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Geotechnical Exploration and Testing for Roads

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1.4 PAVEMENT PERFORMANCE WITH TIES TO GEOTECHNICAL ISSUES

Regardless of which pavement type is used, all of the components make up the pavement system, and failure to properly design or construct any of these components often leads to reduced serviceability or premature failure of the system.

Distress refers to conditions that reduce serviceability or indicate structural deterioration. Failure is a relative term. In the context of this manual, failure denotes a pavement section that experiences excessive rutting or cracking that is greater than anticipated during the performance period, or that a portion of the pavement is structurally impaired at any time during the performance period with incipient failure anticipated from the local distress. There are a number of ways that a pavement section can fail, and there are many reasons for pavement distress and failure.

Yoder and Witczak (1975) define two types of pavement distress, or failure. The first is a structural failure, in which 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. The second type of failure is a functional failure; it 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. 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, and disintegration of the component materials. Excessive loads, excessive repetition of loads, and high tire pressures can cause either structural or functional failures.

Pavement failures may occur due to the intrusion of subgrade soils into the granular base, which results in inadequate drainage and reduced stability. Distress may also occur due to excessive loads that cause a shear failure in the subgrade, base course, or the surface. Other causes of failures are surface fatigue and excessive settlement, especially differential 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 base and subgrade is a major cause of pavement problems (Cedergren, 1987). If the subgrade is saturated, excess pore pressures will develop under traffic loads, resulting in subsequent softening of the subgrade. Under dynamic loading, fines can be literally pumped up into the subbase and/or base.

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 base 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 base materials due to subgrade intrusion. Yoder and Witczak (1975) state that a major cause of pavement deterioration is inadequate observation and field control by qualified engineers and technicians during construction.

After construction is complete, improper or inadequate maintenance may also result in pavement distress. Sealing of cracks and joints at proper intervals must be performed to prevent surface water infiltration. Maintenance of shoulders will also affect pavement performance.

Nearly all measures of pavement performance are based upon observations at the surface of the pavement – *e.g.,* surface rutting, cracking of the asphalt or PCC, ride quality, and others. In some cases, these surface distresses are due directly to deficiencies in the asphalt or PCC surface layers, but in many other cases these distresses are caused at least in part by deficiencies from the underlying unbound layers. Since pavement design is ultimately an attempt to minimize pavement distresses and, thereby, maximize pavement performance, it is important to understand how geotechnical factors impact these distresses.

Table 1-1, Table 1-2, and Table 1-3 summarize the geotechnical influences on the major distresses for flexible, rigid, and composite pavements, respectively. The composite pavement type considered in Table 1-3 is an AC overlay on top of a PCC rigid pavement system and a very common rehabilitation scenario.

The dominant geotechnical factor(s) for many pavement distresses is/are the stiffness and/or strength of the unbound materials. In reality, the stresses that develop in any well-designed in-service pavement are well below the failure strength of the unbound materials. As a consequence, the true strength parameters (*i.e.,* the cohesion and friction angle from triaxial tests) are not typically needed or measured for unbound pavement materials. Strength indices like the California Bearing Ratio[1] (CBR) have been commonly measured in the past as an overall indication of the material quality in terms of stiffness and resistance to permanent deformation. More recent trends have been to replace these quality indices with direct stiffness testing via the resilient modulus[2] (M_R). Fortunately, strength and stiffness are

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[1] California Bearing Ratio is described in more detail in Chapters 3 and 5.

[2] Resilient Modulus is described in more detail in Chapters 3, 4, and 5.

usually closely correlated in most geomaterials (see, for example, the correlations between M_R and CBR described in Chapter 5).

Table 1-1. Geotechnical influences on major distresses in flexible pavements.

	Insufficient Base Stiffness/Strength	Insufficient Subgrade Stiffness/Strength	Moisture/Drainage Problems	Freeze/Thaw	Swelling	Contamination	Erosion	Spatial Variability
Fatigue Cracking	X	X	X	X		X		
Rutting	X	X	X	X		X		
Corrugations	X							
Bumps				X	X			X
Depressions	X		X	X		X		X
Potholes			X	X				X
Roughness	X	X	X	X	X	X		X

Table 1-2. Geotechnical influences on major distresses in rigid pavements.

	Insufficient Base Stiffness/Strength	Insufficient Subgrade Stiffness/Strength	Moisture/Drainage Problems	Freeze/Thaw	Swelling	Contamination	Erosion	Spatial Variability
Fatigue Cracking	X	X	X	X		X	X	
Punchouts (CRCP)	X	X	X	X		X	X	
Pumping			X				X	
Faulting	X		X	X	X	X	X	
Roughness	X		X	X	X	X	X	X

Table 1-3. Geotechnical influences on major distresses in rehabilitated pavements (AC overlay over PCC).

	Insufficient Base Stiffness/Strength	Insufficient Subgrade Stiffness/Strength	Moisture/Drainage Problems	Freeze/Thaw	Swelling	Contamination	Erosion	Spatial Variability
Reflection Cracking	X		X				X	
Roughness	X		X	X	X		X	X

A major effect of the moisture/drainage, freeze/thaw, and contamination (material from one layer intermixing with another) factors listed in Table 1-1 through 1-3 is to degrade the stiffness and strength of the affected unbound materials. Moisture and drainage are combined here because excessive moisture in the pavement system is often the result of inadequate or malfunctioning drainage systems. Freeze/thaw and swelling can cause heaving of the pavement surface. Erosion can produce voids beneath the surface layers, causing a complete loss of foundation support. The spatial variability factor represents the nonuniformity of the geotechnical factors along the pavement and will, in general, apply to all of the other geotechnical factors.

Note that there are many other important pavement distresses, like thermal cracking, low skid resistance, and others, that are not included in Tables 1-1 through 1-3. The influence of geotechnical factors on these other distresses is generally quite small.

Some further comments on the major distress types are given in the following paragraphs:

Permanent Deformations (Rutting, Bumps, Corrugations, and Depressions). Surface rutting is often the controlling stress mode for flexible pavements. It is sometimes caused by an unstable asphalt concrete mixture that deforms plastically within the first few inches beneath the wheel paths. For a well-designed mixture, however, any rutting observed at the surface will be only partly due to permanent deformations in the asphalt layer, with the remainder due to accumulated permanent deformations in the underlying unbound layers and the subgrade. For example, at the AASHO road test, the percent of final total surface rutting attributable to the asphalt layer averaged 32%, versus 18% for the granular base layer, 39% for the granular subbase, and 11% for the subgrade. In other words, two-thirds of the rutting observed at the surface was due to accumulated permanent deformations in the geomaterials in the pavement structure. Potential causes for excessive permanent deformations in the pavement geomaterials include

- inadequate inherent strength and stiffness of the material.
- degradation of strength and stiffness due to moisture effects (including freeze/thaw); inadequate or clogged drainage systems will contribute to this degradation.
- contamination of base and subbase materials by subgrade fines (*i.e.,* inadequate separation of layer materials).

The shape of the rut trough is usually a good indicator of the source of the permanent deformations. Permanent deformations concentrated in the surface asphalt layers tend to give a narrow rut trough (individual wheel tracks may even be evident), while deep seated permanent deformations from the underlying unbound layers and subgrade typically give a much broader rut trough at the surface.

Nonuniform geotechnical conditions along the pavement can contribute to local permanent deformations in the form of bumps, corrugations, and depressions.

Fatigue Cracking. This form of distress is the cracking of the pavement surface as a result of repetitive loading. It may be manifested as longitudinal or alligator cracking (interconnected or interlaced cracks forming a pattern that resembles an alligator's hide) in the wheel paths for flexible pavement and transverse cracking (and sometimes longitudinal cracking) for jointed concrete pavement. Fatigue cracking in both flexible and rigid pavements is governed by two factors: the inherent fatigue resistance of the surface layer material, and the magnitude of the cyclic tensile strains at the bottom of the layer. The inherent fatigue resistance is clearly dependent only on the properties of the asphalt or PCC. The magnitude of the cyclic tensile strain, on the other hand, is a function of the composite response of the entire pavement structure. Low stiffness in the base, subbase, or subgrade materials – whether due to deficient material quality and/or thickness, moisture influences, or freeze/thaw effects – will all raise the magnitude of the tensile strains in the bound surface layer and increase the potential for fatigue cracking. Localized fatigue cracking may also be caused by nonuniformities in the geomaterials along the pavement alignment – *e.g.,* voids, local zones of low stiffness material, etc.

Reflective Cracking. Reflective cracking in asphalt or concrete surfaces of pavements occurs over joints or cracks in the underlying layers. Like fatigue cracking, reflection cracking of asphalt overlays on top of rigid pavements is governed by the inherent fatigue resistance of the asphalt concrete and the magnitude of the tensile and shear strains in the overlay above the joint in the underlying rigid pavement. Inadequate foundation support (*e.g.,* voids) at the joint will allow differential movement between slabs under a passing vehicle, producing large strains in the overlay above. Intrusion of water, inadequate drainage, and erosion of the unbound base material beneath a joint are all major geotechnical factors influencing reflection cracking.

Potholes. Potholes are formed due to a localized loss of support for the surface course though either a failure in the subgrade or base/subbase layers. Potholes are often associated with frost heave, which pushes the pavement up due to ice lenses forming in the subgrade during the freeze. During the thaw, voids (often filled with water) are created in the soil beneath the pavement surface due to the melting ice and/or gaps beneath the surface pavement resulting from heave. When vehicles drive over this gap, high hydraulic pressure is created in the void, which further weakens the surrounding soil. The road surface cracks and falls into the void, leading to the birth of another pothole. Potholes can also occur as a result of pumping problems.

Punchouts. Punchouts are identified as a broken area of a CRCP bounded by closely spaced cracks usually spaced less than 1 m (3 ft).

Pumping. Pumping is the ejection of foundation material, either wet or dry, through joints or cracks, or along edges of rigid slabs, resulting from vertical movements of the slab under traffic, or from cracks in semi-rigid pavements.

Faulting. Faulting appears as an elevation or depression of a PCC slab in relation to an adjoining slab, usually at transverse joints and cracks.

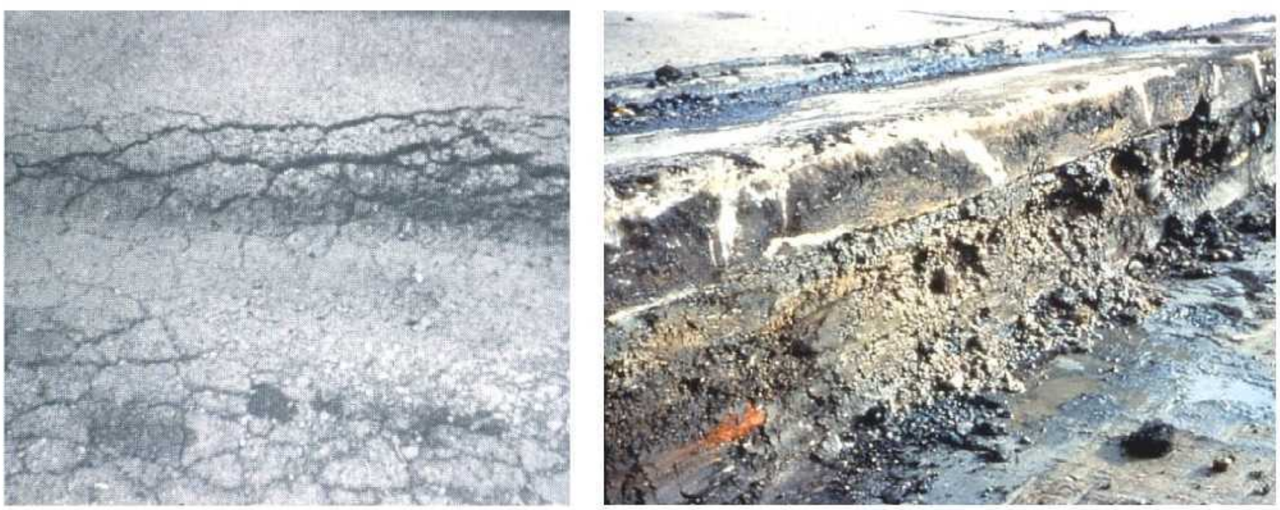
Roughness. Surface roughness is due in large measure to nonuniform permanent deformations and cracking along the wheel path. Consequently, all of the geotechnical factors influencing permanent deformations and cracking will also impact roughness. Nonuniformity of the stiffness/strength of the geomaterials along the pavement, in particular, can be a major contributor to surface roughness. Nonuniform swelling of subgrade soils along the pavement alignment provides a classic example of extreme pavement roughness in some areas of the country.

Liquefaction. The process of transforming any soil from a solid state to a liquid state, usually as a result of increased pore pressure and reduced shearing resistance (ASTM, 2001) is called liquefaction. Spontaneous liquefaction may be caused by a collapse of the structure by shock or other type of strain, and is associated with a sudden, but temporary, increase of the prefluid pressure.

Thermal Cracking. Thermal cracks appear in an asphalt pavement surface, usually full width transverse, as a result of seasonal or diurnal volume changes of the pavement restrained by friction with an underlying layer.

By now it should be apparent that there are a number of ways that a pavement may become impaired to the extent that it is no longer serviceable. In designing a pavement section, the pavement is anticipated to deform over its service life so that at a period in time it will need to be repaired or replaced. Normal failure is defined by rutting of the pavement section, as shown in Figure 1-6, and usually consists of no more than 20 – 25 mm (¾ – 1 in.) within the anticipated performance period. However, as previously reviewed in this section, there are a number of factors that may result in premature failure, long before the performance period, most of which are related to geotechnical issues. Specifically, geotechnical failures, as shown in Figure 1-7, are generally related to excessive subgrade rutting, aggregate contamination or degeneration, subgrade pumping, poor drainage, frost action, and swelling soils. There are other ancillary geotechnical issues, which will impact pavement performance, but are usually addressed in roadway design (*i.e.,* not by the pavement group). These include differential embankment settlement, embankment and cut slope stability, liquefaction, collapsing soils, and karstic (sinkhole) formations. Design methods to evaluate these specific issues, along with procedures to mitigate potential problems, can be found in reference manuals for NHI 132012 Soils and Foundations Workshop (FHWA NHI-00-045 (Cheney & Chassie, 2000)) and NHI 132034 on Ground Improvement Methods (FHWA NHI-04-001 (Elias et al., 2004)).

Figure 1-6. Normal rutting.



a) Excessive rutting

b) Aggregate contamination or degeneration

Figure 1-7. Examples of geotechnical related pavement failures.

c) Subgrade pumping

d) Drainage problems

e) Frost action

f) Swelling soils

g) Differential settlement

h) Collapsing soils, karst conditions, or liquefaction

Figure 1-7. Examples of geotechnical related pavement failures (continued).

1.5 CASE HISTORIES OF PAVEMENT GEOTECHNICS (Failure Examples)

Geotechnical failures are often the result of not recognizing or adequately evaluating conditions prior to construction of the road. The following section provides several case histories of pavement failures that occurred due to inadequate geotechnical information.

1.5.1 Drainage Failure

The existing pavement along a 3 km (2 mile) portion of U.S. Route 1A in a northern state had been plagued by cracking, rutting, and potholes. The highway is a major transport route for tanker trucks that transport oil from the port to a major city. This particular roadway section required frequent maintenance to maintain a trafficable pavement surface, and recently had received a 100-mm (4-in.) overlay. However, within two years of construction, the overlay was badly cracked and rutted, again needing repair. These conditions prompted the reconstruction project. A subsurface investigation encountered moist clay soils (locally known as the Presumpscot Formation) along the entire length of the project. These soils are plastic and moisture sensitive, with water contents greater than 20%. Borings indicated up to 300 mm (12 in.) of asphalt in some sections, and an extensively contaminated base. During the investigation, water was observed seeping out of pavement sections, even though this had been the second driest summer on record in the state. Water in the pavement section was obviously one of the existing pavement section failure mechanisms. Based on soil conditions and past roadway construction experiences, designers initially recommended that the subgrade soils be undercut by 150 mm (6 in.) – with a greater depth of undercut anticipated in some areas – and replaced with granular soil to create a stable working surface prior to placing the overlying subbase course. However, this approach would not solve the drainage problem. Roadway drainage was not conventionally used in this state due to concerns that outlet freezing would prevent effectiveness.

In order to evaluate the most effective repair methods, test sections were established along the alignment consisting of alternate stabilization methods and drainage sections. The test sections were fully instrumented. Monitoring included FWD testing performed prior to reconstruction, after construction and periodically (*e.g.,* before and after the spring thaw) since the project was completed in 1997. An indication of the poor subgrade condition on this project was encountered during construction, when a control section (no stabilization lift) failed and required a 600 mm (24 in.) undercut and gravel replacement to allow construction over the section. A 820 mm (32 in.) pavement section was then constructed over the undercut.

The roadway is performing well in all sections, and at this time (five years after construction) it is too early to determine which stabilization method proved most effective. Minimal frost heave has been observed thus far in all of the test sections, and it may take several additional seasons to provide discernible results. In the drainage section, water flows from the drains and corresponds strongly with precipitation events and water table levels. One surprising result occurs in the spring of each year. More water flows from the drains during the month of spring thaw than all of the other months combined. Over the long-term it is anticipated that this drainage will prove very beneficial to the performance of the pavement system.

1.5.2 Collapsible Soils

Sections of Interstate 15 within a 27 km (17-mi) length of roadway in a western state have been experiencing considerable distress since construction. Maintenance costs have been significant, and it appears that distress may not simply be due to an inadequate pavement section. The problems associated with bumps, cracks, and edge failures were likely associated with troubles in the subgrade soils along the alignment. Potential causes could have included collapsible soil, expansive soil, compressible soil, poorly compacted fill, and poor drainage. A study was performed with the objectives of determining the causes for the problems and developing potential solutions prior to design and reconstruction of the area in question. Based on surficial geology and borehole data, zones were identified where collapsible soils were likely the culprit. Because the zone of collapsible soil extends to depths of up to 6 m (20 ft) below the ground surface, deep dynamic compaction was recommended over excavation and replacement as a treatment method in these zones. Distress related to expansive soils exists throughout the study area, but significant damage concentrations are located in a cut section between mileposts 208 and 207 along I-15. This area is long enough to propose treatments for the area, in order to improve ride quality throughout the cut section. This study recommends a combination of methods to improve the odds of success. Because of the potential for differential settlement on the roadway, asphalt pavement should be used in reconstructing the roadway in the study area. A lack of adequate surface drainage is another critical factor leading to problems with both collapsible and expansive subgrade soils in this area. Deep dynamic compaction was found not to be feasible during construction, most likely due to an intervening fine-grained layer in the deposit.

1.6 CONCLUDING REMARKS

All pavement systems are constructed on earth and practically all components are constructed with earth materials. When these materials are bound with asphalt or cement to form surface layers, they take on a manufactured structural component that is relatively well understood by pavement designers. However, in their unbound state, the properties of these "geotechnical" materials are extremely variable and are the results of the natural processes that have formed them, and natural or man-made events following their formation. Often the earth provides inferior foundation materials in their natural state, but replacement is often impractical and uneconomical. As a result, the design engineer is often faced with the challenge of using the foundation and construction materials available on or near the project site. Therefore, designing and building pavement systems requires a thorough understanding of the properties of available soils and rocks that will constitute the foundation and other components of the pavement system.

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