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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 propageant 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, regions 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.

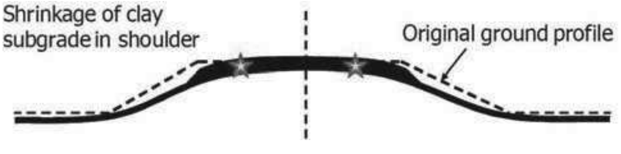

Figure 1. Mechanism of longitudinal crack development on pavement over expansive clays during dry season. (Modified from Zornberg, Gupta & Ferreira, 2010).

Figure 2. Longitudinal cracks near the edge of pavement

Topographical surveys along the longitudinal cracks show that there is a tendency of the soil to settle when the cracks develop, confirming the model explained above.

3 EVALUATION OF THE SWELLING DEFORMATION

The great volumetric expansion and contraction potential of these soils can be explained empirically through a direct correlation to plasticity index (from Texas Department of Transportation method TEX-124-E, "Vertical Rise Potential") or from a theoretical approach (Little 2012). In the latter approach matrix suction is related to volume change. The change from the matric suction that exists under a current or existing moisture regime to a state of drying (where the matric suction increases) or to a state of wetting (where the matric suction decreases) is the trigger of volume change. This volumetric change was determined by Mitchell (1980) as a function of depth, soil type, and climatic conditions using the following relationship:

$$U_z = U_e \pm U_0 \exp\left[-\left(\frac{n\pi}{\alpha}\right)^{0.5} z\right] \qquad [1]$$

Where U_e is equilibrium suction, U_0 is the amplitude of suction variation, n is the number of cycles of wetting and drying within a year, α is diffusion coefficient, and z is depth.

The difference between a current or initial (U_i) and final suction (U_f) as determined from equation [1] can be used to estimate the range of volume changes of the natural soils below the pavement structure. The volumetric strain is calculated using the following relationship (after Hong et al, 2006 and Bulut, 2001):

$$\begin{aligned}\left(\frac{\Delta V}{V}\right)_{swelling} &= -\gamma_h \log_{10}\left(\frac{U_f}{U_i}\right) - \gamma_\sigma \log_{10}\left(\frac{\sigma_f}{\sigma_i}\right)\\ \left(\frac{\Delta V}{V}\right)_{shrinkage} &= -\gamma_h \log_{10}\left(\frac{U_f}{U_i}\right) - \gamma_\sigma \log_{10}\left(\frac{\sigma_f}{\sigma_i}\right)\end{aligned} \qquad [2]$$

Where $\frac{\Delta V}{V}$ is volumetric strain, γ_h is suction compressibility index, and σ_i and σ_f are initial and final overburden stress, respectively. From this relationship it is important to note that, first, volume change, whether shrinkage or swelling is driven by a difference between initial and final matric suction, U. Second, the impact of the driving force for volume change, ΔU, on volume change is determined by the suction compressibility factor, which operates in this constitutive relationship like a modulus in stress-strain constitutive relationships.

The result of the physico-chemical changes achieved through lime treatment of the clay soils had the practical effect of making the most highly susceptible soils to volume change within the active zone practically non-susceptible to volume change. As shown by equation 1, this active zone depth is influenced by climatic variables such as n and soil variables such as diffusivity, α. As one can visualize from equation 1, the upper portion of the active zone provides the greatest driving force, ΔU. Since it is the active, natural clay in this upper zone which is contributing more to the pavement movement, an envident 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.

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

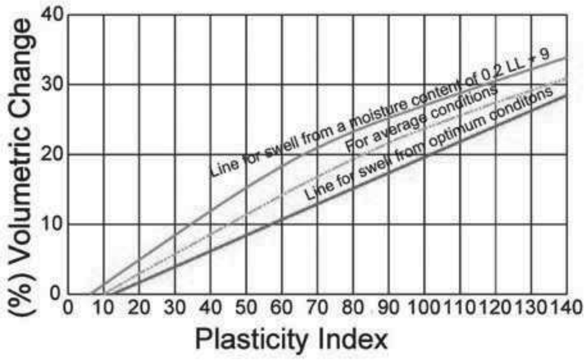

Figure 3. Graph Plasticity Index vs. Percent Volumetric Change. From Tex-124-E

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 Atterberg limits have been plotted in the plasticity chart of Figure 4.

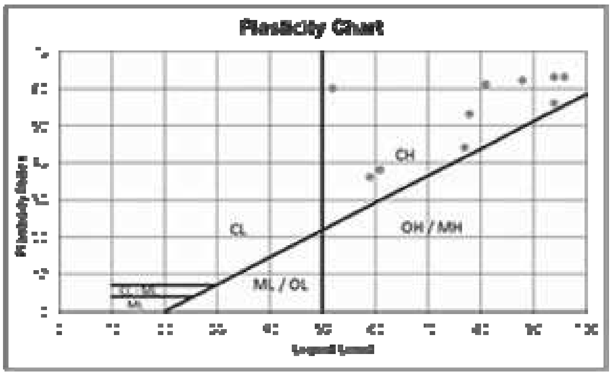

Figure 4. Plasticity chart. SH-130 samples.

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

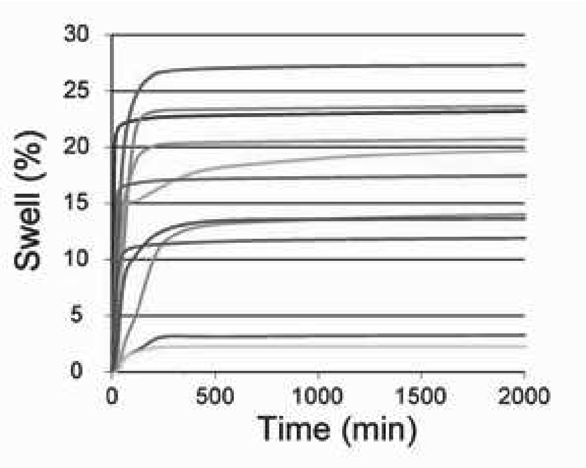

Figure 5. One-dimensional, free swell results.

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

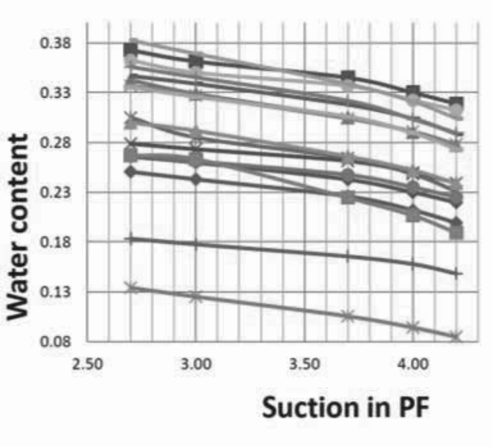

Figure 6. Pressure plate suction vs. water content characteristic curves

The swell deformation values obtained from the oedometers tests have been plotted in the graph of Tex-124-E for comparison purposes. Figure 7 shows that the samples with a moisture content in the very dry side have greater swell deformations than predicted by Tex-124-E standard.

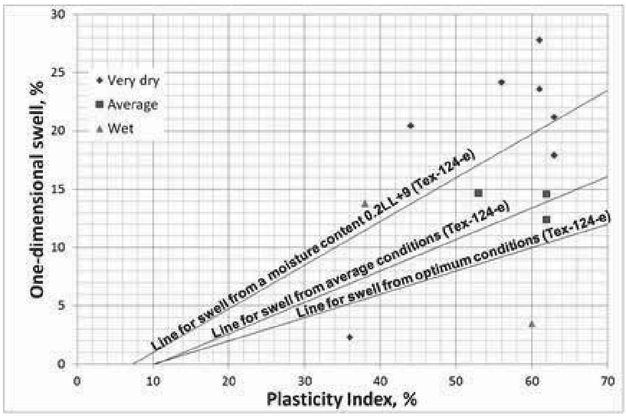

Figure 7. Graph Plasticity Index vs. one dimensional swell

5.2 Suction based method for swell evaluation

There are several approaches to determine the suction compression index (γ_h). The soil water characteristic curve (SWCC) and volume measurements determined in the laboratory, can be used to calculate the γ_h.The Texas A&M University carried out pressure plate tests (see Figure 8) to determine the SWCC of soils sampled in the south Austin area.

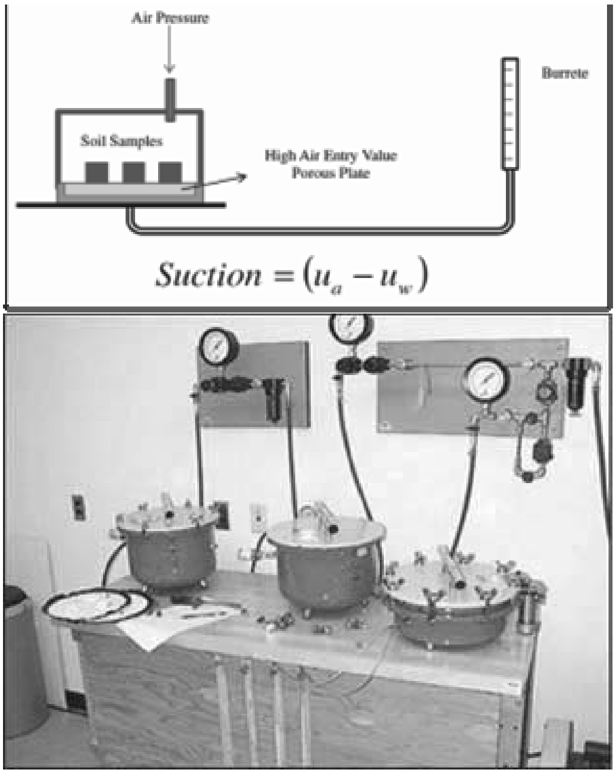

Figure 8. Pressure plate apparatus (from National Research Council Canada website).

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 γ_h can then be plotted.

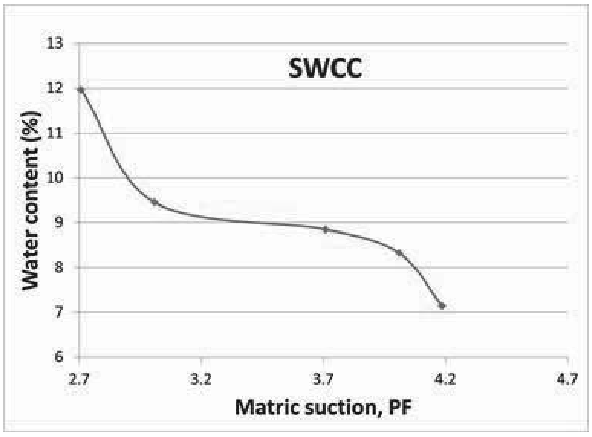

Figure 9. Example of soil water characteristic curve from the SH-130 samples

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The suction compression index (γ_h) can then be determined for agiven range of suction values. The following equation proposed by Lytton (1977) can be applied.

$$\gamma_h = \frac{\left(\frac{\Delta e}{1} + e_0\right)}{\Delta \log(h)}$$

Where:
Δe = difference of void ratio
e_0 = initial void ratio
h = total suction

The suction compression index (γ_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 γ_h calculated in the laboratory and the values estimated from the two authors aforementioned has been carried out for the samples of the test.

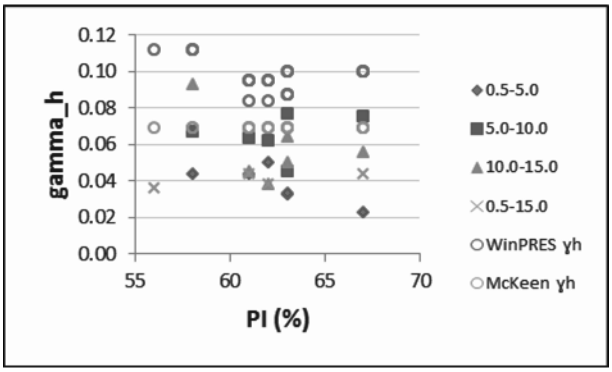

Figure 10. Comparison of γh as calculated from pressure plate tests vs. estimated from routine tests.

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

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

$$\Delta H_{total} = \sum_{i=1}^{n} f_i \left(\frac{\Delta V}{V}\right) \Delta z_i \, H$$

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

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.

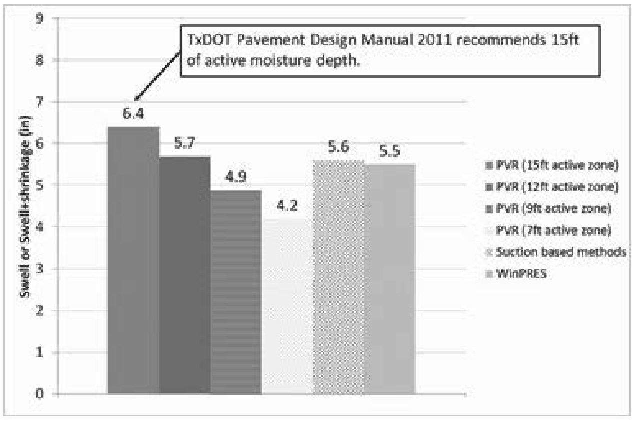

Figure 11. Comparison of vertical movements calculated with different methods

The results showed that the relationships between one dimensional swell and PI presented in the Tex-124-E can be considered acceptable if the "dry" condition is adopted. Based upon the calculations from soils obtained at South Austin, PVR calculations with an active moisture depth of 12ft would result in swelling values comparable to those calculated using suction based methods.

7 REFERENCES

Hong, G. T., Bulut, R., Aubeny, C., Jayatiaka, R. and Lytton, R. L. 2006 "*Design Model for Roughness and Serviceability of Pavements on Expansive Soils*", TRR No. 1967.

Litlle, D. 2012. *"Background for predicting roughness and/or serviceability loss due to expansive soils"*, Internal Memorandum.

Mitchell, P. W. 1979. "*Structural Analysis of Footings on Expansive Soil*", Research Report No. 1, Kenneth W. G. Smith and Associates, Newton, South Australia.

Texas Department of Transportation 2011. "*Pavement Design Guide*".