Suffusion in compacted loessial silts. Interaction with granular filters.

Suffusion dans les limons lœssique compactés. Interaction avec les filtres granulaires

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ABSTRACT: Loess soils, which occupy much of central Argentina, are characterized by their high sensitivity to change in moisture. This condition categorized loess structure as internally unstable soil. Despite this natural condition, silts derived from loess are frequently used as material in roads and hydraulics constructions. In filtration processes, the soil should be shielded from erosion phenomena. The filter must have a particle size consistent with the ground to protect. In particular, sandy silts can be affected by phenomena of suffusion, or internal instability of the soil structure. The filter must control the loss of material and ensure the stability of flow. The present study shows the experimental results of flow applied to loessial silts, with low compaction. Tests have been conducted using filtration columns that simulate the soil-filter-drain. The test methodology applied aims to follow the research lines of similar studies worldwide. Studies have focused on analyzing the influence of variables such as degree of compaction, hydraulic gradient and composition of the filter material. The results obtained allow recommendations with reference to construction systems to be applied and the composition of the filter in order to properly control the suffusion.

RÉSUMÉ : Les lœss, qui occupent une grande partie de l'Argentine centrale, se caractérisent par une grande sensibilité au changement de teneur en eau qui permettent de classer ces sols dans la catégorie des sols à structure interne instable. En dépit de cet état naturel, les limons provenant des lœss sont fréquemment utilisés comme matériau pour les routes et les constructions hydrauliques. Dans les processus de filtration, le sol doit être à l'abri des phénomènes d'érosion. Le filtre doit avoir une granulométrie compatible avec le sol à protéger. En particulier, les limons sablonneux peuvent être affectés par des phénomènes de suffusion ou d'instabilité interne de la structure du sol. Le filtre doit contrôler la perte de matière et assurer la stabilité de l'écoulement. La présente étude montre les résultats expérimentaux de débit appliqués à des limons lœssique faiblement compactés. Des tests ont été effectués en utilisant des colonnes de filtration qui simulent le sol filtre de vidange. La méthodologie de test appliquée vise à suivre les lignes de recherche d'études similaires dans le monde entier. Les études ont porté sur l'analyse de l'influence de variables telles que le degré de compactage, le gradient hydraulique et la composition du matériau filtrant. Les résultats obtenus permettent recommandations par rapport à des systèmes de construction qui doivent être appliquées et la composition du filtre afin de bien contrôler la suffusion.

KEYWORDS: loess, sandy silts, filters, suffusion

1 INTRODUCTION.

In Argentina there are large deposits of sandy loam soils. These soil called loess, have been transported by wind. They have a high sensitivity to moisture changes, so they are considered unstable. One of the features of most interest is the hydraulic behavior of these soils. These silts can be used in the construction of cores in dams and embankments. On the road works in the central plains of Argentina, they are used in the formation of embankments. In these cases, the compacted soil is affected by infiltration processes and filtration through a porous medium. These processes, in some structures, generate erosions, which produce construction damage, or even in total failure.

This publication shows the characteristics of a soil protection system in order to avoid phenomena of erosion by filtration. The soil protection actions can be several. A classic action is granular filter construction. Other possible actions include changes in the internal structure of the soil, including the use of components that increase their internal resistance to erosion, or the construction of "barriers" formed by geosynthetics.

The behavior of natural filters has been one of the main subjects of study in geotechnical engineering. Terzaghi's original studies, since 1929, have been supplemented by Sherard and Dunnigan (1989), who made the most significant advances in the study of the behavior of filters.

Similarly, significant advances have been made by Khor and Woo (1989), Foster and Fell (2000) and Delgado and Locke (2008), Semar et al (2010). These authors have contributed to a better description of the behavior of soils in filtration problems, and have also generated recommendations on controlling erosion.

Erosion by filtration may start from the modification of the physico-chemical composition of the soil, resulting in dispersion phenomena. When soil structural organization, i.e. the accommodation of the particles, can lead to instability and erosion, the phenomenon is called suffusion, erodibility or internal erosion. Indraratna (1997, 2006, 2007), Wan and Fell (2004, 2008), Bonelli (2006), Bendahmane (2008), Indraratma et al (2008, 2011) and Benamar et al (2010), among others, have done important research in this field. These authors have developed new criteria for evaluating the potential of internal erosion, or suffusion in granular soils.

To understand the importance of this problem, we must analyze historical cases of dams whose cores have been constructed with silt. The most notable example is the Nurek dam in Tajikistan. A much discussed case is the Teton Dam in Idaho, USA failed in 1976 during the first fill. The failure is caused by internal erosion. In some cases of failure, it is considered that the material used in the construction of the core has a large influence. Smalley I.J. and Dijkstra T.A. (1991) indicated that the loess should not be used in cores of dams, because they lack the mineralogy and structural properties required for this application. Compacting the slime still remain dilatants and, consequently, their use represents a significant risk.In reply to this claim, Perry (1991) says that the highly erosive nature of the loess is well known. Accordingly, to avoid the dam core piping formed by silty soil, it requires the placement of an appropriate filter downstream. Thus Ririe Dam, built 35 kilometers of Teton Dam, has built a loess core and designed the appropriate filters, showing satisfactory performance.

In Argentina, loessial silts have been used in several dams and roadworks. The most important example is the Rio Hondo Dam, built in the 1960s, regardless dispersion problems (Grandi et al, 1961). The material used in this work is a silt with a clay content between 15 and 20% and plasticity index of 6% (Moretto et al, 1963). In structural revisions made several decades after its construction, it was concluded that the dam has adequate hydraulic behavior. Buraschi and Pujol (1999) have discussed the possibility of internal erosion in this dam.

This paper discusses the hydraulic stability sandy silt soil type, in the compacted state. The material is subjected to erosion situations under the application of several hydraulic gradients. For the protection of silt, it has been used natural filters with different particle sizes. One of the most discussed issues at the international level is the testing methodology. The authors have optimized an analysis methodology based on the use of a filter cell. The results of the test campaign performed with the technique developed by the authors of this publication are presented.

2 COMPOSITION OF THE STUDY

2.1 Soil involved in testing

The characteristics of the soil tested in these studies have been described by different authors, Reginatto (1970), Moll and Rocca (1991). Loessial soils of central Argentina are formed mainly by silt. The grain size composition comprising: sand (2% to 10%), silt (40% to 80%), and clay (20% to 35%). The composition is completed by calcium carbonate, variable between 2% and 10%, which exists in the form of nodules, called "toscas", or precipitate in the contact between particles. These soils are alkaline, with pH> 8.

The physical properties of the soil tested are shown in Table 1.

Table 1.Properties of base material used

Property	Value
Natural moisture (ω), (%)	12.7 - 20.7
Dry Unit Weight (γ_d), (kN/m^3)	12.3
Specific Gravity (Gs)	2.65
Liquid Limit (ω_l), (%)	24.4
Plastic Limit (ω_p), (%)	21.0
Plastic Index (PI), (%)	3.4
Particles< 4.50 mm, (%)	100.0
Fines < 0.075 mm, (%)	93.4
Clay< 0.002 mm, (%)	14.0
USCS Classification	ML

Through compaction tests yielded a value of 15.5% optimum moisture and maximum dry unit weight of 17.6 kN/m^3. To simulate conditions of poor compaction, tests were conducted with the application of 90% of the energy corresponding to Standard Proctor test.

Fine grain sand was used as a base material for the construction of the filter. This type has been called SP, as the unified system. Zeballos et al (2010) have shown the unstable behavior of the system formed by compacted loess and filter, when it is formed only by sand. In the results presented in this paper, using filters formed by a combination of sand and silt loess, the filtration was measured. It has also been analyzing the operation of the set soil - filter, both under transient and steady flow. The mixtures tested as filters, have used combinations of sand and silt with a share of sand: 60%, 75%, 85% and 95%, relative to the total weight. The mixtures formed are presented in Figure 1. In the same Figure, the range corresponding to 15% pass filter (d_{15f}%) frequently recommended, is presented. Each of these mixtures was tested with the application of hydraulic gradients in the order of 20, 40 and 80. Figure 2 shows the location of the soil analyzed according to the classification of Burenkova (1993).

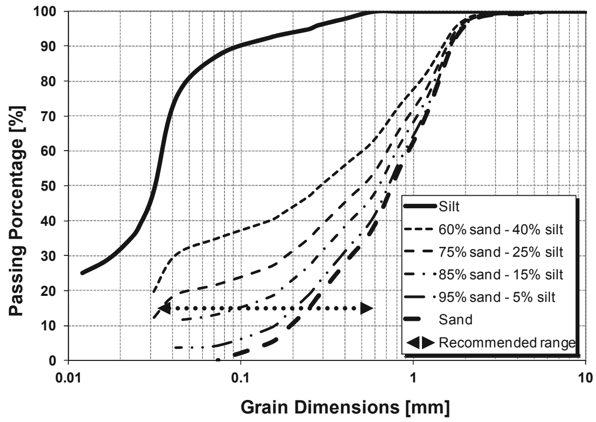

Figure 1.Particle size of the soils used in the study.

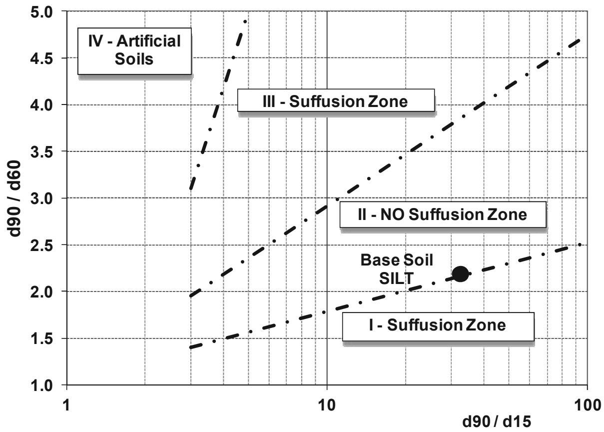

Figure 2.Burenkova chart for characterizing the potential of suffusion. Location of the studied silts.

For the materials used in this study, it is possible to make the following comments:

- Burenkova graph, locates the soil base tested (loess silt), in the limit of the erosive behavior.
- Several filter mixtures tested has fines content greater than that normally recommended for the treatment of these problems, (not exceeding 5% of passing sieve 200).

2.2 Tests Performed

A filtration chamber of large dimensions has been designed. The cylindrical chamber has a height of 500 mm with a span of 105 mm diameter. The chamber was constructed with transparent plastic, which allows visual monitoring of the filtration process. At its top, the chamber is connected with the water injection system pressure. In its lower part is connected to the flow registration system and containment system of solid particles. The chamber used, in schematic form, is presented in Figure 3.

In the upper part of the chamber is placed a granular material (drain) to facilitate the distribution of incoming water to the beaker. This allows the water to reach the probe evenly. The soil tested is located below the drain. The height of the cylinder is regulated depending on the applied hydraulic gradient. The filter is located below the probe, and then places another drain. The test apparatus has a bottom plate with an outlet hole that allows fluid control, and the collection of solid particles which migrate from the soil or filter.

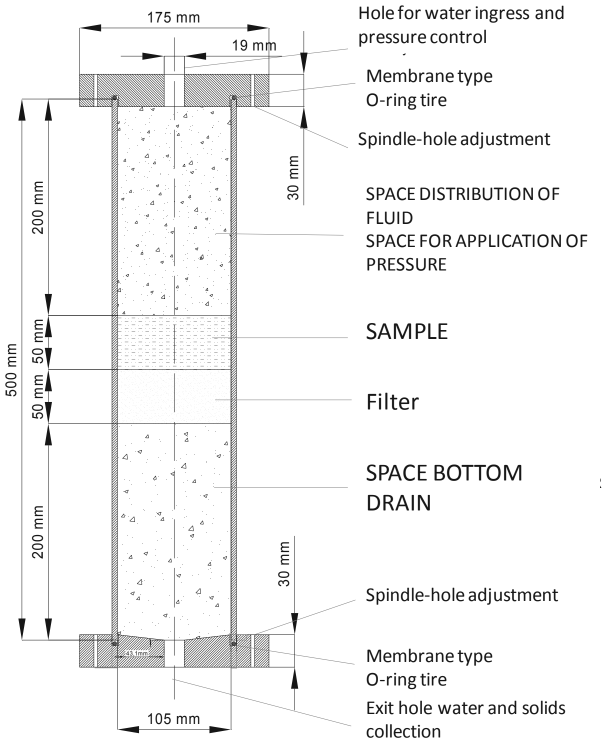

Figure 3. a) Schematic of the test system.

Prior to the execution of tests, a hole is drilled in the central part of the specimen to simulate a crack from uncontrolled erosion which could be initiated, or be achieved the overall instability of the material.

In the preparation of the test system, some difficulties have occurred in the installation of the filter and drain. An internal protocol was developed to avoid the complications caused by the lack of good contact between the various layers of the filtration column.

Tests have been carried out, in all cases, starting the process from the moisture condition of compaction. The filtered water volume and the weight of the solids passing through the filtration system were measured in all trials. In all cases, measurements were performed at intervals of time. Tests have lasted more than one day, until a leak was observed in steady state condition.

3 RESULTS

The variables in the set of tests were as follows: a) volume of water filtered vs. time, b) amount of filtered solids through the system, c) filtration rate, when the process is in steady state, d) steady state permeation.

Within the set of tests, the results for the filters with 60% of sand are not included in this paper. These filters have shown a highly unstable behavior, with great loss of material during filtration.

Figures 4a and 4b, for example, show the variation in the volume of filtered water to the various mixtures made and applied gradients. There is a growing trend for leaks with the gradient applied. The same trend was observed with the sand content in the filter.

In relation to the migration of particles, Figure 5 shows the percentage of solids that migrate with respect to the initial dry weight of the sample. The solids lost during the test tend to increase proportionally to the content of sand in the mixture. The losses are moderate for the filters having no more than 85% sand. For filters with 95% sand, the loss rate increases to more than double, compared to the previous cases. Much of the migration of solids occurs in the first minutes of the test. After the initial stage there is clear water seepage through the system.

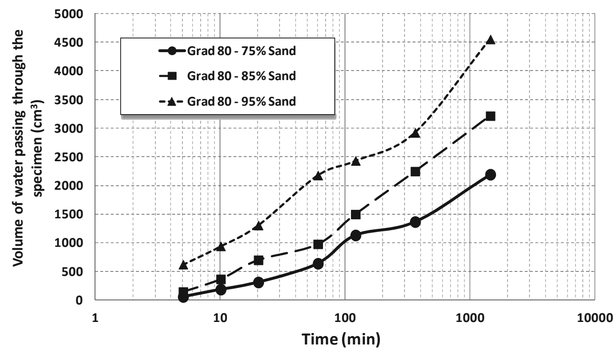

Figure 4.a. Changes in the volume of filtered water, as represented in logarithmic scale.

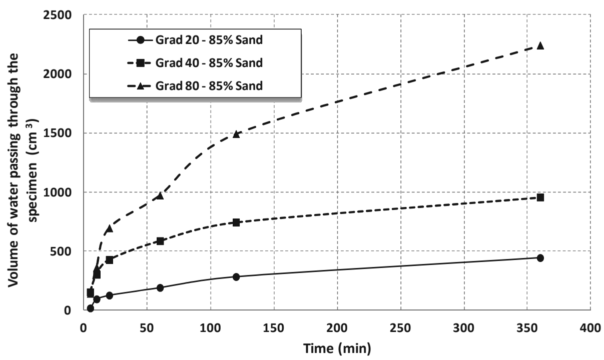

Figure 4.b. Representation of the evolution of the volume filtered, represented in full scale

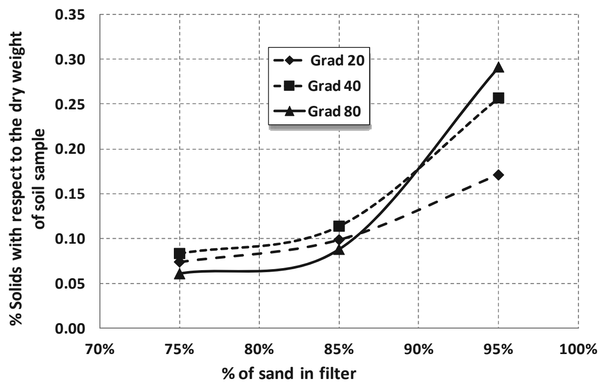

Figure 5.Solids losses during the test.

The filtration system tested shows a leak with the characteristics of a regular stationary regime after an initial transient stage.

The stability of the system can be seen through the identification of the mean values of permeability. These values are constant, even for different values of gradients.

The results, measured as rate of leak flux in the stationary phase and the permeability at this stage are shown in Table 2.

Table 2. Speed of filtration and permeability in the steady state phase.

Grad	Velocity of filtration (cm^3/s)			Permeability (cm/s)		
	75%	85%	95%	75%	85%	95%
20	0.009	0.014	0.017	5.5E-06	8.2E-06	1.0E-05
40	0.019	0.022	0.027	5.6E-06	6.3E-06	7.9E-06
80	0.034	0.050	0.070	4.9E-06	7.2E-06	1.0E-05

4 CONCLUSIONS

The results can be summarized in the following remarks:

- Sandy silt soils of low plasticity, typical "Loessical Formation" located on central Argentina, are in the limit suffusion unstable behavior, according with previous internationals studies.
- A test protocol for evaluation of the capacity of the filter for controlling suffusion instability was made based on set of measurements.
- In the construction of filters for hydraulic control of silty soils stability, materials with fines content greater than 5% have been employed. There has been a satisfactory performance with content not higher than 30%.
- The filter employed as mixtures with fines content between 15% and 25% showed the best conditions of stability. Under these conditions, there has been a small fraction of solid material lost. These losses occur mainly in the early stage, prior to achieving a steady flow.

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