth to meet requirements. For greater compacted thickness, apply the aggregate successively in two or more layers. Spreading should be from dump boards, towed aggregate spreaders, or moving vehicles that distribute the material in a uniform layer. When more than one layer is required, construction procedures are identical for all layers.

Compacting

Immediately following spreading, compact the coarse aggregate the full width of the strip by rolling it with a steel-wheeled roller. Rolling should progress gradually from the sides to the middle of each strip in a crown section, and from the low side to the high side where there is a transverse slope across the road, runway, or taxiway. Continue rolling until the absence of creep or wave movement of the aggregate ahead of the roller indicates that the aggregate is stable. Do not attempt rolling when the subgrade is softened by rain.

Applying Screenings

After the coarse aggregate has been thoroughly stabilized and set by rolling, distribute sufficient screenings (fine aggregates) to fill the voids in the surface. Roll continuously while screenings are being spread, so the jarring effect of the roller will cause them to settle into surface voids. Spread screenings in thin layers by using hand shovels, mechanical spreaders, or moving trucks. Do not dump them in piles on the coarse aggregate. If necessary use hand or drag brooms to distribute screenings during rolling.

Do not apply screenings 100 thick because they will bridge over the voids and prevent the direct bearing of the roller on the coarse aggregate. Continue spreading, sweeping, and rolling until no more screenings can be forced into the voids. Start sprinkling the surface with water after the screenings have been spread. The sprinkling causes the screenings to be flushed down into the voids of the aggregate. The surface is then rolled. Do not saturate and soften the subgrade.

Continue sprinkling and rolling until a mixture of screenings and water forms, fills all voids, and gathers in a small wave before each roller. When a section of a strip has been grouted thoroughly, allow it to dry completely before performing additional work.

FINISHED SURFACES

The base-course surface determines the smoothness of the finished pavement. If the finished base dots not conform to the specified grade when tested with a 12-foot straightedge, the finished pavement also will not conform. The base surface should be smooth and conform to specified design requirements.

When tested with a 12-foot straightedge applied parallel and perpendicular to the centerline of the paved area, the surface of the base course should not show any deviation in excess of 3/4 inch for roads and airfields [for propeller-type aircraft) or 1/8 inch for jet aircraft. Correct any deviation in excess of these figures, and remove material to the total depth of the lift, replacing with new material and compacting as specified above.

SLUSH ROLLING

The purpose of slush rolling (rolling with enough water to produce a slushy surface) is to achieve compaction when conventional methods fail. Slush rolling should be permitted only on a free-draining, cured base course. Slushing requires a considerable amount of water on the surface. The quantity varies greatly with the type of material, the temperature, and the humidity. If the surface is generally satisfactory but has some large areas requiring slushing, slush only the rough areas. Slushing brings fines to the top and creates voids. In general, slush rolling should not be used on a high-quality base-course material. It should be used only when required by the specifications or when conventional compaction methods have failed.

Applying Water

Engineers must calculate a water application rate in terms of gallons per square yard in order to allow the water distributor operator to accurately apply water. A reasonable estimate for applying water to a 6-inch lift is 0.5 to 1.0 gallon per square yard. The rollers must follow immediately behind the water truck to achieve the desired results because the roller should carry a wave of water ahead of it as it passes over the base course.

Rolling Equipment

Use pneumatic-tired, vibratory, or steel-wheeled rollers to obtain a smooth finish on the base course. Continue rolling until compaction has been obtained.

Finishing

There are usually small rivulets or ridges of fines left on the surface after slushing is completed. Where these are excessive or when the thickness of the blanket of fines is excessive, sprinkle the surface with water and hone (dress lightly) with a grader blade. This delicate operation requires a good operator and a sharp, true blade. Follow the grader immediately with a pneumatic roller to reset the surface.

WET ROLLING

All base courses require a final surface finish. The final finish should be obtained immediately after final compaction or proof rolling. For less critical base courses or where deemed necessary by the project engineer, wet rolling and slush rolling may be used to obtain the final finish. Both methods have strong points and, in some cases, a job may require a combination of the two.

Applying Water

Wet rolling does not require the large amount of water demanded for slush rolling, and the base course does not need to go through the curing period required by the slush-rolling method. Apply enough water to the base course to raise the moisture content of the upper 1 to 2 inches of the base course to approximately 2 percentage points above the minimum moisture content. The percent of moisture will vary with the type of material and is a matter of judgement by the project's quality control manager.

Finishing

Finish the surface by having the grader blade lightly cut the final surface. The light blading will loosen the fines; the coarser particles of the base course will be carried along by the blade to form a windrow at the edge of the section being finished. This coarse aggregate can be evenly distributed over the area and incorporated into the surface of the base by a steel-wheeled roller closely following the grader. Additional water may be required, and rolling by the steel-wheeled and pneumatic-tired rollers must be continued until a smooth, dense surface is obtained. This method can also be used for correcting minor surface irregularities in the base course.

QUALITY CONTROL

Quality control is essential to any project's success. Although visual inspection is important, it is not, by itself, sufficient to control the construction of all courses described in this chapter, particularly those which contain considerable fine material. Depending on the type of base, control tests will include determinations of gradation, mixing proportions, plasticity characteristics, moisture content, field density, lift thickness, and CBR values. These tests are described in detail in FM 5-530. Prior to starting construction, a detailed quality control plan should be developed which addresses testing procedures, frequency, location and, most importantly, remedial actions.