Secondary consolidation of some organic Spanish soils

Consolidation secondaire de certains sols organiques espagnols

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ABSTRACT

The results of conventional oedometric tests carried out on organic soil samples have been revised, calculating the coefficient of secondary consolidation at different load increments. A linear relationship has been observed between this coefficient and the logarithm of water content. The result of the monitoring of four embankments on organic soils is also presented and is compared with the results of conventional oedometric tests obtaining an acceptable correlation in two of the four cases.

RESUME

On a révisé les résultats des essais oedométriques conventionnels, réalisés sur des échantillons de sols organiques, en calculant le coefficient de consolidation secondaire pour differents chargements . On a ainsi observé un rapport linéaire entre ce coefficient et le logarithme de l'humidité. On présente également le résultat de l'auscultation de quatre remblais sur des sols organiques, qui a été comparé avec les résultats des essais oedométriques conventionnels, ce qui a permis d'obtenir une corrélation acceptable dans deux cas sur quatre.

INTRODUCTION

An organic soil is an aggregate of mineral particles and basically plants. These can be found in different states of decomposition and humification, and in various sizes (leaves, roots, stems, logs, etc.)

This peculiar structure is one of the reasons why the study of the compressibility of an organic soil cannot be performed in most cases with the Terzaghi classic consolidation theories.

In recent years numerous authors have carried out a large number of experimental works with purely organic soils (peat). Some of them (Berry and Poskitt, 1972; Berry and Vickers, 1975) have developed a general theoretical treatment incorporating a relative amount of the factors which tipify the behaviour of peaty soils.

In general lines it can be said that the primary consolidation is due to the water drainage of the macropores system (among mineral or organic particles), while the secondary consolidation is due to the compressibility of the "mineral-vegetal skeleton". When the vegetal skeleton is clearly fibrous the compressibility can be linked to another form of drainage much slower than the primary, this is the water drainage from micropores towards the macropores.

To differentiate clearly both consolidations in the time scale is a complicated work and, esen even more if we think of the numerous possible mineral-vegetal soil combinations.

The secondary compressibility in highly organic soils is characterized by its slow process and the difficulty to accelerate it by artificial means. Numerous large scale and laboratory experiments in test embankments have permitted to maintain the hypothesis that the secondary consolidation is governed by a law which varies linearly with the logarithm of time. However Vautrain (1978) presented an oedometric test spanning 1.5 years, carried out with peat samples which proved that the secondary settlement did not vary linearly with the logarithm of time.

One of the purpose of this paper is to present the results of the 10 years monitoring of embankments built on organic soils and to compare them with the results obtained from conventional oedometric tests.

The linearity of the secondary settlement seems to appear in them depending on the logarithm of time which allows to establish reasonable conclusions on the appraisal of future settlements.

DESCRIPTION OF STUDIED AREAS

There are wide areas in many locations of the Spanish geography with deposits of organic soils relatively near the surface. A large part of these areas is located in the coast corresponding to river estuaries, old lagoons or deltas.

In the Valencia coastline (figure 1) there are numerous areas of old marshes or swamps mostly associated to river deltas, in a slowly subsiding shore. Almost all of them have lost their original features and now they are refilled (mainly by man) and used as agricultural land. Only the "Albufera de Valencia" and the "Marjal de Pego" and other smaller areas keep part of their original physiognomy.

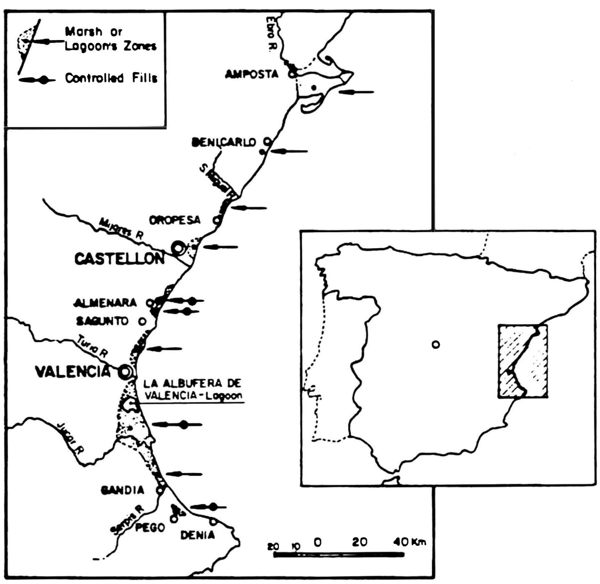

Figure 1. Location of the Areas

A dense system of earth roads passes through these areas as well as modern roads, highways and railroads.

The high compressibility of the sediments of old marshes (generally very organic) originates large settlements in overlying roads, which require frequent repairs, or previous treatments intended to increase the rate of settlements occurrence and/or reduce it.

The areas studied in this paper are as follows:

a) Ebro river mouth

This is an area located upstream the delta of the Ebro river, where large zones have been formed by river deposits (silts, sand and gravels) alternated with organic deposits reaching depths down to 20 m. The peat levels are little humified and they present a clearly fibrous structure.

b) La Llosa and Benavites marshes

Located North and South of Almenara town, dedicated now to horticultural and fruit growing cultivations. In the investigated area there is a 2.50 to 3 m deep layer of organic silts and peats resting on more competent silts and clays of continental origin.

c) Jucar river estuary marshes

These areas are distributed between the river's present course and the old shoreline.

They present deposits of organic silts and peats, frequently at two levels, interbedded with the Jucar river deposits or with rill-wash or sheet-flood type continental deposits, even with beach sandy deposits, etc.

These areas which were dedicated to rice cultivation until not too long ago are experiencing frequent changes due to the drainages and embankments for citrus fruits cultivation.

d) Gandia marshes

South the above zones, there is a 15 km^2 peat bog, between the Vaca and Serpis rivers, formed from a sand bar that isolated a lagoon. The bar can be associated to a deltaic structure with favorable N-S sea currents. An amorphous-fibrous peat level of 3 to 8 m of investigated depth appears in these peat bogs, and in general on fine sand layers deposited on shallow sea waters.

e) Pego marsh

It keeps its original state although in a limited manner, over an area of 20 km^2 of flooded land. There is a peat and organic silt layer down to 4 m depth in the areas subject to testing with frequent fine sand interlayers which correspond to the aeolian belt which separates the swamp from today's shore.

The embankment settlement of highways passing through the east end of the swamp areas of the Llosa, Benavites and Jucar river estuary has been regularly controlled.

DESCRIPTION AND CHARACTERISTICS OF ORGANIC SOILS

These soils consists of silts, clays or sands, with remains of plants in a more or less descomposed state and water content. The colour is generally dark, from bluish gray to blackish tones (in the case of peat).

The presence of organic matter gives them a peculiar appearance, up to the point that it is difficult, and sometimes impossible to qualify them by the typical properties of mineral soils. The granulometric analysis or Atterberg limits and other conventional test are not suitable for soils featuring organic particles.

The content of organic matter, the state and shape of vegetal structure, water content, the density and ratio of voids are physical characteristics of organic soils which permit to differentiate them and even to establish correlations with other mechanical properties, especially the compressibility under load.

In accordance with the MacFarlane classification (1969) it can be said that the peaty fraction of organic soils found in the Valencia region belongs to the (6-7) or (10) cathegory, namely, a mixture of finely fibrous peat with more amorphous and humified zones in which somewhat woody remains appear locally.

Table 1 Characteristics of organic soils

Zone	number of samples	O.M.	W.	γ_d	e_o	C_c	
Ebro River	5	10-68 33,9	40-196 107,7	3,7-12,6 7,7	1-4,58 2,694	0,42-2,15 1,09	Fibrous
La Llosa Benavites	7	2-45 22	35-180 94,8	5-13 7,6	0,8-3,08 2,09	0,69-0,95 0,82	Fibrous Amorph.
Estuary Jucar river	7	18-98	65-413 209,7	1,9-12 6,1	1,49-8,45 4,11	0,6-4,24 2,2	Fibrous Amorph.
Gandia	11	2,6-99 46,1	85-742 312,3	1,4-8,4 4,0	2,04-10,77 5,80	0,5-4,55 2,34	Fibrous Amorph.
Pego North	4	10,2-93,8 34,5	104-366 215,1	2,3-7,1 4,5	1,80-8,01 4,64	0,48-3,0 1,6	Fibrous Amorph.
Pego South	5	9,8-25,6 14,05	26-150 74,9	5,5-17 10,9	0,93-1,62 1,30	0,30-1,60 0,70	Mixture of sand & fibrous peat

O.M. = Organic matter
W = Watter content
γ_d = dry specific weight (KN/m^3)
e_o = voids ratio
C_c = coefficient of compressibility

Samples taken in peat bogs permit to establish an age of 6,000 years.

The table 1 summarizes for each investigated area the range of values and the average value of the properties deemed to be the most representative.

COMPRESSIBILITY

Thirty five conventional oedometric tests have been reviewed using 45 mm diameter and 12-20 mm high cells, and load increments of 1 day of duration and final load pressure = 10 - 20 - 40 - 80 - 150 - 300 - 600 KPa.

The primary and secondary consolidation has been differentiated in each consolidation curve, whenever it has been possible.

After drawing the oedometric curve (e - log σ) corresponding to primary consolidation, the preconsolidation pressure and coefficient of primary compressibility have been calculated:

$$C_c = \frac{e_1 - e_0}{\log \sigma'_0 - \log \sigma'_1}$$

In almost all samples located above three meters depth, it has been possible to check that they were over consolidated with consolidation ratios ranging 2 to 20 times normal pressure. This overconsolidation is probably due to dessication and fluctuations of the water table.

The known relationship existing between C_c and water content has been verified, which in our soils is $C_c = W/95 - 0,3$, although for $W \geqslant 300$ there is a scatter in the results which makes it advisable to slightly reduce the C_c.

The coefficient of secondary compressibility C_s has also been calculated in each load increment, i.e.: the slope of the hypothetical straight line characteristic of the secondary consolidation.

$$C_s = \frac{\Delta H}{H} \times \frac{1}{\log \frac{t+\Delta t}{t}}$$

In figures 2, 3 and 4 a possible correlation between C_s coefficient and moisture has been drawn (for three load increments). Similar correlations have been drawn by NAVFAC DM-7 (1971).

This correlation is expressed as follows: $C_S = \frac{1}{\alpha} (\log W - \beta) \pm$ scatter

where:

$\alpha = 25\text{-}35$

$\beta = 1,5 - 1,6$

These correlations are reasonable, as it is logic that the secondary consolidation should be faster (higher intensity in the same period of time) for greater soil water contents (greater voids ratio).

However, some remarks relative to the oedometric tests from where these coefficients have been obtained should be made.

They refer to conventional oedometric tests not specifically made for this analysis and compiled from several works.

Although the load time length of each increment is not long enough to guarantee a C_s representative value, in each step the consolidation starts when a secondary consolidation has already started under a lower load.

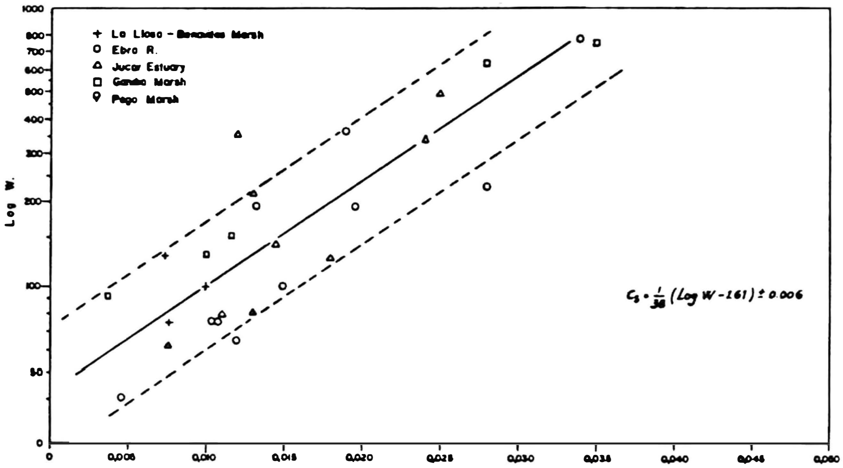

Figure 2. Coef. of secondary compr. C_s vs. Log. water content (Load increment 40-80 KPa)

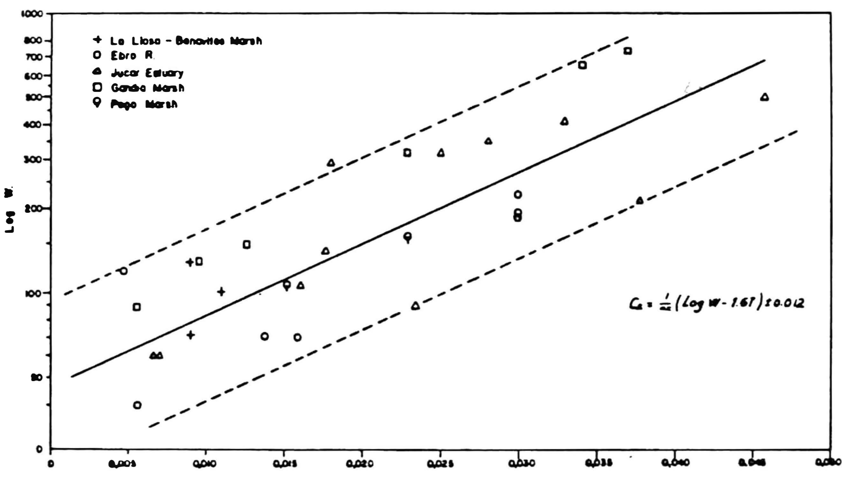

Figure 3. Coef. of secondary compr. c_s vs. Log. water content (Load increment 80-150 KPa)

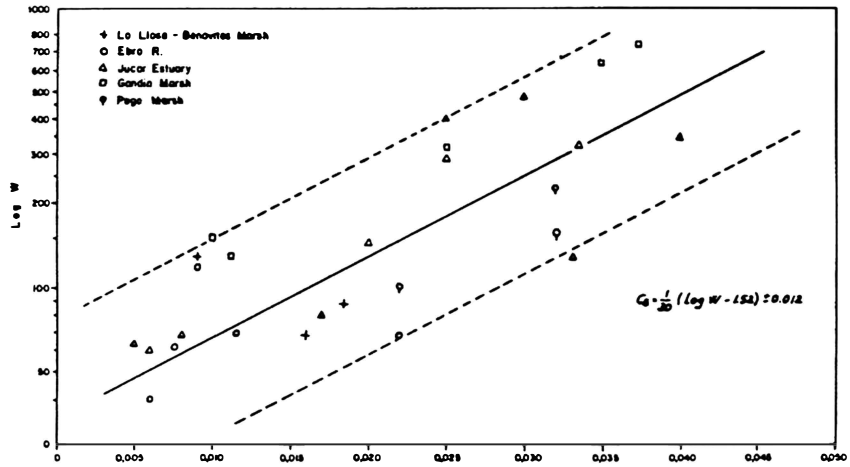

Figure 4. Coef. of secondary compr. C_s vs. Log. water content (Load increment 150-300 KPa)

- For large deformations the bi-dimensional model of the oedometer does not represent the tridimensional phenomenon of the reality.

- Furthermore, the size of the oedometric cell is not valid for certain fibrous peats with remains of stems having a size comparable to that of the cell. In this case the primary consolidation would have not shown up in the oedometer.

- For high water contents, the process of sample cutting and handling can sensibly disturb the test, and even the water content determination itself.

Anyhow, the conclusions arrived at from these conventional tests are deemed to be sufficiently reasonable to be taken into account and could be used for settlements estimation purposes.

IN SITU TESTS

SETTLEMENTS' MONITORING

During several years, AUMAR, S.A. Society Operating of the Tarragona-Valencia-Alicante toll highway, upon a systematic site monitoring has recorded the settlements measured in the embankments built in two of the above mentioned areas and, the monitoring of a third embankment in other zone of the swamp is now being started at present.

The height of the embankments in such areas is limited from the stability, point of view the 3 m high embankements are in no case to be exceeded.

The figure 5 shows the settlements measured in the four zones, with the same origin and time logarithm variable. The initial part of three of the correlations is missing (monitoring could not be made due to constructive reasons) and the fourth one corresponds to a recent embankment.

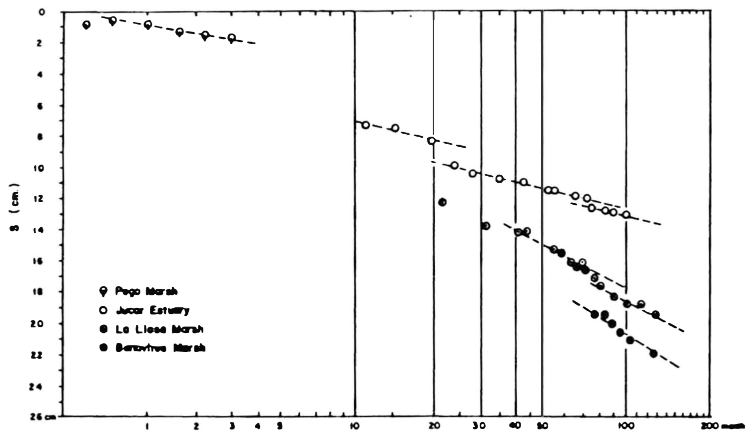

Figure 5. Settlements measured

Table 2 Coefficients of secondary consolidation measured in laboratory and in place

ZONE	C_s measured in				
	Laboratory			In place	
	Date	Sample Depth (m)	C_s	Period of monitoring (years)	C_s
La Llosa	1.971 1.983	1,30 1,40	0,0107 0,0087	1.975 - 1.985	0,030
Benavites	1.971 1.983	2,80 1,30	0,0087 0,0079	1.975 - 1.985	0,042
Estuary Jucar River	1.974	1,50	0,024	1.976 - 1.984	0,020
Pego S	1.974	2,00	0,011	1.984 -1.985	0,015

The correlations drawn allow an approximation with one or two slope straight lines sensibly similar, with breakages or peaks which are always related to marked and steady fluctuations of the water table.

The slope of these straight lines, i.e. the coefficient of secondary consolidation C_s can be seen in table 2.

BORINGS AND LABORATORY TESTS

Eleven years after the filling, exploration borings were made to know the condition of the organic soils after such load period, in the La Llosa and Benavites areas. The tests made on these samples permitted to know:

- The undrained shear strengh C_u has been multiplied by 2 to 3 times.
- The rebound part of the oedometric curve has a noticeable slope, indication therefore of a marked overconsolidation.
- The secondary consolidation measured in the oedometer, in a load increment maintained during 10 days, is governed by a coefficient C_s of a value very similar to that obtained in the original borings.

RESULTS

The table 2 summarizes the coefficient C_s measured in each zone, both in laboratory and soil, which allow to arrive to the following conclusions.

- The coefficient of secondary consolidation obtained in the oedometer has practically not changed in almost 12 years for the clearly organic samples.
- In the monitoring periods the settlement seems to change linearly with the logarithm of time, except for some discontinuities originated generally by sharp variations of the usual conditions of the water table.
- The C_s coefficient measured in place in two of the four areas is very near to that obtained in the oedometric test. In the other two, the coefficient measured in place is three to five times greater than that of the oedometers.

FINAL CONCLUSIONS

A correlation existing between water content (W) and the coefficient of secondary consolidation C_s obtained from conventional oedometric tests has been checked. This correlation seems to be linear between C_s coefficient and the logarithm of W.

The estimation of settlements by secondary consolidation in the organic soils could be aproximately obtained from the C_s coefficient measured in oedometric test with long load increments.

The samples must be representative of the reality requiring samples of larger size the more fibrous is the vegetal structure.

The load increments must reproduce the real load on the soil. For peaty fibrous soils, initially very pervious , the load increments can be replaced by only one with the tests final load, while in peaty soils more amorphous, the duration of load increments should allow the almost complete drainage of the macropores system.

However, a continued monitoring during the first years of service is advisable, to adjust the coefficient obtained and to allow for the necessary provisions for compensation of estimated settlements.

REFERENCES

ADAMS J.I., (1965). The Engineering Behaviour of a Canadian Muskeng, Proc. 6th International Conference on Soil Mechanics and Foundation Engineering, Vol. 1, p. 3-7.

BERRY P.L., POSKITT T.J., (1.972): The consolidation of peat Geotechnique, Vol. 22, p. 27-52. London.

BERRY P.L., VICKERS B., (1.975): Consolidation of fibrous peat. J. Geot. Eng. Div., p. 741-753.

MAC FARLANE I.C., (1.969): Muskeg Engineering Handbook, Muskeg Subcommittee of the NRC, - Associate Committee on Geotechnical Research, University of Toronto Press.

NAVFAC DM-7 (1.971). Design Manual Soil Mechanics Foundations and Earth Structures. Department of the Navy, Naval Facilities Engineering Command, Washington DC.

ROMAN F. (1.971): Los Suelos Organicos, su origen y propiedades, Sem. Ingeniería Geotécnica, E.T.S. Ing. Caminos, Valencia.

VAUTRAIN J. (1.978): Influence de la structure et des constituants de la Tourbe sur son comportement, Bull. Liaison Labo. P. et Ch., vol. 96, p. 7-16, París.