6F-1 Pavement Subbase Design and Construction

A. General information

Pavement systems generally consist of three layers: prepared subgrade, subbase, and pavement. This section will deal with the proper design and construction of subbases. The subbase is the layer of aggregate material that lies immediately below the pavement and usually consists of crushed aggregate or gravel or recycled materials (see Section 6C-1, Pavement Systems, for more information). Although the terms “base” and “subbase” are sometimes used interchangeably to refer to the subsurface layers of a pavement, base course is typically used in asphalt pavements, primarily as a structural load-distributing layer, whereas the subbase layer used in concrete pavements primarily serves as a drainage layer. Aggregate subbase is typically composed of crushed rock, comprised of material capable of passing through a 1 1/2 inch screen, with component particles varying in size from 1 1/2 inch down to dust. The material can be made of virgin (newly mined) rock or of recycled asphalt and concrete.

The function of the pavement subbase is to provide drainage and stability to achieve longer service life of the pavement. Most pavement structures now incorporate subsurface layers, part of whose function is to drain away excess water that can be deleterious to the life of the pavement (see Section 6G-1, Subsurface Drainage Systems). However, aggregate materials for permeable bases must be carefully selected and properly constructed to provide not only permeability, but uniform stability as well. Proper construction and QC/QA testing operations can help to ensure good performance of the subbase layer. Excessive compaction can alter the gradation and create additional fines that may result in lower permeabilities than determined in laboratory tests and used in the pavement system design. However, the optimization of structural contributions from high stability, versus the need to provide adequate drainage for pavement materials is still a point of debate. The focus of this section is to provide guidance on selection of proper subbase materials, best construction practices, and suitable QC/QA testing methods.

B. Granular subbases

1. **Purpose.** Subbases serve a variety of purposes, including reducing the stress applied to the subgrade and providing drainage for the pavement structure. The granular subbase acts as a load-bearing layer, and strengthens the pavement structure directly below the pavement surface, providing drainage for the pavement structure on the lowest layer of the pavement system. However, it is critical to note that the subbase layer will not compensate for a weak subgrade. Subgrades with a CBR of at least 10 should provide adequate support for the subbase.

2. **Materials.** As the granular subbase provides both bearing strength and drainage for the pavement structure, proper size, grading, shape, and durability are important attributes to the overall performance of the pavement structure. Granular subbase aggregates consist of durable particles of crushed stone or gravel capable of withstanding the effects of handling, spreading, and compacting without generation of deleterious fines.

3. **Gradation.** Aggregates used as subbase tend to be dense-graded with a nominal maximum size, commonly up to 1 1/2 inches. The percentage of fines (passing No. 200 sieve) in the subbase is limited to 10% for drainage and frost-susceptibility purposes. The Engineer may authorize a change in the gradation at the time of construction based on materials available.

   a. **Particle shape.** Equi-dimensional aggregate with rough surface texture is preferred.

   b. **Permeability.** The fines content is usually limited to a maximum of 10% for normal pavement construction and 6% where free-draining subbase is required.

   c. **Plasticity.** Plastic fines can significantly reduce the load carrying capacity of subbase; plasticity index (PI) of the fines of 6 or less is required.

4. **Construction.** Granular subbases are typically constructed by spreading the materials in thin layers compacting each layer by rolling over it with heavy compaction equipment to achieve a density greater or equal to 70% relative density.

5. **Thickness requirement.** Typically, the thickness of the subbase is 6 inches with a minimum of 4 inches. Additional thickness beyond 6 inches could allow consolidation of the subbase over time as traffic loads accumulate. Pavement problems may result from this consolidation.

C. Recycled materials

Recycled materials with the required particle distribution, high stiffness, low susceptibility to frost action, high permeability, and high resistance to permanent deformation can be successful subbases. Recycled aggregate can solve disposal problems, conserve energy, and lower the cost of road construction.

1. **Recycled concrete aggregate.** To reduce the use of natural aggregate and help preserve the environment, recycled concrete aggregate can be used. Consider the following precautions:
   - The breakage of particles results in faces, which can react with water and produce high pH. This may result in poor freeze-thaw performance.
   - The breakage of particles due to compaction and traffic loading will increase the fines percentage. This increasing fine percentage will reduce freeze-thaw resistance and permeability of bases.
   - Increased pH due to cement hydration can cause corrosion of aluminum and steel pipes.

2. **Recycled asphalt pavement.** Consider the following precautions:
   - 20% to 50% RAP is typically used. High percentages of RAP are not used in normal construction.
   - The stiffness increases with higher percentage of RAP, while there must be limits on percentage of RAP to incorporate into virgin material.

D. Effects of stability and permeability on pavement foundation

The subbase is the layer of aggregate material that lies immediately below the pavement and usually consists of crushed aggregate or recycled materials.

1. **The main roles of the subbase layer in pavements.** Include provision of the following (Dawson 1995):
   - Protection for the subgrade from significant deformation due to traffic loading
   - Adequate support for the surface layer
   - Stable construction platform during pavement surfacing
   - Adequate drainage for the infiltration of rain water through cracks and joints, particularly in PCC pavements (see Section 6G-1, Subsurface Drainage Systems)
   - Subgrade protection against frost and environmental damage

2. **Effect of undrained water on pavement foundation.** Undrained water in the pavement supporting layers is a major contributor to distress and premature failure in pavements. Some of the detrimental effects of water, when entrapped in the pavements structure are that (Yang 2004):
   - Water reduces the strength of unbounded granular materials and subgrade soils.
   - Water causes pumping of concrete pavements with subsequent faulting, cracking, and general shoulder deterioration.
   - With the high hydrodynamic pressure generated by moving traffic, pumping of fines in the base course of flexible pavements may also occur with resulting loss of support.
   - In northern climates with a depth of frost penetration greater than the pavement thickness, high water table causes frost heave and the reduction of load-carrying capacity during the frost melting period.
   - Water causes differential heaving over swelling soils.
   - Continuous contact with water causes stripping of asphalt mixture and durability or “D” cracking of concrete.

   Accumulated water in the subbase is a key contributing factor to subbase instability and pavement distress. Thus it is important to understand how water becomes trapped in the subbase layer. A number of other factors also affect the engineering behavior of aggregates, including fines content; aggregate type, grading, size, and shape; density; stress history; and mean stress level. Table 1 summarizes the relative effects of these factors. From this table, it can be seen that:
   - Aggregate stiffness is increased by an increase in most of the controlling factors, with the exception of fines content and moisture content, which decrease the stiffness.
   - An increase in susceptibility to permanent deformation can be caused by increasing fines content and moisture content, while most other factors decrease the susceptibility.
   - Strength is generally increased with an increase in density; good grading; and aggregate angularity, size, and stress level.
   - Fines content has a major effect on permeability, with increased fines leading to a decrease in permeability. A well-graded aggregate is also much less permeable than a uniform gradation.
   - Increased fines content decreases durability, while the changes caused by most of the other factors are minor in comparison.

Table 1: Effects of intrinsic and manufactured properties of aggregates as controlling factors on engineering properties of granular material in pavement layers

Controlling Factor	**PROPERTY**				
	Stiffness	**Susceptibility to Permanent Deformation**	**Strength**	**Permeability**	**Durability**
Fines content	↓?	↑	varies	major↓	↓
Type: gravel instead of crushed rock	↑	↑	↑	none	usually↑
Grading: well graded instead of single-sized	minor↑	↓	↑	major↓	↓
Maximum size: large instead of small	↑	↓?	minor↑	↑	↓?
Shape: angular/rough instead of rounded/smooth	↑	↓	↑	minor	minor
Density	↑	↓	↑	↓	minor
Moisture content	major↓	major↑	major↓	major↑	varies
Stress history	↑?	major↓	minor↓	none	?
Mean stress level	↑	↓	↑	minor↓	↓

Notes:

↑ = Value of property increases with increase (or indicated change) in controlling factor

↓ = Value of property decreases with increase (or indicated change) in controlling factor

? = Effect of property variation not well established

Source: Dawson et al. 2000

E. Effect of compaction

According to Merriam-Webster's Collegiate Dictionary Eleventh Edition (2003), compaction is defined as "the act or process of compacting; the state of being compacted; to closely unite or pack, to concentrate in a limited area or small space." It is thus a process of particles being forced together to contact one another at as many points as physically possible with the material. Density is defined as "the quality or state of being dense; the quantity per unit volume," as the weight of solids per cubic foot of material. Thus, density is simply a measure of the number of solids in a unit volume of material; density and degree of compaction differ. Two aggregate bases may have the same density but different degrees of compaction due to differences in gradation.

Also, the maximum achievable density, when calculated based on standard lab procedures at a certain level of degree of compaction, is true only when material tested in the laboratory is identical to the field material in all respects of engineering parameters, or the same compactive effort is used to achieve compaction. Therefore, differences in materials and compactive effort can significantly change the density, thereby rendering the calculated percent compaction meaningless. Laboratory compaction testing performed on subbase layers according to AASHTO T 99; Standard Proctor density shows a significant change in density and optimum water content with change in gradation in similar aggregate types. Therefore, it is recommended to use relative density values correlated to gradation for compaction control of aggregate materials in the field to avoid inadequate compaction. A relative density of at least 70% is recommended.

F. Influence of aggregate properties on permeability of pavement bases

The drainability of a pavement subbase is measured using the coefficient of permeability, denoted as k, which defines the quantity of water that flows through a material for a given set of conditions. The quantity of flow through a given medium increases as the coefficient of permeability increases.

The coefficient of permeability is defined as “the rate of discharge of water at 20^{o} C under conditions of laminar flow through a unit cross-sectional area of a soil medium under a unit hydraulic gradient” (Thornton and Leong 1995). Coefficient of permeability measured in pavement subbases is denoted as hydraulic conductivity, which has the same units as velocity, and is expressed in units of length per time (cm/sec or feet per day). (Note: 1 cm/s = 2835 feet per day). Various properties that influence hydraulic conductivity of a pavement subbase include: gradation and shape of aggregate, hydraulic gradient, viscosity of the permeant, porosity and void ratio of the mix, and degree of saturation (Das 1990).

1. **Effect of gradation and shape of aggregate.** According to Cedergren (1974), the life of a poorly drained pavement is reduced to one-third or even less of the life of a well drained pavement.

   Miyagawa (1991) conducted both laboratory and in-situ hydraulic conductivity tests on a wide range of pavement subbases in Iowa. Laboratory test results indicate that crushed limestone has higher hydraulic conductivity with a range of 7,000 to 36,900 feet per day, compared to crushed concrete with a range of about 340 to 12,780 feet per day. A procedure was developed to obtain a relative idea of in-situ hydraulic conductivity tests. This consisted of coring out an approximately 4 inch diameter hole to a depth of 4 to 5 inches, filling the hole with 1 liter of water, and measuring the time taken to drain the water from the hole. Compared to laboratory test results, in-situ tests produce on the order of 20 to 1,000 feet per day. This reduction is believed to be a result of changes in gradation during compaction of the subbase material.

2. **Thickness design for achieving desired drainability.** The major sources of water in pavement systems are surface infiltration, ground water seepage, and melting of ice lenses. A complete pavement drainage system is typically composed of an aggregate subbase, subdrains, and connections to storm sewage systems (see 6G-1, Subsurface Drainage Systems). A positive drainage system should transport water from the point of infiltration to the final exit (transverse drains) through material having high hydraulic conductivity and should eliminate any conditions that would restrict the flow (Moulton 1980).

G. Construction methods

Benefits of using open-graded permeable subbase layers are widely accepted throughout the world. But working with open-graded material in the field and obtaining a workable platform for the overlying surface is not yet well defined. According to White et al. (2004), significant segregation of fines is observed on subbase projects in Iowa, thus contributing to the high variation (coefficient of variation = 100%) in the measured in-place permeability. To reduce segregation, the following construction operations were recommended:

- A motor grader with a sharp angle (i.e., 45 degrees), should be used to push the aggregate transversely from a center windrow/pile, instead of spreading the aggregate material longitudinally along the pavement section (Pavement Technology Workshop 2000).
- When recycled PCC is used for granular subbases, construction traffic on the subbase should be minimized.

- A motor grader with GPS-assisted grading (i.e., stakeless grading control should be used to prepare the final surface for paving, rather than trimming equipment.

If trimming equipment must be used, the aggregate should be delivered to the site with sufficient water content (7% to 10%) to bind the fines during trimming to prevent segregation.

The key to a properly constructed subbase is keeping the material uniformly moist and homogeneously blended. The modified subbase material may be placed and trimmed with an auto-trimmer or dumped from trucks and spread with a motorgrader. The placement and compaction should be completed to minimize segregation and with a minimal increase in fines.

H. Quality control/quality assurance testing

1. In-situ measurement of stability of aggregate subbase.

a. **Dynamic Cone Penetrometer (DCP) test.** DCP is an instrument designed for rapid in-situ measurement of the structural properties of existing pavements with unbound granular materials (Ese et al.1994). The cone penetration is inversely related to the strength of the material. DCP test is conducted according to ASTM D 6951 (Standard Test Method for Use of Dynamic Cone Penetrometer in Shallow Pavement Applications), which was first released in 2003. This test involves measurement of penetration rate per each blow of a standard 17.6-pound hammer, through undisturbed and/or compacted materials. Primary advantages of this test are its availability at lower costs and ease to collect and analyze the data rapidly (See Section 6E-1, Subgrade Design and Construction, for more information).

b. **Clegg impact hammer test.** This test was standardized in 1995 as ASTM D 5874, (Standard Test Method for Determination of the Impact Value IV of a Soil). This is a simple and rapid in-situ test that can be performed on subbase and subgrade materials. This test method is suitable to evaluate the strength characteristics of soils and soil aggregates having maximum particle size less than 1.5 inches (ASTM D 5874).

c. **GeoGauge vibration stiffness test.** The GeoGauge is a 22 pound electro-mechanical instrument, which provides a direct measure of in-situ stiffness (MN/m) and modulus (MPa). The test is a simple non-nuclear test on soils and granular materials that can be performed without penetrating into the ground.

d. **Portable Falling Weight Deflectometer (PFWD) test.** The PFWD test is a simple and rapid non-destructive test that does not entail removal of pavement materials, and hence is often preferred over other destructive methods. In addition, the testing apparatus is easily transported. Layer moduli can be back-calculated from the observed dynamic response of the subbase surface to an impulse load.

e. **Falling Weight Deflectometer (FWD) test.** The FWD is a trailer-mounted system that is similar to the PFWD but generally imparts a higher load pulse to simulate vehicle wheel loads. FWD tests are normally performed on the pavement surface, but, with special testing criteria, they can be performed directly on granular base layers and can be used to back-calculate layer moduli up to about 6 feet deep. FWD results are often dependent on factors such as the particular model of the test device, the specific testing procedure, and the method of back-calculation (FAA 2004).

2. **In-situ hydraulic conductivity resting.** Construction operations might significantly alter the material properties from what are tested in the laboratory. Hence, in-situ hydraulic conductivity testing provides better insights to evaluate the performance of pavement subbases. Although a variety of approaches to determine the field permeability have been documented (Moulton and Seals 1979), virtually no in-situ testing is being conducted as part of the construction practice to verify the hydraulic conductivity of granular subbase layers; yet the impact of drainage on design calculations and long-term performance is well documented. This lack of field permeability measurement provides little confidence that assumed design values are representative of the actual field conditions and does not address the fact that permeability is one of the most highly variable parameters in geotechnical engineering practice. Some of the factors that contribute to the high level of variability include inherent variations in the material gradation and morphology; segregation caused from construction activities to deposit and spread the aggregate; and particle breakdown from compaction and construction traffic (White et al. 2004).

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