Pavement Systems

A. General Information

This section addresses the importance of pavement foundations and the potential for pavement problems due to deficient foundation support.

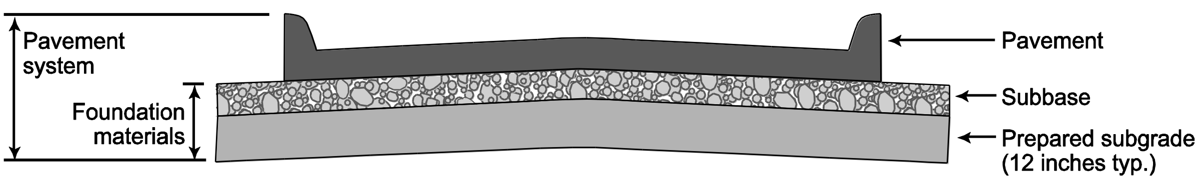
1. **Pavement System:** Consists of the pavement and foundation materials, which are layers of subbase, and subgrade (see Figure 6C-1.01). Failure to properly design or construct any of these components often leads to reduced serviceability or premature failure of the system.

2. **Pavement Materials:** Consist of flexible or rigid pavements, typically HMA or PCC, respectively, or a composite of the two.

3. **Subbase:** Consists of the granular materials underlying the pavement and above the subgrade layer.

4. **Subgrade:** Consists of the naturally occurring material on which the road is built, or the imported fill material used to create an embankment on which the road pavement is constructed. Subgrades are also considered layers in the pavement design, with their thickness assumed to be infinite and their material characteristics assumed to be unchanged or unmodified. Prepared subgrade is typically the top 12 inches of subgrade.

Figure 6C-1.01: Pavement System Cross-section



B. Pavement Support

The prepared subgrade is the upper portion (typically 12 inches) of a roadbed upon which the pavement and subbase are constructed. Pavement performance is expressed in terms of pavement materials and thickness. Although pavements fail from the top, pavement systems generally start to deteriorate from the bottom (subgrade), which often determines the service life of a road. Subgrade performance generally depends on two interrelated characteristics:

1. **Load-bearing Capacity:** The ability to support loads is transmitted from the pavement structure, which is often affected by degree of compaction, moisture content, and soil type.

2. **Volume Changes of the Subgrade:** The volume of the subgrade may change when exposed to excessive moisture or freezing conditions.

In determining the suitability of a subgrade, the following factors should be considered:

- General characteristics of the subgrade soil
- Depth to bedrock
- Depth to 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

C. Pavement Problems

There are a number of ways that a pavement section can fail as well as many mechanisms, which lead to distress and failure.

1. Pavement Failures:

a. Structural Failure: Occurs when a collapse of the entire structure or a breakdown of one or more of the pavement components renders the pavement incapable of sustaining the loads imposed on its surface.

b. Functional Failure: Occurs when the pavement, due to its roughness, is unable to carry out its intended function without causing discomfort to drivers or passengers or imposing high stresses on vehicles.

2. Foundation Failures: The cause of these failure conditions may be due to inadequate maintenance, excessive loads, climatic and environmental conditions, poor drainage leading to poor subgrade conditions, non-uniform support of the surface layer, poor subgrade soil, and disintegration of the component materials. Utility cuts through existing pavements also result in premature pavement failure if not properly restored. Excessive loads, excessive repetition of loads, and high tire pressures can also cause either structural or functional failures.

Pavement failures may occur due to the intrusion of subgrade soils into the granular subbase, which results in inadequate drainage and reduced stability. Distress may also occur due to excessive loads that cause a shear failure in the subgrade, subbase, or surface layer. Other causes of failures are surface fatigue and excessive settlement, especially differential settlement of the subgrade. Volume change of subgrade soils due to wetting and drying, freezing and thawing, or improper drainage may also cause pavement distress. Inadequate drainage of water from the subbase and subgrade is a major cause of pavement problems. If the subgrade is saturated, excess pore pressures will develop under traffic loads, resulting in subsequent softening of the subgrade. Under traffic (dynamic) loading, fines can be pumped up into the subbase layers.

Improper construction practices may also cause pavement distress. Wetting of the subgrade during construction may permit water accumulation and subsequent softening of the subgrade in the rutted areas after construction is completed. Use of dirty aggregates or contamination of the subbase aggregates during construction may produce inadequate drainage, instability, and frost susceptibility. Reduction in design thickness during construction due to insufficient subgrade preparation may result in undulating subgrade surfaces, failure to place proper layer thicknesses, and unanticipated loss of subbase materials due to subgrade intrusion. A major cause of pavement deterioration is inadequate Quality Control/Quality Assurance (QA/QC) of pavement materials and pavement surface during construction. The following are the some of the significant causes leading to pavement distress and failure:

a. **Poor Soils:** Poor soils can seriously impede construction of adequate subgrades, as well as affect the long-term performance of a pavement during its service life. In use as subgrades, these soils often lack the strength and stability necessary to support trucks hauling construction materials, which forces project delays and adds costs. Special problem soil conditions include frost heave-susceptible soils, swelling or expansive soils, and collapsible soils.

Highly compressible (very weak) soils are susceptible to large settlements and deformations with time that can have a detrimental effect on pavement performance. Highly compressible soils are very low in density, saturated, and are usually silts, clays, peat, organic alluvium, or loess. If these compressible soils are not treated properly, large surface depressions with random cracking can develop. The surface depressions can allow water to pond on the pavement's surface and more readily infiltrate the pavement structure, compounding a severe problem. More importantly, the ponding of water will create a safety hazard to the traveling public during wet weather. The selection of a particular treatment technique for poor soils is discussed in Section 6H-1 - Foundation Improvement and Stabilization.

As with highly compressible soils, collapsible soils can lead to significant localized settlement of the pavement. Collapsible soils are very low-density silt-type soils, usually alluvium or wind-blown (loess) deposits, and are susceptible to sudden decreases in volume when wetted. Often, their unstable structure has been cemented by clay binders or other deposits, which will dissolve upon saturation, allowing a dramatic decrease in volume. Native subgrades of collapsible soils need to be soaked with water prior to construction and rolled with heavy compaction equipment. In some cases, residual soils may also be collapsible due to leaching of colloidal and soluble materials. If pavement systems are to be constructed over collapsible soils, special remedial measures may be required to prevent large-scale cracking and differential settlement.

Swelling or expansive soils are susceptible to volume change (shrink and swell) with seasonal fluctuations in moisture content. The magnitude of this volume change is dependent on the type of soil (shrink-swell potential) and its change in moisture content. A loss of moisture will cause the soil to shrink, while an increase in moisture will cause it to expand or swell. This volume change of clay-type soils can result in longitudinal cracks near the pavement's edge and significant surface roughness (varying swells and depressions) along the pavement's length. Expansive soils are a significant problem in many parts of the United States and are responsible for premature maintenance and rehabilitation. Expansive soils are especially a problem when deep cuts are made in a dense (over-consolidated) clay soil.

b. **Utility Cuts:** The impact of utility cuts on pavement performance has been a concern of public agencies for many years. In large cities, thousands of utility cuts are made every year. These cuts are made to install, inspect, or repair buried facilities (See Chapter 9 - Utilities).

The results of studies conducted by public agencies show that the presence of utility cuts lower measured pavement condition scores (indexes) compared to pavements of the same age with no utility cuts. The link between the presence of utility cuts and accelerated pavement deterioration is understood by most agencies.

The resulting reduction in pavement life, despite high-quality workmanship repairing the cut can be explained by the trenching operation. The process of opening the trench causes sagging or slumping of the trench sides as the lateral support of the soil is removed. This zone of weakened pavement adjacent to the utility cut (known as the zone of influence) can fail more rapidly than other parts of the pavement. This can be observed in the field by the presence of fatigue (alligator) cracking occurring around the edges of the cut or spalling around the cut edges.

c. **Transition Between Cuts and Fills:** The alignment for many roadway projects does not always follow the site topography, and consequently a variety of cuts and fills will be required. The geotechnical design of the pavement will involve additional special considerations in cut-and-fill areas. Attention must also be given to transition zones (e.g., between a cut and an at-grade section) because of the potential for non-uniform pavement support and subsurface water flow.

The main additional concern for cut sections is drainage, as the surrounding site will be sloping toward the pavement structure; and the groundwater table will generally be closer to the bottom of the pavement section in cuts. Stabilization of moisture-sensitive natural foundation soils may also be required. Stability of the cut slopes adjacent to the pavement will also be an important design issue, but one that is treated separately from the pavement design itself.

The embankments for fill sections are constructed from compacted material, and in many cases, this construction results in a higher-quality subgrade than the natural foundation soil. In general, drainage and groundwater issues will be less critical for pavements on embankments, although erosion of side slopes from pavement runoff may be a problem, along with long-term infiltration of water. The primary additional concern for pavements in fill sections will be the stability of the embankment slopes and settlements, either due to compression of the embankment itself or to consolidation of soft foundation soils beneath the embankment. This is usually evaluated by the geotechnical unit as part of the roadway embankment design (see Section 6D-1 - Embankment Construction).

d. **Foundation Non-uniformity:** Non-uniform subgrade/subbase support increases localized deflections and causes stress concentrations in the pavement, which can lead to premature failures, fatigue cracking, faulting, pumping, rutting, and other types of pavement distresses for rigid and flexible pavement systems. Some recognized direct causes of subgrade/subbase non-uniformity include the following.

- Expansive soils
- Differential frost heave and subgrade softening
- Non-uniform strength and stiffness, due to variable soil type, moisture content, and density
- Pumping and rutting
- Cut/fill transitions
- Poor grading

Some techniques to overcome these subgrade deficiencies are:

- Moisture-density control during construction
- Proper soil identification and placement
- Over-excavation and replacement with select materials
- Mechanical and chemical soil stabilization
- Onsite soil mixing to produce well-graded composite materials
- Good grading techniques (e.g., uniform compaction energy/lift thickness)
- Waterproofing of the subgrade and control of moisture fluctuations

Although emphasis is placed on subgrade stiffness (i.e., modulus of subgrade reaction, k) for designing PCC thickness, performance monitoring suggests that uniformity of stiffness is the key for ensuring long-term performance. Because of the relatively high flexural stiffness of PCC pavements, the subgrade does not necessarily require high strength, but the subgrade/subbase should be uniform with no abrupt changes in degree of support. The uniformity has a significant influence on the stress intensity and deflection of the pavement layer, and the magnitude of stresses in the upper pavement layer depends on a combination of traffic loads and uniformity of subgrade support. Non-uniform stiffness and the resulting stress intensity contribute to fatigue cracking and differential settlement (deflection) in the pavement layer, and eventually to an uneven pavement surface. This uneven surface causes a rough ride for traffic and contributes to early pavement deterioration and high maintenance costs.

e. Poor Moisture Control: Pavements are strongly influenced by moisture and other environmental factors. Water migrates into the pavement structure through a combination of surface infiltration (e.g., through cracks in the surface layer), edge inflows, and from the underlying groundwater table (e.g., via capillary potential in fine-grained foundation soils). In cold environments, the moisture may undergo seasonal freeze/thaw cycles. Moisture within the pavement system nearly always has detrimental effects on pavement performance. It reduces the strength and stiffness of the pavement foundation materials, promotes contamination of coarse granular material due to fines migration, and can cause swelling (e.g., frost heave and/or soil expansion) and subsequent consolidation. Moisture can also introduce substantial spatial variability in the pavement properties and performance, which can be manifested either as local distresses like potholes, or more globally as excessive roughness. The design of the geotechnical aspects of pavements must consequently focus on the selection of moisture-insensitive, free-draining subbase materials, stabilization of moisture-sensitive subgrade soils, and adequate drainage of any water that does infiltrate into the pavement system.

To avoid moisture-related problems, a major objective in pavement design should seek to prevent the subbase, subgrade, and other susceptible paving materials from becoming saturated, or even exposed to constantly high-moisture levels. The three common approaches for controlling or reducing the problems caused by moisture include:

- Preventing moisture from entering the pavement system.
- Using materials and design features that are insensitive to the effects of moisture.
- Quickly removing the moisture that enters the pavement system.

No single approach can completely negate the effects of moisture on the pavement system under heavy traffic loading over many years. For example, it is practically impossible to completely seal the pavement, especially from moisture that may enter from the sides or beneath the pavement section. While materials can be incorporated into the design which are insensitive to moisture, this approach is often costly and in many cases not feasible (e.g., may require replacing the subgrade). Drainage systems also add costs to the road, as maintenance is required to maintain drainage systems as well as to seal systems for effective performance over the life of the system. Thus, it is often necessary to employ all approaches in combination for critical design situations.