CHAPTER 2

SUBGRADES, SUBBASES, AND BASES

2-1. Pavement types

There are two basic pavement types discussed in this manual. Subgrade, subbases, and bases are also discussed as they relate to the two types of pavements.

a. Flexible pavement. Flexible pavement consists of the subgrade or natural in-place soil, select material or subbases, the base course, and the asphalt pavement surface. Base courses and subbases for flexible pavements are placed to distribute the surface-induced stresses from the vehicle and aircraft wheel loads so that the resulting stresses on the subgrade do not exceed its strength (fig. 1-1). The subgrade ultimately supports the load placed on the surface of the pavement, and the strength of the subgrade partially determines the thickness of pavement structure (surface, base, and subbase). Information for flexible pavements is provided in TM 5-825-2/AFM 88-6, chapter 2, section A/NAVFAC DM-21.3.

b. Rigid pavement. Rigid pavement consists of the subgrade or natural in-place soil, any aggregate courses, and the portland cement concrete slabs. Aggregate courses under concrete slabs are not always used but are generally provided to prevent water migration or pumping, or to minimize frost action. Concrete slabs are designed to distribute the stresses from the wheel loadings over large areas. However, concrete slab stresses (and deflections) at free edges will be higher than stresses in the middle of slabs. Hence, load transfer is a must. In continuously placed unreinforced concrete, contraction joints are placed at a uniform spacing based on the thickness of the pavement, and load transfer is obtained by interlocking the concrete aggregate. Transfer decides such as dowels or keys are used to transmit loads between slabs at butt or fully formed joints and at construction joints in reinforced concrete. Where transfer devices are not used or strengthening by extra steel along edges is not used, provision for slab edge support is made by using a cement-treated base under slabs or by thickening the concrete at the edges of the slab. Strong foundation materials beneath concrete slabs result in a reduced slab design thickness as compared with the thickness that would be required for a weak foundation.

c. Effects of water on foundation soils. Saturation of pavement bases and subgrades generally decreases their load-carrying capacity. Failures as a result of saturation may be minimized by preventing infiltration of surface water into the base or subgrade and by removing excess moisture or trapped water from beneath the pavement. Infiltration of surface water can be prevented by sealing large cracks and periodic application of surface seals to bituminous pavements, by replacing ineffective sealers in joints of concrete pavements, and by proper drainage of surface water from the pavement area. In areas of high water tables under pavements, properly designed subsurface drainage, stabilized bases, or free-draining materials that are not adversely affected by moisture are required. In areas where frost is a consideration, selected materials, as required by specifications, are needed to limit frost penetration and subsequent frost heave or weakening of materials during the frost melting period.

2-2. Subgrade

The subgrade is the natural in-place soil under a pavement. In general, compaction increases the strength of most soils; however, there are a few soils (some clays and silts) that decrease in stability when scarified, worked, and rolled. There are also some soils that shrink excessively during dry periods and expand excessively when allowed to absorb moisture. When these soils are encountered, special treatment is required. Unsuitable soils that will not support equipment used in maintenance or repair operations will be stabilized or removed and replaced with more suitable soils. Unsuitable subgrade soils under a failed pavement will be repaired or removed and replaced prior to other correction action.

a. Clays. The types of clays that show a decrease in strength when scarified and rolled are generally organic and inorganic clays having high plasticity and organic silts. These materials are classified in the CH and OH groups according to ASTM D 3282. These materials are clays that have been consolidated to a very high degree, either under an overburden load or by alternate cycles of wetting and drying, or by some other means and thus have developed a finite structure. They have a high strength in the undisturbed state. Scarifying, reworking, and rolling these soils in cut areas may produce a lower bearing strength than that of the undisturbed soils. When the undisturbed soil has a higher bearing value than in a disturbed state, then no compaction will be attempted, and construction operations will be conducted to produce the least possible disturbance of the soil.

b. Silts. Experience has shown that some deposits of silt, very fine sand, and rock flour (predominantly having a USCS classification of ML an SC) (ASTM D 2487), when compacted in the presence of a high water table, will pump water to the surface and become "quick" or "spongy" with loss of strength. This condition can also develop in most silts and poorly drained very fine sands if these materials are compacted at a high moisture content, because the compaction reduces the air voids so that the available water fills practically all the void space. Drying is not difficult if the source of moisture can be removed since the soils are usually friable and can be scarified readily. In cases of high water table, drying is usually not satisfactory until the water table is lowered because recompacting operations will again cause water to be pumped to the surface. Local areas of this nature are usually treated satisfactorily by replacing the soil with subbase and base materials or with a dry soil insensitive to water. Where drainage is not feasible and a high water table cannot be lowered, every effort will be made not to disturb the subgrade. Also, additional thicknesses of base and pavement surface layers will be used to ensure that the subgrade will not be overstressed or compacted during subsequent traffic by vehicle or aircraft.

c. Expansive soils. Soils with expansive characteristics occur universally, and local determinations must be made. Extensive trouble occurs in certain areas of the West Gulf Coastal Plains and the Great Plains where climatic conditions are conducive to significant changes in moisture content of the subgrade during different seasons of the year. Such soils also give trouble in any region where construction is accomplished in a dry season and the soils absorb moisture during a subsequent wet season. Conversely, problems arise in areas where construction is accomplished in the wet season and the soils lose moisture during the subsequent dry season. If highly compacted, these soils will swell and produce uplift pressures of considerable intensity if the moisture content of the soil increases after compaction. This action may result in intolerable differential heaving of pavements. A common method of treating a subgrade with expansive characteristics is to compact it at a higher moisture content and to maximum unit weight. This solution may be temporary due to reasons given above. Another method of reducing the shrinking or swelling is to use a stabilization method such as lime. Special solutions to the problem of swelling soils are sometimes possible and should not be overlooked where pertinent. For instance, where climate is suitable, it may be possible to place a permeable layer (aquifer) over a swelling soil and limit or prevent drainage from it. Moisture buildup in this layer maintains the soil in a stable, saturated condition.

d. Blanket/filter courses. Whenever the subgrade is composed of fine-grained soil and the base course to be placed on it is composed of open-graded crushed rock or gravel, a blanket course of 1 to 2 inches of sand or crusher screenings, or an equivalent geotextile fabric will be placed on the subgrade. This course will be compacted with a rubber-tired or steel-wheel roller. A hand or pneumatic tamper is used if the area is too small for powered equipment. Compaction equipment should not be used directly on geotextiles. This blanket/filter course helps prevent the fine soil from working up into the base under repeated loadings if excess water is present. A blanket course is not necessary if the base material is dense graded.

e. Frost effects. In regions where frost may penetrate the subgrade or subbase, frost effects should be anticipated. To minimize damaging effects of frost, maintenance methods will be adjusted from those used in more temperate climates. The most detrimental effects of frost occur during the thawing period when the soil, which has expanded as a result of freezing, becomes saturated and unstable. By following design procedures applicable for construction of pavements in areas with deep frost penetration maintenance problems can be minimized. Procedures should be adjusted to reduce the possibility of damage by differential heaving and frost boils.

(1) *Drainage.* Surface water drains and outlets for subgrade drainage will be kept free of obstructions so that a minimum of moisture reaches the subgrade.

(2) *Repair.* When repairing areas of pavement are affected by frost action, care must be used in selecting materials and methods which will ensure against repeated failure. TM 5-825-2-1/AFM 88-6, chapter 2, section ANAVFAC DM-21.3, and NAVFAC DM-5 discuss the treatment of pavements in frost areas.

f. Permafrost. Permafrost is a layer of soil or rock at a variable depth below the surface of the earth in which a temperature below freezing has existed continuously for many years. In the permafrost areas, the greatest maintenance problems occur in the spring and early fall. Preventive measures are similar to those for frost action. Permanent repairs are usually restricted to the summer and must comply with the minimum specification and design used in the original construction. In winter, the major maintenance problem is snow and ice removal (see chap 9). In winter months during inspections, low areas which flood and freeze must be noted so that corrective drainage measures can be carried out during spring and summer maintenance and repair activities. Snowbanks should not be allowed to develop since they act as snow traps. Culverts and drainage ditches should be cleared of snow by early spring in preparation for the runoff from the thawing snow.

2-3. Subbase

For economic reasons, it is common practice in flexible pavement design to use locally available or other inexpensive materials between the subgrade and base course. These layers are designated as subbases or select materials. The use of subbase or select materials will permit a reduced thickness of base course material, normally a more costly material. The specification requirements for subbase materials are more restrictive than those for select materials. Because of this, subbase materials are limited to a design California Bearing Ratio (CBR) greater than 20 while select materials are limited to a design CBR of 20 or less. Therefore, the required pavement and base course thickness will be greater above select materials than for a subbase material. Select materials for pavements may consist of heavy loads and large volumes (e.g., airfields, primary roads, and highways) and as base courses, low-volume pavements (e.g., secondary roads, range patrol roads, etc.). Select materials and subbases may consist of locally occurring coarse-grained soils or blended and processed soils. Materials such as limerock, coral, shell, ashes, cinders, caliche, and disintegrated granite may be used when they are economical and when they meet the requirements set forth in table 2-1. These requirements are imposed to ensure the use of materials that can be readily processed and will meet the strength requirements. Material stabilized with commercial admixes may be economical as a subbase in certain instances. Also, by using sufficient amounts of lime, portland cement, or fly ash, it may be possible to decrease the plasticity of some materials making them suitable as subbases. Stabilization of materials is discussed in chapter 5.

Table 2-1. Select materials and subbases

Material type	Maximum size Aggregate (inches)	Maximum percentage no. by weight of material passing the no. 200 sieve	Material passing the 40 sieve	
			Liquid index	Plasticity index
Select material	3	25	<35	<12
Subbase material	3	15	<25	<5

2-4. Base course

Experience has shown that high-quality materials must be used in the base course (the layer directly beneath the pavement surface layer). For flexible pavements, a low subgrade strength requires a substantial thickness of select material, subbase, and base material to reduce the imposed stress on the subgrade. Where the subgrade strength is high, only a base course may be required to provide for adequate load distribution. Since the stresses in the base courses are always higher than those in the subgrade, the base course must have a higher strength than the subgrade and be sufficiently compacted to prevent consolidation under traffic. For both flexible and rigid pavements, select materials, subbases, and base courses provide the following functions: (a) additional structural strength, (b) more uniform bearing surface for the pavement, (c) replacement for soft highly compressible or expansive soils, (d) protection for the subgrade against detrimental frost action, (e) drainage and prevention of pumping, and (f) suitable surface for the operation of construction equipment during adverse weather conditions. Positive drainage will be provided for all base courses to ensure against water being trapped and saturating the layers. Saturated layers reduce pavement strength and promote the pumping condition that the base course is designed to prevent.

2-5. Materials for subbases and base courses. A wide variety of gravels, sands, gravelly and sandy soils, and other natural materials such as limerock, coral, shells, and caliche are used alone or blended to provide satisfactory select material, subbase, or base course. Natural materials often require crushing or removal of the oversize fraction to maintain gradation limits. Other natural materials may be controlled by mixing crushed and pit-run materials together to form a satisfactory select material, subbase, or base course material. These materials are occasionally used without further surfacing, but they usually require constant maintenance to correct for traffic wear, prevent dusting, and minimize infiltration of surface waters.

a. Gravel and sand. Many natural deposits of sandy and gravelly materials make satisfactory select material, subbase, and base courses. Gravel deposits vary widely in the relative proportions of coarse and fine material and in the character of the rock fragments. Satisfactory select materials, subbases, or base materials can be produced by blending materials from two or more deposits. Clean washed gravel alone is unsatisfactory for a select material, subbase, or base course because fine material which acts as the binder and fills the voids between the coarser aggregate is needed to provide adequate shear resistance. A binder material will be added to the material if needed; however, care will be taken so that fines meet the plasticity requirements for a select material, subbase, or base material. Addition of clay fines to a washed gravel may cause the material to become unstable with increases in moisture content. A base course made from sandy and gravelly materials would normally have a high shear strength and could be used to support heavy loads.

b. Sand-clay. Natural deposits suitable for mixtures may be found in alluvial deposits of varying thickness. Often there are great variations in the proportions of sand and clay from top to bottom of a pit. With proper proportioning and construction methods, sand-clay mixtures will make satisfactory base courses for secondary type roads. This material is most often used for select material and subbase courses in stage construction where higher quality materials are to be added later. This type of material should be investigated to assure that the clays are not highly plastic or swelling clays.

c. Processed materials. Processed materials are prepared by crushing and screening rocks, gravel, or slag. A properly graded crushed rock base produced from sound durable rock particles makes the highest quality base materials. Crushed rock may be produced from any rock that is hard enough to require drilling, blasting, and crushing. Existing quarries, ledge rock, slag, cobbles and gravel, talus deposits, coarse mine tailings, and similar hard durable rock fragments are the usual source of processed materials. Materials which slake on exposure to air or water should not be used. Processed materials are normally more expensive than readily available gravels or sand-clays.

(1) *Composite base materials.* A composite base material is one in which all the materials ranging from coarse to fine are intimately mixed either before or as the material is laid in place. Because the aggregate obtained from deposits such as those produced in crushing operations is often deficient in fines, it may be necessary to blend in select fines to obtain a suitable gradation. Screenings, crusher run fines, or natural soil may be added and mixed either in the processing plant or during the placing operation. Where a soil is used, care will be taken to limit the clay content so that the plasticity index of the blended material will not exceed specification requirements.

(2) *Macadam-type base.* A macadam-type base material is composed of uniformly crushed rock, gravel, or slag. The term "macadam" is usually applied where the coarse aggregate is placed and rolled, and then fine aggregate or screenings are placed and rolled and broomed into the coarse aggregate until it is thoroughly keyed in place. This is commonly referred to as dry-bound macadam. Water may be used in the compacting and keying processes, and this is then referred to as water-bound macadam. Any hard durable crushed aggregate can be used provided the coarse aggregate is primarily of uniform size and the fine aggregate will key into the coarse aggregate. This type of base is rarely used in modern maintenance operations.

d. Recycled materials. Recycled materials will consist of broken up asphaltic concrete (AC) or portland cement concrete (PCC). These materials are obtained by utilizing a milling machine or by full-depth breakup and removal of the pavement. The milling machine provides a material which is directly usable while the broken up materially generally requires further processing or crushing. Reinforcing in PCC will negate the use of a milling machine. Recycled materials can fulfill the same requirements as new materials and usually at reduced costs.

e. Other materials. In many geographical areas, deposits of natural sands and gravel and sources of crushed rock are not available. This has led to the development of select material, subbase, or base courses from materials that normally would not have been considered. These include caliche, limerock, shells, cinders, coral, iron ore rubble, and other select materials. Some of these are primarily soft rocks that crush under construction traffic to produce a composite select material, subbase, or base material similar to those described in paragraph 2-5c. Others develop a cementing action which results in a satisfactory select material, subbase, or base. These materials cannot be judged on the basis of the gradation limits used for other materials, but instead, they must be judged on the basis of service behavior. Strength tests on laboratory samples are not satisfactory because the samples prepared in the laboratory seldom duplicate the material in place. The plasiticity index is a reasonably good criterion, and, as a general rule, a low plasticity is a necessity. Observations of the performance of these materials in existing pavements provide the most reliable clues to whether they will perform satisfactory on future projects. Consultation with local engineers who have had experience in the use of these local materials will prove beneficial.

(1) *Coral.* This material is commonly found in the Pacific and Caribbean areas. Uncompacted coral has a high capillarity, and if poorly drained, its moisture content is normally above optimum, and the material does not have a high degree of stability. The bonding properties of coral provide its greatest asset as a construction material. The bonding properties vary with the calcareous content, proportion of fine and coarse materials, age, length of exposure to the elements, climate, traffic, sprinkling, and method of compaction. Proper moisture control, drainage, and compaction are essential to obtain satisfactory results.

(2) *Caliche.* One of the most common characteristics of caliches which make many of them valuable for select material, subbase, or base courses is their capability of recementation when saturated by water, subjected to compaction, or given a "setting" period. This is especially true of caliches which are cemented with lime, iron oxide, or salt. Caliche is variable, in both mineral content (limestone, silt, and clay) and degree of cementation. This accounts for widespread differences of opinion as to its suitability for road or airfield construction. Therefore, it is important that caliche of good uniform quality be selected from available deposits and that it be compacted at optimum moisture content. After caliche has been slaked for 72 hours, the liquid limit of the fines must not exceed 34 and the plasticity index 10. For base material, caliche will generally be crushed to meet the following gradation: maximum size of 2 inches, 15 to 35 percent passing the No. 40 sieve, and from 0 to 20 percent passing the No. 200 sieve. Where the construction is to be made on surface deposits, undesirable material should be removed by stripping operations.

(3) *Tuff.* Tuff is a term applied to compacted deposits of the fine materials ejected from volcanoes such as cemented dust and cinders. Tuffs, prevalent in the Mediterranean area, are more or less stratified and in various states of consolidation. Tuff and other cementitious materials of volcanic origin may be used for select material, subbase, or base courses. Tuff bases are constructed in a manner similar to other base courses. After the tuff is dumped and spread, the oversize pieces are broken and the base compacted.

2-6. Construction and repair procedures

The materials used to repair a subbase or base course should meet or exceed the requirements of the existing material. The following are mixing and placing procedures applicable to both subbase and base courses.

a. Mixing. Uniform mixing and blending of materials are essential for durability. Materials can be mixed in the pit with either excavating equipment or in a stationary plant. Materials can also be blended and mixed on site by scarifiers, plows, graders, or tillers. During the mixing, the materials are spread evenly in correct proportions with the finer material on top. Initial mixing to work the fines into the coarse material may be accomplished with grader-scarifier attachment or with harrows. Final mixing is accomplished with a rotary tiller or a grader. When a grader is used, the materials are thoroughly mixed by alternately blading the entire layer to the center and back to the edges of the working strip. During compaction, water content should be maintained in the material within range of the optimum water content. The required water content can be obtained by rewetting the material if too dry and by blading and aerating if too wet.

b. Placing. Areas to be repaired, when possible, should use existing work for control of surface grades and linear placement. Larger areas usually require grade stakes and forms be used to ensure proper surface gradients as well as to identify limits of work. Trucks, scrapers, and other hauling vehicles can be used to deposit material directly on the subgrade. Mechanical spreaders or controlled tailgate openings help to govern the rate of spread from trucks. On areas large enough to accommodate them, spreading can be accomplished by dozer or grader blading. On smaller areas materials can be placed and spread by hand.

c. Compacting. Subbase and base course layers containing gravel and soil-binder material are compacted with steel-wheel, rubber-tired vibratory compactors. Equipment and methods should be adjusted on each job to suit the characteristics of the material. Table 2-2 gives more information concerning compaction equipment and other characteristics for various soil types.

d. Finishing. Finishing operations will closely follow compaction to furnish a crowned, tight, water-shedding surface. A grader is used for finishing graded aggregate bases. The material is bladed from one side of the operation area to the middle and back to the edge until the required lines and grades are obtained. Before final rolling, the bladed material will be at its optimum moisture content so that it can be compacted to maximum density. If proper compaction is not obtained, thin layers of the material may peel from the underlying layer.

Table 2-2. Characteristics and ratings of unified soil system classes for soil construction

Class	Compaction Characteristics	Maximum-Standard Proctor Dry Density (tons/m ^{3})	Maximum-Standard Proctor Unit Weight (lb/ft ^{3})	Compressibility and Expansion	Drainage and Permeability
GW	Good: tractor, rubber-tired, steel wheel, or vibratory roller	2.00-2.16	125-135	Almost none	Good drainage, pervious
GP	Good: tractor, rubber-tired, steel wheel, or vibratory roller	1.84-2.00	115-125	Almost none	Good drainage, pervious
GM	Good: rubber-tired or light sheepsfoot roller	1.92-2.16	120-135	Slight	Poor drainage, semipervious
GC	Good to fair: rubber-tired or sheepsfoot roller	1.84-2.08	115-130	Slight	Poor drainage, impervious
SW	Good: tractor, rubber-tired or vibratory roller	1.76-2.08	110-130	Almost none	Good drainage, pervious
SP	Good: tractor, rubber-tired or vibratory roller	1.60-1.92	100-120	Almost none	Good drainage, pervious
SM	Good: rubber-tired or sheepsfoot roller	1.76-2.00	110-125	Slight	Poor drainage, impervious
SC	Good to fair: rubber-tired or sheepsfoot roller	1.68-2.00	105-125	Slight to medium	Poor drainage, impervious
ML	Good to poor: rubber-tired or sheepsfoot roller	1.52-1.92	95-120	Slight to medium	Poor drainage, impervious
CL	Good to fair: sheeps-foot or rubber-tired roller	1.52-1.92	95-120	Medium	No drainage, impervious
OL	Fair to poor: sheeps-foot or rubber-tired roller	1.28-1.60	80-100	Medium to high	Poor drainage, impervious
MH	Fair to poor: sheeps-foot or rubber-tired roller	1.20-1.60	75-100	High	Poor drainage, impervious
CH	Fair to poor: sheeps-foot roller	1.28-1.68	80-105	Very high	No drainage, impervious
OH	Fair to poor: sheeps-foot roller	1.12-1.60	70-100	High	No drainage, impervious
Pt	Not suitable			Very high	Fair to poor drainage

* Adapted from Sowers 1979 and TM 3-357.