ALTERNATIVE SUBGRADE DESIGN FOR PAVEMENTS IN EXPANSIVE SOILS

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Abstract

Standard pavement design for light to moderate traffic consists principally of a concrete or asphalt section over a subgrade that is chemically stabilized to six to eight inches. Although this section has been effective for most conditions, highly expansive soils can result in excessive differential movement.

Expansive clays are also difficult to properly place and compact within utility excavations. Placement at or below optimum moisture can result in excessive heave or settlement of the ditch line, increasing the differential movement of the pavement. At present, specifications frequently identify required density, but do not specify the means and methods for achieving the compaction.

Incorporation of utility construction into the pavement subgrade treatment can result in less potential for heave or settlement by specifying the required excavation limits and general means and methods.

Two case studies are presented to illustrate the concept. One deals with gross settlement associated with collapse of the backfill. The second illustrates differential movement associated with post-construction heave.

Introduction

Little if any changes in the philosophy of designing light- to moderate-duty pavement in expansive soils has changed in the last 50 years. Typical sections consist of an asphalt or concrete surface over either a six- to eight-inch thick chemically-stabilized subgrade or a flexible base. This design has served relatively well where the potential for differential movement is moderate and where the movement is associated with seasonal moisture changes. It does not however address conditions where the potential for heave is severe.

Texas has extremely variable geologic and climatic conditions. Some of the more expansive soil profiles in the world extend north-south through the central part of the state, to include the municipalities of Dallas/Fort Worth, Austin and San Antonio. This portion of the state also tracks along the 0 (Dallas/Fort Worth) to -15 (San Antonio) Thornthwaite Index line. This climatic index indicates that wide swings in yearly rainfall and soil moisture will occur and that the addition of even a moderate amount of irrigation can result in a gradual increase in soil moisture. Increasing soil moisture within an otherwise dry subgrade can result in heave.

Expansive CH clay is also difficult to compact properly, and particularly within confined spaces typical of utility trench excavations. Compaction of CH clay below optimum moisture to high density can result in heave upon wetting. Alternatively, because clays frequently excavate as clods, low compaction effort (generally excessive lift thickness), coupled with inadequate moisture, can result in a meta-stable condition which collapses upon wetting.

Examples are presented to illustrate the above conditions. Alternative design recommendations are provided following the case studies.

Case Studies

Case Study 1, Collapse of Backfill – Excavated clay can be difficult and time consuming to place and compact to controlled moisture and density conditions, especially in the confined space of a utility excavation.

It has been well documented that moderately to highly plastic clay compacted to 95 percent of ASTM D 698 density at a moisture content below optimum will expand upon wetting. The magnitude of expansion is directly related to the degree of compaction, i.e., the greater the compaction, the greater the observed swell. This mode of movement causes heave of the pavement immediately above the utility. Because of the confinement of most trench excavations and the difficulty of over-compacting clay in limited space, this mode of failure is rarely observed.

Excavation of relatively dry expansive clay or clayey soils frequently results in development of small to large clods, dependent upon the prevailing weather. The strength of the clods is related to the natural cohesion in the soil, but to a greater extent is dependent on the negative pore pressure or suction. The higher the suction, the higher the apparent strength. This higher strength should be considered to be transient, since the apparent strength will be reduced as suction is reduced.

Placement of dry clay clods into a utility trench results in point-to-point contact between the clods, with stability of the backfill dependent upon the transient strength of the clay clods, which is in turn dependent upon maintaining the negative pore pressure or suction within the clay. Post-construction moisture infiltration into the clay clods results in loss of strength, and subsequent collapse of the backfill into voids between the clods.

The magnitude of collapse varies dramatically, dependent upon the specific compactive effort exerted by the contractor during backfilling operations and the moisture (or more specifically, the suction) in the clay at the time of placement. The greater the compactive effort and/or the higher the moisture (lower suction), the more the point-to-point contacts will be crushed during placement, resulting in less voids within the backfill. The compactive effort can be changed by either increasing the actual load (using a different piece of equipment) or decreasing the lift thickness.

Examples of settlement of utility trench backfill which is attributed to collapse are shown in Photographs 1 and 2. It should be noted that this type of settlement is sometimes attributed to loss of the clay into the pipe bedding. Although this may occur in some very specific conditions, it is not likely to occur within well compacted clay. The permeability of even moderately plastic sandy clay is too low to allow sufficient seepage pressure at the backfill/bedding interface to result in migration of the clay fines into the gravel.

Photograph 1. Collapse of utility ditch backfill.

Photograph 2. Gross settlement of utility backfill around a sanitary sewer manhole.

Gross settlement of utility excavations below pavement of the type illustrated in Photograph 2 requires significant effort to correct the condition. Typically, the pavement has to be demolished, the utility trench excavated to the top of pipe and the soils backfilled to grade under controlled conditions. Because the existing backfill is generally saturated, replacement with imported material is frequently required. Costs associated with the effort can exceed original construction.

Case Study 2, Heave – Pavements constructed over expansive soils can be subject to differential movement associated with heave. The magnitude of heave is dependent upon the specific geologic setting. Some of the factors that influence the potential for differential movement include the activity of the geologic profile, pre- and post-site topography, prevailing climatic conditions at the time of construction and the presence (or absence) of vegetation.

Two municipalities within north Texas, Frisco and Midlothian, address the potential for differential movement of pavement subgrade associated with heave. These two municipalities have incorporated design procedures in their city standards to specifically reduce the potential for movement prior to construction of the pavement surface. Several other municipalities address the potential for lime- or sulfate-induced heave in their pavement guidelines, but do not address reduction of the potential for post-construction heave associated with expansive soils.

Pavement placed over dry, expansive subgrade will experience movement. Because heave is generally associated with a source of water, heave occurs differentially. The differential movement is frequently observed in the pavement structure as "edge" lift similar to slab-on-ground foundations placed over a dry subgrade. Where backfill within utility excavations is compacted "correctly", the magnitude of heave can be reduced over the utility. This condition can decrease the span over which the differential movement occurs, exacerbating the distress.

It can be difficult to ascertain whether the observed pavement distress is associated with differential heave or differential settlement of the utility backfill. There are, however, several key differences. Settlement of utility backfill of the nature discussed in Case Study 1 is associated with a significant loss of soil strength within the utility ditch backfill. Differential heave, on the other hand, is generally associated with a significant change in the suction pressure between the area of heave and the lower, drier areas. Detailed topographic surveys can also be performed to evaluate the elevation of the pavement relative to deeper, more stable utilities such as storm and sewer manholes.

Examples of differential pavement movement associated with heave are shown in Photographs 3 and 4.

Photograph 3. Differential heave along Northgate Boulevard, Irving, Texas. Pavement is approximately 25 years old.

Photograph 4. Differential heave of subdivision pavement in Carrollton, Texas. Pavement was approximately 2 years old.

Photographs 3 and 4 illustrate differential heave of older pavements. This type of movement in the past has been generally accepted by the municipalities; however, with the advent of home owner associations and more budget-strapped municipal governments, there appears to be an increase in litigation associated with this type of distress where it occurs during the first one to two years of completion of the project.

Chemical stabilization of the upper six to eight inches of subgrade will not reduce the potential for differential movement. Significantly more effort will be necessary to address this condition.

Multiple alternatives are employed by engineers to address the potential for differential movement below structures. Methods generally include replacement of a portion of the expansive profile with non-expansive soils, or some type of preswelling (either mechanical or injection) to reduce the potential for heave prior to placement of the structure. Further discussion of various options is presented in the following section.

Alternative Subgrade Design Thoughts

A typical pavement and infrastructure civil design consists of a set of plans specifying the location and grade of the pavement and associated utilities. Subgrade treatment below the pavement generally consists of chemical stabilization of on-site soils to a depth of six to eight inches to reduce the potential for the subgrade to “pump”.

Compaction criteria for backfill below the roadway or within utility excavations is frequently based on individual municipal standards or within North Texas, the “Standard Specifications for Public Works Construction” developed by the North Central Texas Council of Governments (NCTCOG). Specifications generally require a minimum of 95% of Standard Proctor (ASTM D 698) density. The moisture at which the soil is compacted may or may not be specified, but when it is, it is frequently identified as -2 to +3 percentage points of optimum.

The specific “means and methods” of utility construction are generally not specified. This presumably allows for the most cost-effective method for placement of the utility and backfill. However, this can result in very deep and narrow trenches. A trench box is utilized as protection for the workers; however, use of a trench box complicates placement and compaction of the backfill.

Although quality compaction can be accomplished by use of narrow trenches and trench boxes if the contractor limits the lift thickness to approximately six inches, economics frequently dictate fast track construction. Because of the meta-stable condition of highly plastic clay when placed below optimum moisture, the realization of collapse as illustrated in Photographs 1 and 2 can be after the contractor has exited the project.

Testing of the backfill is also difficult to perform within narrow trenches and within the confines of a trench box. If a nuclear density gage is used, it must be calibrated within the confines of the ditch. Municipalities also typically retain the testing company, who periodically tests the backfill. Test intervals of 200 to 300 feet horizontally and 2 feet vertically are common. This testing pattern results in a significant volume of backfill that is untested. Where collapse of the backfill has been observed, lift thicknesses of two feet or more have been documented.

It is also extremely expensive, relative to initial construction, to correct the condition illustrated in Photograph 2. Correction of the condition requires demolition of the pavement and excavation and compaction of the original ditch. In addition, the existing fill is frequently saturated, requiring use of imported material as backfill.

Use of narrow trench-type construction also does nothing to address the potential for subgrade treatment where the potential for movement is “excessive”. The precise amount of movement that would be considered as “excessive” is undefined; however, post-construction movement in specific geologic formations can exceed 10 inches.

Excessive differential movement of the pavement degrades the life and use of the pavement. In addition, “bird-baths” develop that are generally unacceptable to the end user and or city staff.

Excavation and recompaction of a portion of the upper soils at elevated moisture to reduce the potential for differential soil movement below the pavement could be integrated into construction of utilities. Although this would significantly increase the initial cost of the infrastructure improvements, it should result in lowering the overall cost of maintenance and/or replacement.

An idealized cross-section of this concept is presented in Figure 1. Some method of limiting post-construction shrinkage along the curb line may have to be integrated into the design where significant vegetation abuts the pavement. The magnitude or depth of required reworked material would be dependent upon the desired reduction in potential for heave.

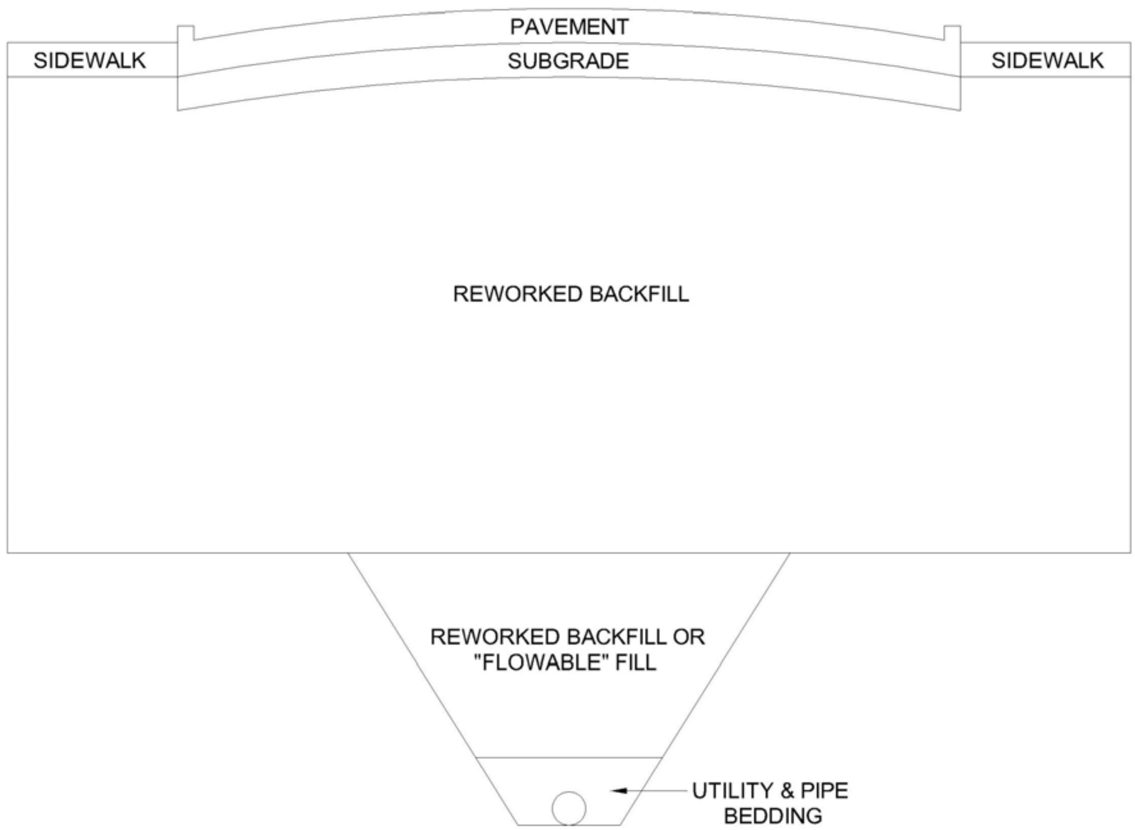

FIGURE 1. IDEALIZED PAVEMENT SUBGRADE TREATMENT

Implementation of the concept illustrated in Figure 1 would be limited to geologic areas where the potential for post-construction movement is considered “excessive”.

As discussed above, gross settlement of utility backfill is frequently associated with excessive lift thickness and lack of compaction effort, principally because of limited work space. By defining larger construction space, each contractor would be pricing on more equal basis. “Opening up” the utility construction would also benefit the overall inspection and testing of the constructed fill.

Conclusions

Present infrastructure design and construction does not address the potential for post-construction movement associated with differential heave of the subgrade. Civil designs also do not address any means and methods of construction, which all too frequently results in excessive settlement of utility backfill and pavement failure.

Modification of the design thought process to integrate construction of utilities and required backfilling with reduction in the potential for post-construction heave should be considered, especially where the potential for post-construction movement is excessive.