RELATIVE COLLAPSE OF A LOESS SOIL

AFFAISSEMENT RELATIVE D'UN SOL LOESSIQUE

E.R. Redolfi[1] *C. Oteo Mazo*[2]

[1]Prof. of Geotech. Eng., National Univ. of Córdoba, Argentine
[2]Prof. of Geotech. Eng., Politech. Univ. of Madrid, Spain

SYNOPSIS: To predict the collapse settlement in a period of time, it is necessary to know the characteristic stress-strain relationships of the soil. The stress-strain behavior is greatly influenced by its water content. Therefore, water content effect should be addressed accordingly.
With the object of determining these stress-strain relationships at different water contents a number of oedometric tests was conducted under constant suction condition on soil samples of Argentinean loess. Variation of the water content was very small when loading under constant suction. Collapse susceptibility can be characterized by a parameter called **Relative collapse**.
An exponential function was fitted to the experimental soil collapse curves with satisfactory agreement.

INTRODUCTION

Collapse settlement computation of soils needs to take into account the following considerations:

a. Collapse Susceptibility of the soil as a function of the water content and state of stresses.
b. Extension and shape of the wetted zone and its progression in time.

Collapse susceptibility due to wetting can be characterized by a parameter named **Relative collapse** (δ_{col}). Relative collapse is defined as the ratio of the settlement due to wetting to the initial height of a sample, loaded under a constant axial stress (δ_{col}).

$$\delta_{col}(\sigma) = \frac{\varepsilon(w_{HN}) - \varepsilon(w)}{1 - \varepsilon_1} \qquad (1)$$

where:

$\varepsilon(w_{HN})$ = axial strain due stress σ, before wetting,
$\varepsilon(w)$ = axial strain upon wetting or an increase of water content, $(w - w_{HN})$, under σ,
ε_1 = axial strain due to overburden, at natural water content.

Relative collapse is required under different increments in water content $(w - w_{HN})$ for studying strain behavior and to compute settlement.

In this work, relative collapse is determined in oedometric tests by changing water content and axial stresses.

It is also necessary to account variations of water content and stresses with depth, during the wetting process:

$$w = f(z,t)\ ;\ \sigma = f(z,t)$$

These functions depend on the extension and shape of the wetted zone. (Mochalov and Vinogradova, 1971; Lin and Liang, 1982).

TEST PROGRAM

A test program was developed to study the behavior of an argentinean loess from Córdoba city. This soil was an aeolian type with dry unit weight γ_d=13.3 kN/m^3; liquid limit w_L=22.8%; and plastic limit w_P=18.3%.

The following tests were performed: Suction tests, oedometric tests at natural water content and saturated, and oedometric tests at controlled suction.

Suction test allows to know suction variations with water content and the time required for pressure homogeneization within the sample (Jimenez Salas and Justo Alpanez, 1971).

Figure 1 shows the results of suction tests S1 and S2. They are also compared with results obtained by Kane (1973) on an Iowa loess similar to the argentinean one. The later loess has greater suction variation within the natural water content range (10-12%).

Oedometric tests at controlled suction (Escario and Saez, 1973) allows to establish the variation of relative collapse as a function of water content and suction. Table 1 presents a summary of conditions of performed tests.

Kane (1973) performed oedometric tests at constant water content with suction measurements. He observed that for a given water content, suction is independent of the degree of saturation (S_r), except when S_r exceeds 85 or 90 %. He related those measurements to the behavior of soil structure.

Silt particles were bonded or recovered with clay particles or clay clusters.

When the soil is subsaturated (Sr < 80%), water is dispersed throughout clay clusters. Variations in macroporous can lead to compaction or volume reduction without changing clay clusters. Thus, compaction does not modify water menisci characteristics and negative water pressure.

When Sr is greater than 80%, and water menisci reach macroporous, it takes place reductions in void ratio. It generates an increment in the degree of saturation and thus it reduces suction.

Kane performed tests at constant water content while the tests described in Table 1 were run at constant suction. Both tests should give similar results since water content remains constant.

To corroborate this hypothesis, water content was determined in different stages, as follows:

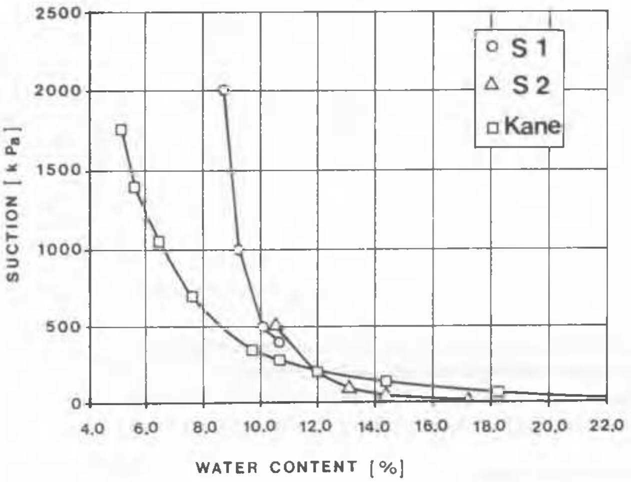

Fig 1. Suction and water content comparison between argentinean loess and Iowa loess (Kane, 1973).

1. Initial water content (w_0), was measured with standard procedures before the test.

2. The sample was maintained at a given suction to allow water content homogeneization. Time duration and suction were determined with previous suction tests. After 7 to 15 days in oedometer cell, water content (w_{er}) was determined and compared with the obtained in suction tests (w_e).

3. Final water content (w_f) was measured at constant suction after the test.

Table 2 presents water content of suction tests (w_e) and oedometer tests at controlled suction (w_{er} and w_f). By comparison, it is concluded that the tests were executed at constant water content.

In test C 2 initial condition were: axial pressure, 800 kPa and suction, 500 kPa. Afterward, suction was reduced to 200 kPa without changing axial pressure. That produced a settlement, due to wetting, and a 2% increment in water content.

Figure 2 represents a state surface of the tests, in a three dimensional plot (axial strain, axial pressure %, and suction) (Matyas y Radhakrishna, 1968).

Test C 1, at natural water content (w=11.78%) fit fairly well with a line curve of constant suction at 300 kPa.

Table 1. Summary of oedometer test conditions

Oedometric Test Type	Designation	Suction (kPa)
Natural Water Content	C 1	Unknown
Controlled Suction	C 2	500
Saturated	C 3	0
Controlled Suction	C 4	100
Controlled Suction	C 5	25

Table 2. Water content determined at different stages of the tests with suction control.

Test designation	Suction pressure (kPa)	Sample water content w_0 (%)	Initial water content of test w_{er} (%)	Final water content of test w_f (%)	Suction test water content w_e (%)
C 2	500 200	10.37	10.41	 12.26	10.62 12.02
C 4	100	10.02	13.10	13.38	13.17
C 5	25	10.43	17.38	18.02	17.20

DETERMINATION OF RELATIVE COLLAPSE CURVES

To study the characteristics of the argentinean loess, the oedometer test at a suction of 500 kPa was selected as reference.

Figure 3 shows the variations of relative collapse as function of axial pressure, for different water content (11.7%, 13.4%, 17.4% and saturation).

The curves shows three main parts: a first part with exponential increment (concave); a second part with logarithmic growth (convex) and the third part in which decreases with the pressure (Steffanov, 1962).

First and second part inflections occur between 100 and 400 kPa, depending on water content. Third part is only developed in saturated soil.

Several authors have proposed mathematic formulations for these curves.

Mustafaev and Sadetova (1983) had presented an exponential relationship between relative collapse ($\delta_{col}(w)$) and pressure (σ):

$$\delta_{col}(w) = \alpha \ \sigma^{\beta} \qquad (2)$$

where α and β are empirical parameters to characterize soil deformability with different water content.

Lomize (1968) formulated a logarithmic expression:

$$\delta_{col}(w) = S \,.\, \log \sigma \ - R \qquad (3)$$

where $S(w)$ and $R(w)$, are empirical parameters that are function of water content.

For the argentinean loess, Eq.2 is valid up to the inflection point of the first part of the curve. Figure 3 shows that inflection points depend on water content. It varies between 100 kPa (for saturated curve) and 400 kPa (for lower water content).

On other hand, values given by Eq.3 match well with experimental curves for pressures greater than inflection points.

The soil tested was estimated under its own weight with axial pressure lower than that of the inflection point (100 kPa). For this reason Lomize equation was not considered in the study.

However, for each particular case, it is necessary to analyze the validity of those equations as function of the stresses inside the soil structure. Redolfi (1990) pointed out that the first part of the curve does not appear in some soils. Thus, Lomize equation covers the whole range of stress. In the other hand, some less collapsible soils can be modeled with an exponential-type equation like (2).

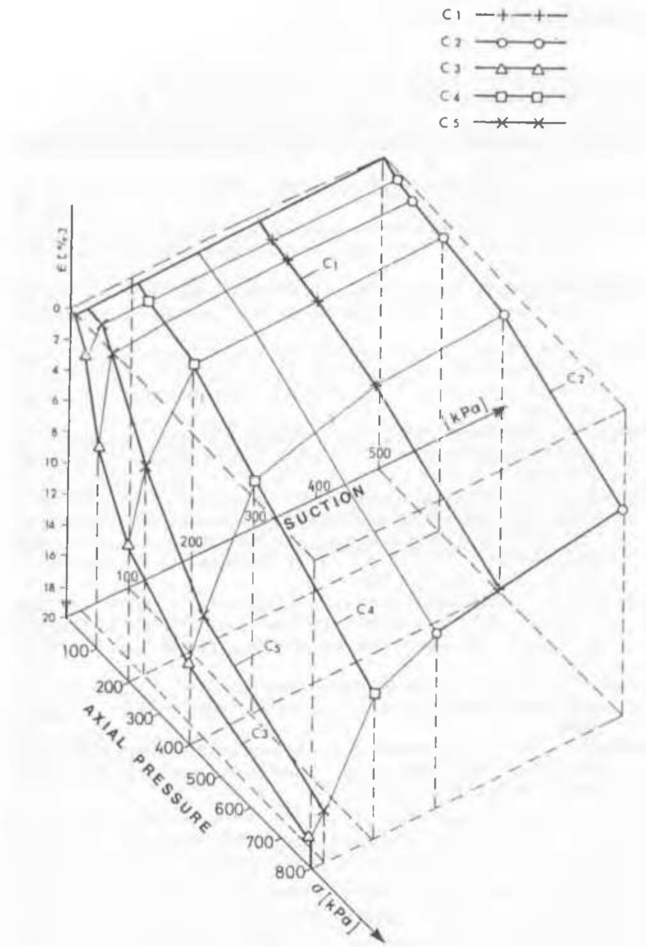

Fig 2. State surface for an argentincan loess in a test at controlled suction.

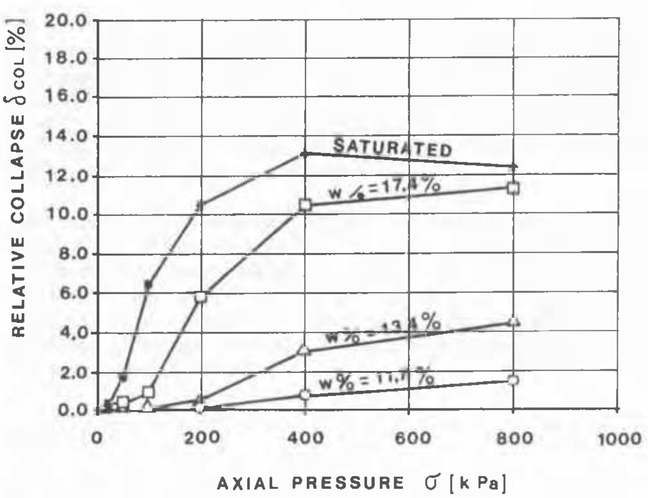

Fig. 3. Relative collapse vs. axial pressure for different water contents respect to a reference water content of 10.4 %.

From experimental results, Table 3 shows that the value of β is almost independent of water content, and nearly equal to 2. On the other hand, the value of α is a linear function of water content. The correlation coefficients of these regression analysis are good.

Table 3. Experimental coefficient of Eq.2 obtained by regression analysis.

Test	Water Content (%)	α	β	Correlation Coefficient
C 1	11.7	0.0411	1.988	0.971
C 4	13.1	0.1180	2.219	0.996
C 5	17.4	1.4216	1.937	0.992
C 3	37.1 - 23.7	6.4639	2.087	0.999

Saturated test C 3 was the only one with changes in water content, from 37.1 to 23.7%, for variations in pressures from 5 to 800 kpa.

For this study, an arbitrary saturated water content was selected, corresponding to 100 kPa. Therefore, variation of coefficient α with water content can be expressed, as follows:

$$\alpha = 0.338\, w - 4.37 \qquad (4)$$

Other expression for α, is as a function of initial or natural water content and saturation water content:

$$\alpha = 7.27\, [(w - w_O)/(w_{sat} - w_O)] - 0.86 \qquad (5)$$

For values of w_O = 10.4% and w_{sat} = 31.7%, and replacing in Eq.5:

$$\alpha = 7.27\, [(w - 10.4)/21.3] - 0.86 \qquad (6)$$

For values of α and β obtained from test data, Eq.2 gives:

$$\delta_{col}(w, \sigma) = (0.338\, w - 4.37)\, .\, \sigma^{2} \qquad (7)$$

Figure 4 presents a family of curves that results from Eq.7 and the experimental curves from oedometer test.

Mustafaev and Sadetova (1983) have proposed other method to relate relative collapse and water content, using the following expression:

$$\delta_{col}(w) = \delta_{col\,(sat)} \left(\frac{(w - w_O)}{(w_{sat} - w_O)} \right)^{n} \qquad (8)$$

where,

n = empirical coefficient
w_O = initial or reference water content
w_{sat} = saturation water content

For the cases studied, Eq.8 is difficult to implement due to the dependence of saturation water content with the applied stress of the soil. Nevertheless, if it is selected a pressure of 100 kPa and coefficient n=1.75 (as proposed by the authors), the resultant curves are similar to the experimental ones as seen in Figure 5.

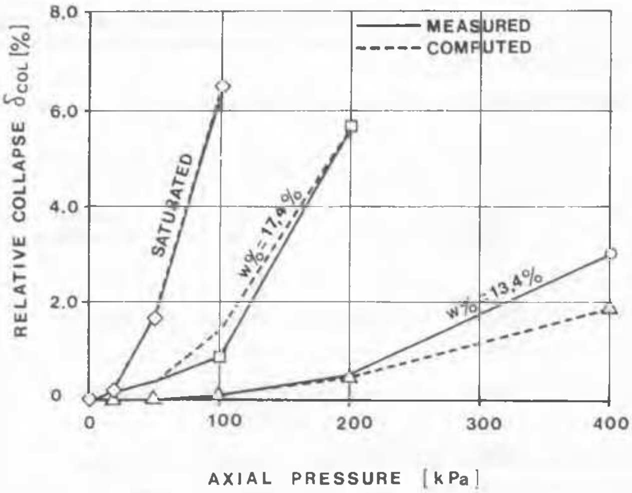

Fig.4. Measured and computed relative collapse curves (using Eq.7)

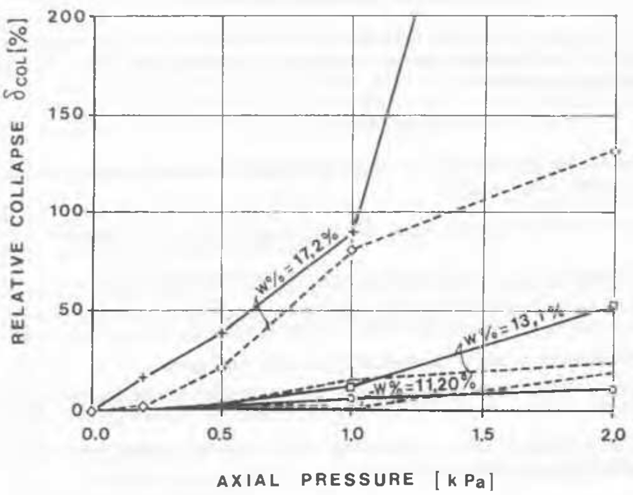

Fig.5. Measured and computed relative collapse curves (using Eq.8 and n = 1.75)

CONCLUSIONS

In macroporous soils like loess, water content does not vary significantly during a load process at constant suction. Thus, oedometer tests with constant suction are enough to obtain relative collapse curves with different increments of water content.

Tests on argentine loess showed that relative collapse can be modeled with an exponential mathematical form with a reasonable confidence.

These expressions are useful in computing settlement, where infiltration processes are analyzed.

REFERENCES

Escario, V. and Saez, J. (1973). Medidas de las Propiedades de Suelos Expansivos y Colapsables bajo Succión Controlada. *Boletín de Información del Laboratorio de Transportes y Mecánica de Suelos*, MOPU N0 100, Nov. - Dic. 1973, pp. 1 - 8

Jimenez Salas, J.A and Justo Alpañez,J.L. (1971). *Geotecnia y Cimientos I*. Ed. Rueda, Madrid.

Kane, H. (1973). Confined Compressions of Loess. *Proc.of the 8° Inter.Conf. on Soil Mech. and Found. Eng.*, Moscu, URSS. Vol 2.2, Session 4/19, pp. 115 - 122.

Ling, Z. and Liang, W. (1982). Engineering Properties and Zoning of Loess and Loess Like in China. *Canadian Geotechnical Journal*, Vol 19, pp. 76 - 91.

Lomize, G.M. (1968). One-Dimensional Problem of Percolation and Slump Type Settlement in Homogeneous Loess Soils. *Gigrotekhnicheskoe. Stroitt'stvo*, N° 10, pp. 22 - 27. Translated *Hydrotech. Const.* N° 10, pp. 881 - 888.

Matyas, E.S. and Radhakrishna (1968). Volume Change Characteristics of Partially Saturated Soils. *Geotechnique*, London, England. Vol 18, pp. 432 - 448.

Mochalov, I.P. and Vinogradova, G.N. (1971). Analysis of the Deformation of Loess Soils Highly Prone to Slump-Type Settlement when Wetted from Sources Having Different Dimensions. *Osnovanija, Fundamenty i Mekhanika Grunkov*, N° 2, pp. 33 - 34. Translated to *Soil Mechanics Foundations*. Vol 7, pp. 145 - 150.

Mustafaev, A.A. and Sadetova, E.M. (1983). Prediction of Collapse with Time in Bases of Structures. *Osnovanija, Fundamenty i Mekhanika Grunkov*, N° 3, pp. 14 - 17. Translated to *Soil Mechanics Foundations*. Vol 18, pp. 109 - 114.

Redolfi. E.R. (1990) *Comportamiento de pilotes en suelos colapsables*. Doctoral thesis submited to E.T.S.I.C.C.y P. Politechnical U. of Madrid, Spain.

Stefanoff, G. (1961). A Rapid Method for Determining the Collapse of Loessial Soil. *Proc.of the 5° Inter. Conf. on Soil Mech. and Found. Eng.*, Paris, Francia. Vol II, pp. 795 - 797.