Evaluation of roadbed potential damage induced by swelling/shrinkage of the subgrade

Effet du retrait-gonflement des sols sur les structures de chaussées

Simic D.

Head of Geotechnical department. Ferrovial-Agromán

ABSTRACT: The expansive soils in arid and semi-arid regions are subject to seasonal moisture variations that trigger changes in volume. These movements are reflected in swellings along the wet months and shrinkages along the dry months; seasonal movements that induce significant damages in the pavements. Traditionally, the construction of pavements on expansive clays has resulted in roads with a poor comfort level for the customers and a great maintenance cost for the administration. Such facts make very problematic the construction of road pavements in expansive soils. This paper analyzes the behavior of the pavement subject to deformations due to swelling and shrinkage of the subgrade, in order to evaluate some of the published design methods for the protection of the pavement against the swelling phenomena of underlying clays. To introduce the design methods, this paper will describe first the usual pathologies due to swelling and shrinkage, and their explanation by means of the analysis of some instrumented sections in existing roads. The different design methods will be summarized, showing also some limitations of the assumptions adopted in each analysis method.

RÉSUMÉ : Les sols gonflants situés dans des régions au climat aride sont soumis à des variations en teneur d’eau accompagnées de changements volumétriques : des gonflements en période humide et rétraction en période sec. Ces déformations se propagent au niveau de la chaussée donnent lieu à d’importants coûts de maintenance. Ces coûts rendent problématique la construction si ces problèmes ne sont pas correctement cernés et gérés. Dans cet article, le comportement de la chaussée soumise aux déformations de gonflement est décrit et les pathologies et méthodes d’analyse existantes dans la littérature sont évaluées. Des exemples sont montrés ainsi que les limitations des hypothèses retenues dans les procédés analysés.

KEYWORDS: expansive soils, roads, semi-arid regions.

MOTS-CLÉS: sols expansifs, routes, régions semi-arides.

1 INTRODUCTION.

Expansive soil is a term usually applied to any soil that has a potential for shrinking or swelling due to changes in its moisture content. It is recognized that there are two main factors that provides the potential of the soil to swell and/or shrink: the properties of the soil and the environmental conditions of the area. The main soil parameters that are included within the first factor are the clay mineralogy, the soil water chemistry, the soil suction, the structure of the soil (fabric) and its dry density. Within the environmental conditions of the area the initial moisture condition, the moisture variations and the stress conditions are the factors believed to control the soil movement.

2 MECHANISM OF SWELLING/SHRINKING

The mechanism of the development of longitudinal cracks at the pavement in arid environments has been described by Zornberg, J. G.; Gupta, R. and Ferreira, J. A. Z. (2010). Tensile stresses induced by flexion of the pavement during settlements caused by the dry season leads to the development of longitudinal cracks. See Figures 1 and 2 below.

During the dry season there is a drop off in moisture content of the soil in the shoulders of the pavement structure. The consequence of this reduction in moisture is a settlement in the shoulders that does not take place in the centre of the pavement where the moisture of the soil remains stable thorough the year. The appearance of cracks in the shoulder of the pavement accelerates the evaporation of the interstitial water of the soil reaching also greater depths.

1357
Suction values at depth for the application of equation 1 have normally a minimum suction value of \( U = 2.0 \) pF and a maximum suction value of \( U = 4.5 \) pF as measured in semi-arid zones. The suction values at the surface do not have limits and depend solely on the climatic region.

### 4 POTENTIAL VERTICAL RISE (PVR)

Texas method (TEX-124-E), is widely used in Texas to determine the required depth of replacement of expansive soils with inert soils, based on the expansion characteristics of the soils. This standard determines the Potential Vertical Rise (PVR) in soil strata, which is described as the “latent or potential ability of a soil material to swell, at a given density, moisture, and loading condition, when exposed to capillary or surface water, and thereby increase the elevation of its upper surface, along with anything resting on it”. Figure 3 shows the correlation between the PI of the soil and the volumetric change due to swelling.

![Figure 3. Graph Plasticity Index vs. Percent Volumetric Change.](Image)

However, this method has a series of shortcomings:

1. Soil at all depths has access to water in capillary moisture conditions.
2. Vertical swelling strain is assumed as one-third of the volume change at all depths.
3. Remolded and compacted soils adequately represent soils in the field.
4. PVR of 0.5 inch (or 1 inch) produces unsatisfactory riding quality.
5. Volume change can be predicted by use if the plasticity index alone.

### 5 LABORATORY EVALUATION OF SWELLING

Twelve samples from five boreholes were collected from a project in south Austin. The samples were selected to provide three replicate samples within a lower (<40%), intermediate (40 to 60%) and high (>60%) range of plasticity indices.

#### 5.1 Comparison with the PVR analysis

The following laboratory tests were completed:

- Material passing 75 microns.
- Oedometer tests and free swell.
- Atterberg limits.
- Suction potential by pressure plate method.

The result of the physico-chemical changes achieved through lime treatment of the clay soils had the practical effect of replacing this layer in large portion which is contributing more to the pavement movement, an evident remedial measure to replace this layer in large portion by an inert soil or the same natural clay treated with lime. In doing so, the swell and shrink volume change potential is greatly mitigated.
The Atterberg limits have been plotted in the plasticity chart of Figure 4.

Swell deformations were obtained from the oedometer tests. The results are shown in the following Figure 5.

The suction water characteristic curves from the pressure plate suction tests are represented in Figure 6 below.

In the test, the weight and volume of the soil samples are recorded at the end of each pressure cycle. The volume is measured using the Ottawa sand displacement method. The mass of the sand displaced is measured to calculate the increments in volume of the samples. Three PVC samples blocks with smooth surface are used to calibrate the volume measurement equipment and obtain a relation between the change in mass and volume of the samples. The SWCC and the $\gamma_h$ can then be plotted.
6 CONCLUSIONS. COMPARISON OF THE SWELLING DEFORMATION OF PVR WITH THE SUCTION BASED METHODS

The average suction compression index of the plate load tests and the routine soil parameters were adopted to carry out a comparison between the methods of estimating swelling deformation (See Figure 11). The active moisture depth is the depth below ground level where the shrinkage and swelling movements of the soil are zero. The weather conditions and the properties of the soil are the most important parameters that determine the active moisture depth in a specific location. As it is already known, the PVR method is very dependent of the active moisture depth, which should be adopted based on the local experience. In this example, different depths have been adopted in the calculations.

The suction compression index ($\gamma_h$) can be determined for a given range of suction values. The following equation proposed by Lytton (1977) can be applied.

$$\gamma_h = \frac{\Delta \varepsilon}{1 + \varepsilon_0}$$

Where:

- $\Delta \varepsilon$ = difference of void ratio
- $\varepsilon_0$ = initial void ratio
- $h$ = total suction

The suction compression index ($\gamma_h$) can also be estimated based on routine soil testing as the Atterberg Limits, % passing sieve #200 and % passing 2µm. In 2004, Lytton proposed alternative charts that are implemented in the WinPRES software. The comparison of the $\gamma_h$ calculated in the laboratory and the values estimated from the two authors aforementioned has been carried out for the samples of the test.

The vertical strain or movement, can be calculated from the following:

Finally the summation of vertical movement can be calculated from the following equation:

$$\Delta H = \sum \int_{\text{layer}} \left( \frac{\Delta V}{V} \right) \Delta \varepsilon \cdot H$$

$$\Delta H = f \left( \frac{\Delta V}{V} \right)$$

7 REFERENCES


Little, D. 2012. “Background for predicting roughness and/or serviceability loss due to expansive soils”, Internal Memorandum.


Texas Department of Transportation 2011. “Pavement Design Guide”.

Figure 9. Example of soil water characteristic curve from the SH-130 samples

Figure 10. Comparison of $\gamma_h$ as calculated from pressure plate tests vs. estimated from routine tests.

Figure 11. Comparison of vertical movements calculated with different methods.