Design of Pavements in High Groundwater Areas

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There are three basic pavement structures typically used to support ranges of traffic loading from high to low volume. These structures include rigid, flexible, and composite pavement sections. All pavement sections can be affected by groundwater and to accomplish a responsive performance design, the effects must be known and considered.

Description of Pavement Section Types

Rigid pavements generally consist of portland cement concrete (PCC) used as a surfacing and structural layer, supported by a compacted granular subbase. This type of pavement can be used for low to high traffic volume applications and its forms range from jointed, unreinforced sections to continuously reinforced sections, depending upon the application and the desires of the design engineer or end user.

Flexible pavements usually consist of asphaltic concrete surface and structural layers supported by succeedingly "weaker" layers of granular bases, subbases, and subgrade layers. These pavement sections can also be used for low to high traffic volume applications and represent the majority of pavement applications in use today.

Composite pavements consist of some variation on the rigid or flexible pavement sections, most often using the advantages of a semi-rigid base structure such as soil-cement or cement stabilization with a flexible surface course. There are other combinations of composite pavements that take the opposite approach by using rigid materials placed over supporting layers typically used for flexible pavement applications. These pavement sections are typically used for low volume or specialized loading conditions such as those encountered in industrial applications.

Effects of Groundwater on Existing Pavements

Pavements are often designed with the history of existing pavements in the area as the primary predictor of performance and the model for the selection of pavement sections and properties. This can lead to extremes in design, whereby overly conservative approaches are used which make costs excessive, or the design can be non-conservative when perceived traffic patterns change in an area, thus overloading the pavement section which may have performed adequately in prior years under a lower traffic or load frequency.

One element of historical design input that can be used effectively is the *presence of groundwater* influence on existing pavement sections in the area. Since laboratory and field tests often fall short of their in-place modeling capability, observations of pavement section performance under similar conditions can be of tremendous benefit to the design engineer in selecting a new pavement section.

Design engineers should use caution in depending on the performance observations of pavements in the *absence of groundwater*. Localized development can significantly influence groundwater levels and flow, thus currently drained pavements can become inundated in the future. It is therefore more important to note the effect of future groundwater influence if there is currently no groundwater problem, as problems could develop in the future relative to the pavement structure.

Observations of existing performance problems related to groundwater influence are usually more pronounced in flexible pavements than in rigid pavements. As an example, base failures resulting in potholes often show sooner in a flexible pavement or composite pavement than under-slab stability problems in rigid pavements. Conversely, joint problems related to "pumping" in rigid pavements may show at any time after traffic is allowed on the section, even immediately after construction. Some typical observations that show groundwater problem influence are:

- White, grey, or tan residue around cracks in asphaltic concrete surface courses

- Dark staining or the presence of materials in or around the joints in portland cement concrete pavements

- Early longitudinal wheel path or alligator cracking in flexible pavement systems indicating a loss of subgrade stability

- Standing or slowly draining water along shoulders or in side drainage swales

Paying attention to these indicators of groundwater problems in existing pavements can help in the selection of materials, sections, and drainage features for the new pavement section.

Effects of Groundwater on Materials Properties

When designing pavement sections, the design engineer has several options of design methodology to use, regardless of the pavement type. With any of the methodologies, there are input parameters that, once selected, will stay relatively constant throughout the design process such as the expected design life, anticipated traffic loading, and the drainage features. Using these parameters, selections are made for pavement type, materials for the various layers, and layer thicknesses. Each pavement section structural analysis methodology utilizes a combination of material properties relative to layer thicknesses to achieve the required structural capacity.

Using the empirical design approach developed from the original AASHO Road Test and subsequently modified by AASHTO procedures given in the "AASHTO Guide For Design of Pavement Structures, 1986", Volume I, modified layer coefficients are integrated into the flexible pavement design equation in the following manner:

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

where: SN = Structural Number
a_i = AASHTO layer coefficient
D_i = Layer thickness
m_i = modification value from Table 1

Table 1 - Recommended m_i Values for Modifying Structural Layer Coefficients of Untreated Base and Sub-base Materials in Flexible Pavements (AASHTO Guide For Design of Pavement Structures, 1986)

Quality of Drainage	Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation			
	Less Than 1%	1% - 5%	5% - 25%	Greater Than 25%
Excellent	1.40-1.35	1.35-1.30	1.30-1.20	1.20
Good	1.35-1.25	1.25-1.15	1.15-1.00	1.00
Fair	1.25-1.15	1.15-1.05	1.00-0.80	0.80
Poor	1.15-1.05	1.05-0.80	0.80-0.60	0.60
Very Poor	1.05-0.95	0.95-0.75	0.75-0.40	0.40

For rigid pavements, a drainage coefficient, C_d is applied to the AASHTO performance equation. These values are shown in Table 2.

Table 2 - Recommended Values for Drainage Coefficient, C_d, for Rigid Pavements (AASHTO Guide For Design of Pavement Structures, 1986)

Quality of Drainage	Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation			
	Less Than 1%	1% - 5%	5% - 25%	Greater Than 25%
Excellent	1.25-1.20	1.20-1.15	1.15-1.10	1.10
Good	1.20-1.15	1.15-1.10	1.10-1.00	1.00
Fair	1.15-1.10	1.10-1.00	1.00-0.90	0.90
Poor	1.10-1.00	1.00-0.90	0.90-0.80	0.80
Very Poor	1.00-0.90	0.90-0.80	0.80-0.70	0.70

It should be noted that the drainage conditions for the AASHO Road Test were considered to be fair, thus the tabular values reflect positive influence for drainage conditions considered to be better than those in the AASHO Road Test and negative influence for those conditions considered worse. The m-value and C_d for the AASHO Road Test are 1.0 for each pavement type, regardless of the section materials.

When using elastic layer techniques for computing pavement stresses, there are relationships that exist for resilient modulus, M_R and AASHTO layer coefficients. With this is mind, the layer coefficient modifications and drainage coefficients may be similarly applied to modulus values used in the analysis. Also, the Poisson's ratio values used in elastic layer analyses can be adjusted for the moisture condition of granular materials. This adjustment, however, will typically have little effect on the overall results of the stress or strain computations in the analysis. If actual drained and undrained modulus values are known for the materials, these values should be used for the analysis instead of applying a modification factor.

The stability of pavement materials varies greatly with drainage conditions. While compaction and stability are closely related, they are not the same properties and should be considered separately. As an example, the typical accepted stability values such as the California Bearing Ratio (CBR), the Limerock Bearing Ratio (LBR), or the "Bearing Ratio of Laboratory Compacted Soils" as given in ASTM D1883 are defined at maximum compaction. Correspondingly, if less than maximum compaction is specified, such as "compact to 98 percent of the maximum dry density", then less than the desired stability will likely result in the field. This problem can be overcome by specifying both the compaction and the stability at that level of compaction. As an example, if a CBR of 100 is desired for a base material, it should be specified to achieve a CBR value of 100 at the desired compaction, preferably at least 98 percent of the maximum dry density as determined by the Modified Proctor moisture-density relationship (ASTM D1557 or AASHTO T-180).

As can be seen from the curve in Figure 1, the stability value is not symmetric about the maximum compaction value. As the dry unit weight of a soil material increases, its dependency on moisture also increases. Typically, materials are more stable if dry of the optimum moisture content and less stable on the wet side of optimum. Further, the slope of the curve is usually much steeper on the wet side of optimum, thus allowing for little room for compaction errors in the field. For this reason, better performance will be obtained from a pavement material if it is compacted to 100 percent of its maximum dry density as determined in the laboratory.

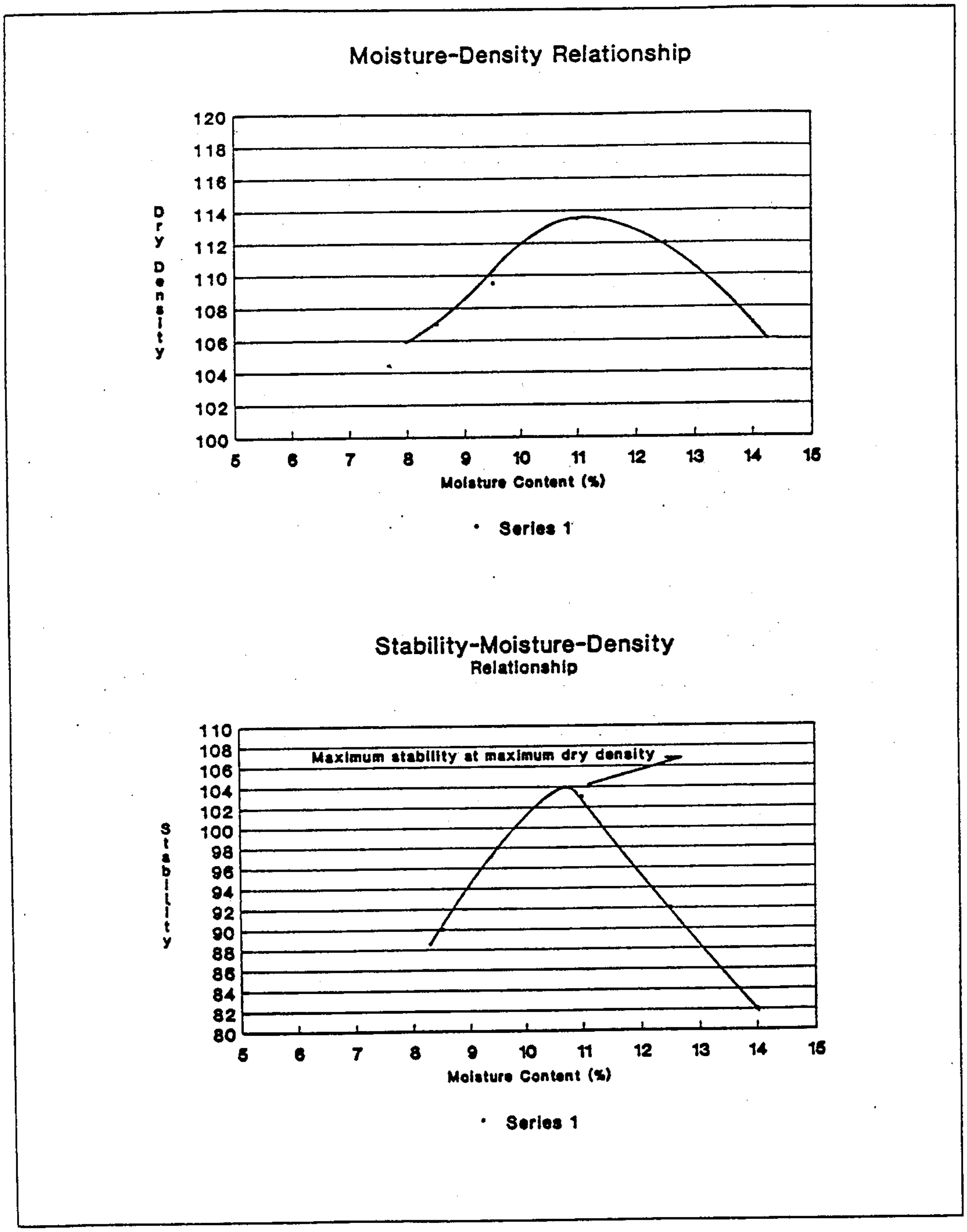
Many contractors and some engineers believe that materials such as graded limerock or other graded aggregate base materials will disintegrate in the presence of groundwater. Most laboratory stability tests are performed while the soil is saturated or nearly saturated. To a large degree, this negates the argument; however, it must be understood that field compaction has a much greater influence on the ultimate stability of the materials than groundwater that might infiltrate or come in contact with the base material.

Compensating for High Groundwater Conditions

Soil-cement or cement stabilization is often used as a base material in areas of high groundwater. The mistaken assumption is that soil-cement will not be affected by the groundwater and that most, if not all, groundwater problems will be solved by using soil-cement in lieu of a graded aggregate base. While soil-cement is a viable base material and can be used successfully in many applications, it has its own series of problems to consider and high groundwater is one of them.

Groundwater affects soil-cement in two major ways; pumping of fines through the inherent shrinkage cracks, and a loss of durability through wet-dry cycling. The problem with pumping is exacerbated by poor load transfer capability across the cracks. While it is assumed that a soil-cement base requires no stabilization of the subgrade, the pumping problem is made worse when stabilization is not used. Stabilization can also help with wet-dry cycling since stabilized materials often have a reduced permeability when compared to unstabilized sands, thereby impeding upward groundwater flow. Conversely, stabilized materials, because of the reduced permeability, tend to retain water for longer periods of time and allow a higher capillary fringe above the water table. This may allow slower drainage of the pavement; however, since the materials are stronger, the pavement can better withstand the additional moisture.

Figure 1



A good soil-cement base material should be designed to provide an in-place compressive strength of at least 300 psi at 7 days. This is an amount adequate to withstand fatigue cycling in properly designed thicknesses and to provide the necessary durability or resistance to wet-dry cycling. While most specifications for soil-cement in the past have addressed compaction of the material using the Standard Proctor moisture-density relationship, for sandy soils the Modified Proctor relationship should be used for compaction comparison. After all, soil-cement is just a soil material until hydration of the cement occurs. Until that time, the material should be worked as soil and densified to its best capability. Since soil-cement durability and strength are affected by the hydration of the cement, care should be taken to mix, place, compact, and plane the material under tight time constraints related to the hydration of the cement. While some autogenous "healing" of fine cracking caused by late compaction can occur, this phenomenon should not be assumed to compensate for poor field control.

Graded aggregate base materials can be successfully used in high groundwater areas, provided stability tests are done under the same or similar moisture conditions expected in the field. Materials should be compacted to 100 percent of the maximum dry density determined in the laboratory by the Modified Proctor method. In order to achieve proper compaction in the base, it is usually necessary to stabilize the subgrade. This procedure is needed for constructability and also enhances the structural pavement section. As previously noted, the compaction requirements relative to stability need to be clearly outlined.

In addition to the structural pavement sections, the design engineer may also consider the use of geotextiles to provide layer stability and to prevent the intrusion or exfiltration of materials as required by the material parameters. Woven or non-woven fabrics may be used, depending upon the application, and often increase the shear resistance of the soil layer.

Although materials and design procedures can be used to compensate for high groundwater conditions, the most desirable method of dealing with high groundwater is to provide at least some level of drainage to the pavement section and its subgrade materials. At the least, swales intercepting the groundwater adjacent to the shoulders should be used to lower the groundwater profile immediately beneath the pavement. A further step to lower the groundwater would be to install subsurface drains beneath the swales if a positive outfall can be provided to intercept and assist in draining the groundwater.