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# Characterization of swelling materials by Huder-Amberg oedometric test

## Caractérisation des matériaux gonflantes avec l'essai oedometrique Huder-Amberg

M. Romana & J.B. Serón
*Department of Geotechnical Engineering, Polytechnic University of Valencia, Spain*

ABSTRACT
The Geotechnical Engineering Department of the Polytechnic University of Valencia is currently doing a research program on swelling materials (soils and soft rocks) and the long time effect of swelling on tunnels. In this program several swelling oedometric tests, by the Huder-Amberg technique, have been carried out. The usual Huder-Amberg test takes a lot of time, so it is frequent that they are finished before the actual end of the swelling of the probes. In this research some of the tests have been maintained during more than a year, with almost continuous expansion of the samples (argillite with some gypsum inclusions) in each one of the deloading steps. This paper describes the testing techniques, and the special testing challenges and problems derived from the extraordinary time length of the tests; discusses some simple numerical models to forecast the end of each swelling step (in order to reduce as much as possible the testing time); and gives some preliminary results of the expansion parameters for clayey materials, (comparing them with other published data) which can be useful in tunnel design.

RESUME
Le Département de Génie Géotechnique de l'Université Polytechnique de Valencia a un programme de recherche sur le matériaux gonflantes et son effet sur les tunnels a long terme. Dans le cadre de ce programme on a fait plusieurs essais oedometriques avec la technique Huder-Amberg. Le essai courante par cette technique a une durée très longue, donc c'est habituel le fait de les finir avant de la vrai finition du gonflement. Dans ce programme de recherche on a maintenu quelques essais pendant plus d'une année, toujours avec gonflement des semples.(argillite avec quelque inclusion de gypse) dans chacune des étapes de décharge. Cette communication décrie les techniques d'essaie, et les problèmes dérivées de l'extraordinaire durée de l'essaie; discute les modèles numériques pour la prévision de la fin de chaque étape de gonflement (pour réduire la durée de l'essaie) et donne quelques valeurs du module de gonflement (en les comparant avec d'autres valeurs publiées) qui peuvent être d'utilité pour le projet des tunnels.

## 1 INTRODUCTION

Swelling soils, and rocks, are defined as those materials, which increase in volume when they come into contact with water, without prior change of the stress field. If the increase in volume is impeded, total or partially, a secondary stress field develops. The magnitude of this secondary stress field depends on the degree of confinement around the swelling region of the rock mass. In tunnel construction swelling of rock often causes the heave of the tunnel floor, or an increased pressure on the tunnel floor, which fails. In tunnels with invert arch the heaving is restricted, pressure increases and the entire tunnel can experience a global upward displacement, or failure of the invert arch (fig. 1). The most common swelling materials are anhydrite and clayey soft rocks (claystones, clayshales), containing minerals like corrensite, montmorillonite and others. Different authors referred to tunnel failures because of rock swelling and explained correctly the process (Grob, 1972; Gysel, 1977; Wittke and Pierau 1979, Kovari, Amstad and Anagnostou, 1988). The basic laboratory test for characterization of swelling rocks was developed by Huder and Amberg (1970). The first comprehensive design method was presented by Wittke and Ribler (1976), taking account of the local three-dimensional stress state.

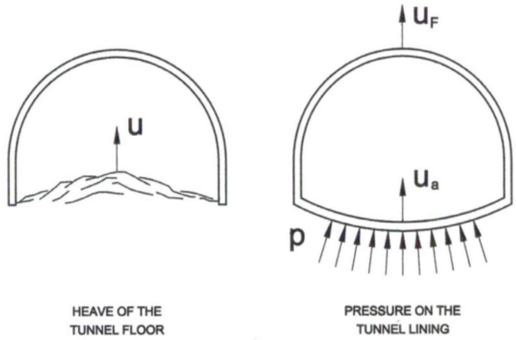


Figure 1. Effect of swelling in tunnels (Kovari et al, 1988)

## 2 THE HUDER-AMBERG TEST

Huder and Amberg proposed a standard test to quantify the expansive deformation because of swelling. This test has been widely mentioned in the technical literature and is now generally accepted due to his simplicity. The process is a follow (see fig. 2 by Wittke and Pierau, 1979).

An "undisturbed" sample is put in an oedometer which prevents displacement in any direction except the vertical one.

The sample, with its undisturbed water content, is subjected to a first loading (1) in order to compensate for the destressing relief caused by the sample extraction.

Without changing the water content the sample is unloaded (2) and reloaded (3).

The sample is saturated from the upper and the lower ends, without changing the vertical stress, and therefore expands vertically (4).

After the end of the swelling vertical expansion, the sample is unloaded by steps, waiting at each one the time necessary in order to allow for the end of the successive expansion that occurs after each decrement of load (5)

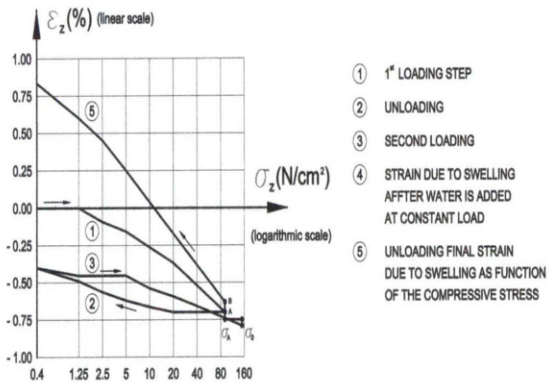


Figure 2. Characterisitc swelling diagram in a Huder-Amberg test (Wittke and Pierau, 1979)

The process of expansion can be cumbersome, taking weeks or even months, so the commercial tests are finished at a previously fixed small deformation.

The curves 5 and 3 define the deformation – stress behavior of the sample with and without the swelling deformation due to the increment of the water content. Their intersection, therefore, defines the point corresponding at a critical stress at which no swelling deformation can occur.

Wittke and Ribler (1976) proposed that the real swelling behavior were approximated by a straight line in a diagram: deformation vs. logarithm of stress whose equation would be:

$$E_{qz} = k\,(1 - \log \sigma_z \,/\, \log \sigma_o) \qquad (1)$$

where $\underline{\sigma_o}$ is the stress at which swelling deformation in zero. $\underline{k}$ is the strain due to swelling for a stress $\sigma_z = 1$

The above equation (1) was extended to the three-dimensional stress state

$$I_{1\in} = k\left[1 - \log(\alpha I_{1\sigma}) \,/\, \log(\alpha I_{1\sigma_o})\right] \qquad (2)$$

where I, are the first invariants of strains and stresses and $\alpha = (1 - \nu) / (1 + \nu)$ is a constant depending from the Poisson number $\underline{\nu}$. The equation (2) is presented graphically in figure 3

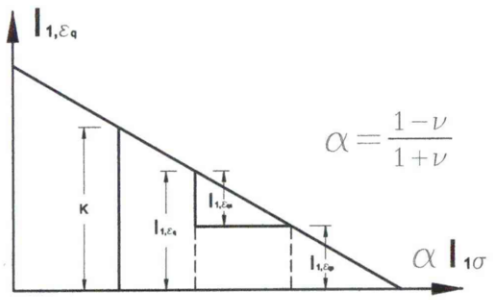


Figure 3 Evaluation of volume increase due to swelling (Wittke and Ribler, 1976)

## 3 PRECEDENTS IN SPAIN AND ALGERIE

The senior author has been involved in the design of several tunnels in swelling rocks. (Portillo et al, 1981;Romana, Simic and Cedrun, 1981; Romana and Simic, 1983; Ingeotec, 2001) in Spain and Algeria. The Huder-Amberg test were used for rock swelling characterization in all cases and the Wittke-Ribler formulation was the basis of computation, done with relatively simple finite-elements software in the 80´s and with FLAC in the last year.

The Martorell tunnel is a railway two-tracks tunnel in the connection Madrid-Barcelona near Barcelona. Length is 850 m with a maximum rock cover of 100 m. Approximately one half of the tunnel was bored through Ordovician schists and the other half through Miocene claystones and marls, with fine interbeddings of dolomites, limestones and gypsum, which was expansive. Figure 4 shows a typical Huder-Amberg test for the marls.

The Bou-Roumi hydraulic scheme in Algeria includes three tunnels: Oued Chiffa (12.5 km long), Oued Djer (3 km long) and Oued Harbil (4.5 km long) with maximum rock cover of around 500 m, 200 m and 80 m respectively. The geologic periods traversed are Cretaceous schists and calcoschists, and Miocene swelling marls with some limestones and sandstones

The El Perdon tunnels are located in Navarra, a north part of Spain, and will be part of the future Pamplona-Estella highway. They are 1.350 m long with a maximum rock cover of 170 m. The geologic period is Oligocene and they cross a thick layer of claystones and marls, with interbeddings of gypsum. The laboratory tests for these tunnels have been the first phase of a research program in the Polytechnic University of Valencia, program that will be described later. Ingeotec performed the design of the tunnels.

The table 1 includes the swelling modulus $\underline{k}$ obtained from laboratory test, and used in the design of the tunnels, in the above mentioned cases: These modulus are in the same order of magnitude than the value proposed as standard by Wittke and Pierau (1979): $k = 50 \times 10^{-3}$

## 4 RESEARCH IN COURSE

The problem of swelling in tunnels is getting more importance in Spain because of damages in the floor of two important road and highway tunnels, several years after construction. Expansion was not severe but the tunnels were closed to traffic during several months and reopened often the construction of an invert arch.

The Rock Mechanics Research Group of the Polytechnic University of Valencia was in charge of the swelling tests for the El Perdon tunnels and took the opportunity to begin a program of research on expansive rocks. Figure 6 show the swelling –time curve of a sample under a pressure of 0,8 MPa. Figure 7 shows the curve strain velocity vs. time.

Table 1 Several average swelling modulus *with interbeddings of gypsum

| | Material | Rock cover | K | Reference |
|---|---|---|---|---|
| Martorell | Marl* | 80 m | $26{,}5 \times 10^{-3}$ | Portillo et al 1981 |
| Oued Djer | Marl | 200 m | $6{,}0 \times 10^{-3}$ | Romana and Simic 1983 |
| Oued Harbil (I) | Marl | 40 m | $8{,}0 \times 10^{-3}$ | Romana and Simic 1983 |
| Oued Harbil (II) | Marl | 80 m | $46{,}0 \times 10^{-3}$ | Romana and Simic 1983 |
| El Perdon | Marl* | 170 m | $25{,}0 \times 10^{-3}$ | Ingeotec 2001 |

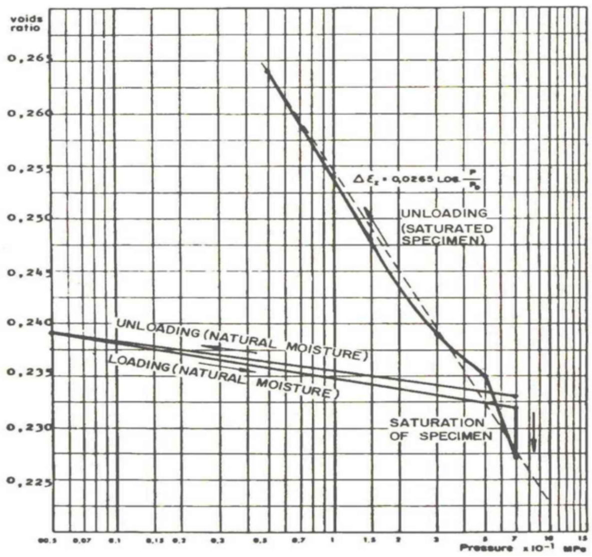


Figure 4. Result of a Huder-Amberg test in marl with gypsum (Martorell tunnel, Romana et al., 1981)

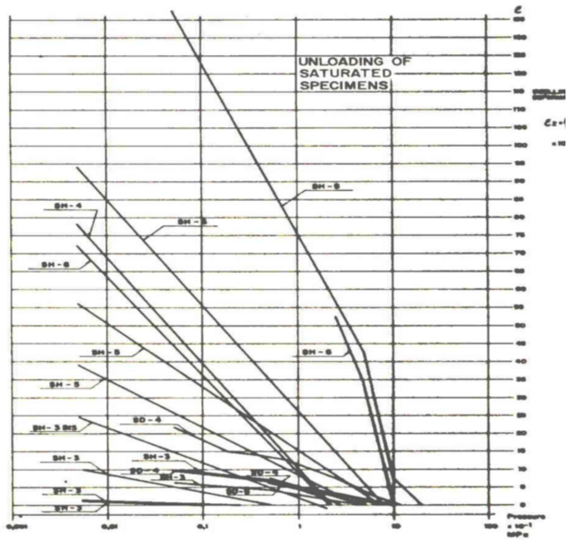


Figure 5. Result of several Huder-Amberg tests in Algerian marls (Romana and Simic, 1981)

A.total expansion time of 46 days was inferred. As there was no more time available these results were the basis for the design with a value of expansion coefficient of 25 x $10^{-3}$ . Table 2 presents some more swelling data for these rocks.

Table 2. Swelling Characteristics Of El Perdon Marls

| Characteristic | Mean | Maximum | Minimum |
|---|---|---|---|
| Swelling pressure (MPa) | 0,29 | 0,76 | 0,02 |
| Free swelling (%) | 2,19 | 5,05 | 0,15 |

Therefore one of the goals of our research is to establish a testing protocol with a shorter testing time without losing significant information. The curves strain-time can be extrapolated if they can be adjusted analytically. Between several models The Huder-Amberg test has two important drawbacks which, in practice, difficult them: the degree of alteration / inalteration of the sample and the long enduring time needed to maintain the test if it is necessary to know the real time for the end of swelling at each destressing step.

The sample is seldom really representative, because of the discontinuous appearance of gypsum inclusions in the marls and also because the process of sampling itself is hazardous requiring special and expensive techniques (i.e. a sampler including the oedometer ring, so the sample has not to be extracted in the laboratory, Esteban 1992). We are now trying to establish a classification of the available samples and sampling techniques in order to find a correlation between the accuracy of testing results and the respective cost and time. This correlation could be useful in practice for choosing the sampling technique more convenient in each case.

The Huder-Amberg test has, if properly done, a long enduring time, seldom less than 100-150 days and frequently over 200 days. The two first research tests in the Polytechnic University of Valencia rock mechanics laboratory are now 450 days old. One of them could have ended at 350 days but we are prolonging it for research's sake. The other is still swelling. This long time poses problems, which don't appear in other geotechnical tests:

a) Automatic reading devices are not prepared, can fail; cuts or overcharges, of energy can occur.
b) Human reading is not practical because of holidays, change of operator.
c) Corrosion can develop (gypsum is almost always present) in the testing apparatus

Therefore one of the goals of our research is to establish a testing protocol with a shorter testing time without losing significant information. The curves strain-time can be extrapolated if they can be adjusted analytically. Between several models two have been previously selected:

"Subway analogy"

The movement begins with a strain velocity nil and a positive acceleration until a maximum velocity is reached (with zero acceleration) during a time; afterwards acceleration becomes negative until the moment in which the velocity becomes zero again (the name denotes the similarity with the movement of a subway train between stations).

"Gun analogy"

The movement begins with a fixed initial velocity $\underline{v_o}$ and a negative acceleration $a = - b\, t$, so the deformation variation with time is $\varepsilon = (v_0 / b) \times (1 - e^{-bt})$ and the final swelling value is $\underline{v_o/b}$ (the name denotes the similarity with the backwards movement of a gun after firing a shot)

## 5 PRELIMINARY CONCLUSIONS

As seen in figure 7 the use of strain velocity allows for a forecast of final time

The second model seems more promising, with a correlation coefficients of 0,95 (see figure 6). The goal is to establish a relationship between the number of days in each step and the magnitude of the final error in the estimation of the swelling modulus $\underline{k}$. Probably this will conduct to the need of working, not with a single value of $\underline{k}$, but with a range. In any case the variability of the available data suggests that this range approach could be sound. This is a time consuming research (with many practical problems, see figure 8) and we expect to be involved in it several years yet.

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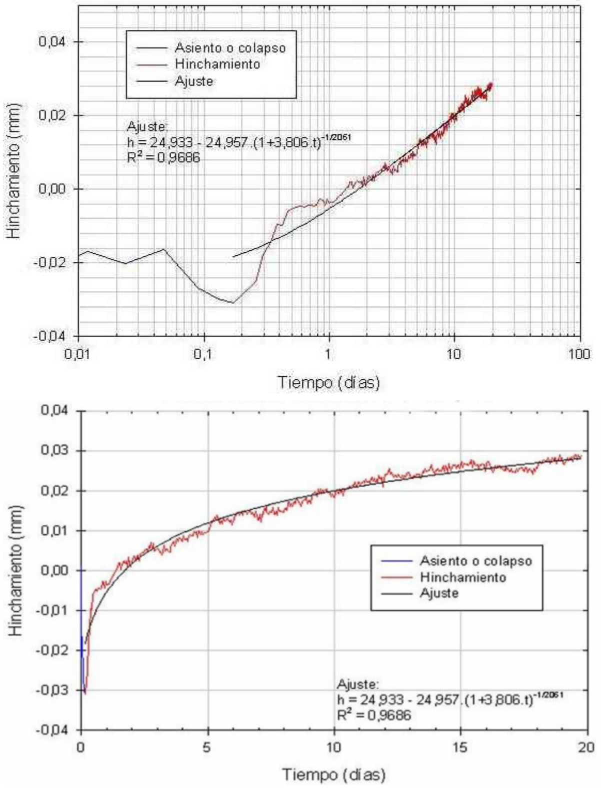


Figure 6 Diagrams showing swelling strain vs. time for a sample of El Perdón marls at two different scales. Vertical stress 0,8 Mpa (Polytechnic University of Valencia)

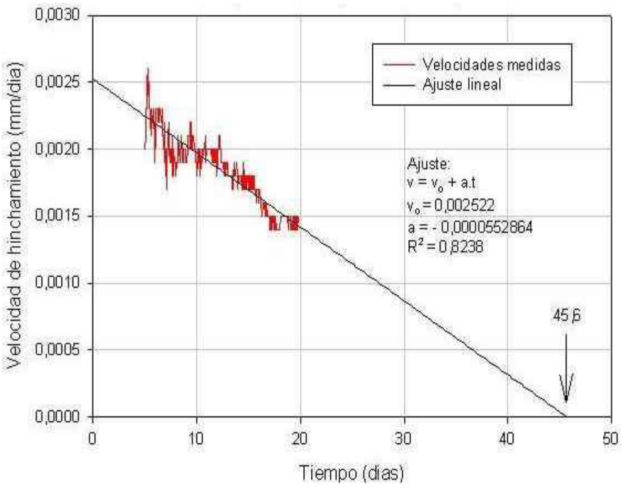


Figure 7 Diagram showing swelling strain velocity vs. time for the sample of figure 6 (Polytechnic University of Valencia)

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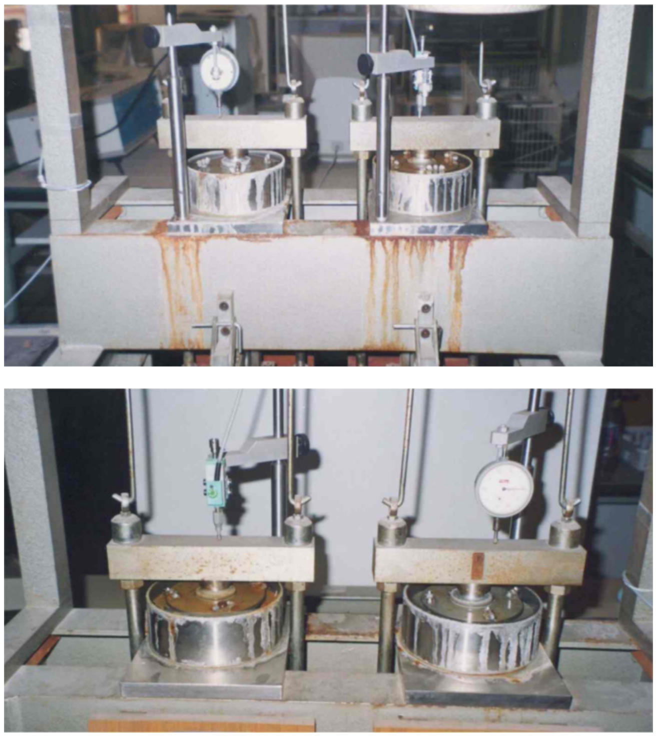

Figure 8 Pictures showing several practical problems ( oxidation, external contamination of the oedometers) due to the long time needed for the tests (Polytechnic University of Valencia)