Compacted silt anti-contamination barriers

Barrières anticontamination de limon compacté

A. Serrano – *U.P.M., Madrid, Spain*
E. Dapena – *U.P.M., Laboratorio de Geotecnia, Cedex, Madrid, Spain*

ABSTRACT: This work studies the characteristics of the compacted silts that are used as anti-contamination barriers to isolate the permeable soil layers in which the main buildings of a nuclear plant were situated, whose purpose was to add a further barrier with a view to preventing contamination in the event of a leak from the buildings. An analysis is made of the properties most closely linked to the isolating capacity of the silt barrier: their mineralogical composition and the characteristics of the compacted material, especially as regards permeability, for the conditions in which the barrier was laid.

RÉSUME: Ce dossier est une étude des caractéristiques des limons compactés qui sont utilisés comme barriéres anticontamination pour isoler les couches de sol perméable sur lesquelles sont construits les principaux bâtiments d'une centrale nucléaire, afin d'ajouter une barrière supplémentaire en cas de contamination provenant de fuites dans les installations. Le dossier contient une analyse des propriétés se rapportant plus précisément aux capacités d'isolation des barriéres de limon: composition minéralogique et caractéristiques du matériau compacté, en particuller celles concernant la perméabilité, dans les conditions d'utilisation prévues pour les barriéres.

1 INTRODUCTION

A Nuclear Power Plant consisting of two electric power production generators, was constructed on a meander of the River Ebro, Fig. 1. A 1,5 m. thick surface layer of very low-permeability earth, and a 4 m. thick surrounding screen, also made with the same soil, were designed with a view to isolating the Generator 1 environment, lying on a terrace susceptible to river flooding, from both river water flowing in to the foundation area, and to prevent water that might contain contaminants from flowing out.

The material used in the construction of these anti-contaminant barriers, consists of silts of aeolian origins, that were covering the Ebro terraces in that area.

This paper contains the characteristics of the compacted silts used in the construction of these barriers.

2 GRAIN SIZE

These silts, owing to their aeolian origins, are generally made up of fine material. The average values of the sand, silt and clay contents of this layer can be taken as 10%, 77% and 13%, respectively.

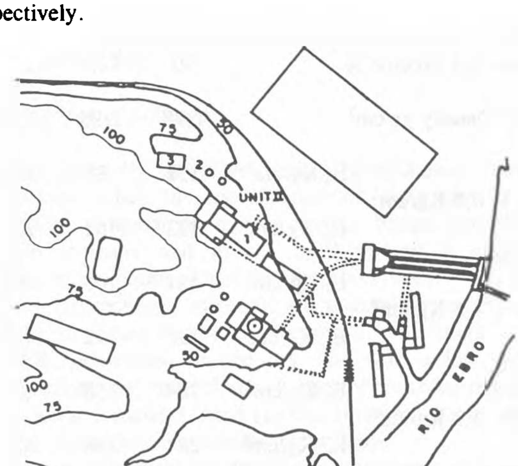

Figure 1. Nuclear Power Plant Site

3 MINERALOGICAL COMPOSITION

The carbonate and sulphate contents were determined by means of the test for quantifying CO_2 and SO_3 test in the samples.

Bearing in mind both the clay content obtained from the grain-size analysis and the hypothesis that all the carbonates were calcium carbonate (CO_3Ca) and that all the sulphates were in the form of gypsum ($SO_4Ca.2H_2O$), the average representative mineralogical composition of the silt layer could be as shown in Table I

4 PLASTICITY

The Atterberg limits of 69 samples were determined, and somewhat over half of these proved to be non-plastic, whereas the rest, although they were lying above Line A, Fig. 2, mostly had a plasticity index of between 4 and 7, which is also characteristic of silty materials.

Table I. Mineralogical composition.

MINERAL	%
Carbonates	37
Sulphates	1,6
Clays	13
Quartz and others	48,4

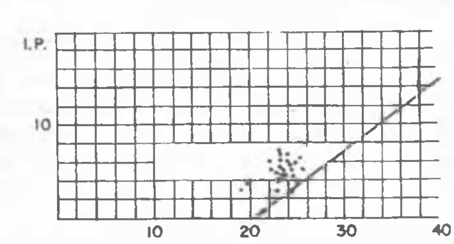

Figure 2. Plasticity of the silt layer

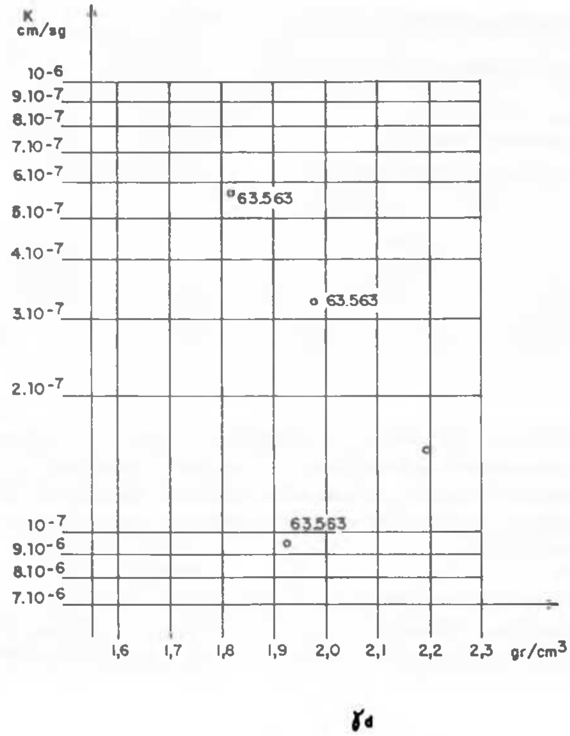

Figure 3. Variation of the permeability coefficient with the density.

5 CHARACTERISTICS OF THE COMPACTED SILTS

5.1 Dry density and moisture

The result of the Modified Proctor test was taken as a reference in the silt compaction. A maximum density of γ_{max} = 1.98 gr/cm^3, for a moisture of 11.4% was obtained.

5.2 Permeability

Permeabilities ranging from the interval of 5 x 10^{-6} cm/sec. $\leq$ K $\leq$ 1 x 10^{-7} cm/sec. Fig. 3, were obtained with densities between 1.80 and 2 gr./cm^3.

These permeabilities are considered to be sufficiently low to allow the anti-contamination barriers to fulfil the purpose for which they were designed.

5.3 Cohesion and angle of friction

The cohesion and angle of friction of the unsaturated and saturated samples can be seen in Tables II and III, respectively.

An angle of friction for the compacted saturated sample above 95% of the P.M. density, can be considered greater than φ = 34°.

Table II. Cohesion and angle of friction* Unsaturated Compacted Silts.

W %	γ_d gr/cm^3	Proctor %	c Kg/cm^2	φ °
13,4	1,78	90,0	0,55	33
13,0	1,95	98,5	1,04	36
10,6	1,99	100,4	1,50	37,5

* Determined in total stresses

Table III. Cohesion and Angle of Friction** Saturated Compacted Silts

Proctor %	c' Kg/cm^2	φ' °
90	0	34
98,5	0	35,5
100,4	0	36

** Determined in effective stresses

In the saturated compacted silts, the cohesion is zero and the angle of friction varies slightly, between 90% of the P.M. density and 100% of the P.M. density.; it goes from φ = 34° to φ = 36°.

5.4 Undrained resistance

Undrained unconsolidated triaxial tests were performed on remoulded samples with three densities and lateral pressures of 0.5; 1.5 and 3 Kg/cm^2. The results are shown in Table IV. For a confining pressure of σ_3 = 1.5 Kg/cm^2, the resistance ranges from 5.46 Kg/cm^2 with a density of 90% of the P.M., to 10.73 Kg/cm^2 with a density of 100% of the P.M.

5.5 Deformability

The deformation moduli obtained in the consolidated triaxial and undrained failure tests carried out upon three samples with different degrees of compaction, can be seen in Table V, both for those corresponding to the initial load section, E_o, and the section at approximately 50% of the failure load E_m.

Fig. 4 shows the relationship between the modulus of deformation and the confining pressures for different densities, which were taken to define the hyperbolic stress-strain model for the silt behaviour.

Table IV. Triaxial Test Resistance. Compacted Silts.

Modified Proctor %	90	98,5	100
Dry Density gr/cm^3	1,78	1,95	1,99
σ_{rot} Kg/cm^2 (σ_3 = 0,5 Kg/cm^2)	3,22	5,81	7,60
σ_{rot} Kg/cm^2 (σ_3 = 1,5 Kg/cm^2)	5,46	8,22	10,73
σ_{rot} Kg/cm^2 (σ_3 = 3,0 Kg/cm^2)	9,15	12,97	14,42

$\sigma_{rot} = (\sigma_1 - \sigma_3)_{rot}$

Table V. Deformation Modulus in Triaxial Test. Compacted Silts.

Modified Proctor %		90	98,5	100
Dry Density gr/cm^2		1,78	1,95	1,99
σ_3 = 0,5 Kg/cm^2	E_o Kg/cm^2	122	89	235
	E_m Kg/cm^2	122	151	235
σ_3 = 1,5 Kg/cm^2	E_o Kg/cm^2	241	168	402
	E_m Kg/cm^2	241	212	402
σ_3 = 3,0 Kg/cm^2	E_o Kg/cm^2	284	358	626
	E_m Kg/cm^2	284	358	626

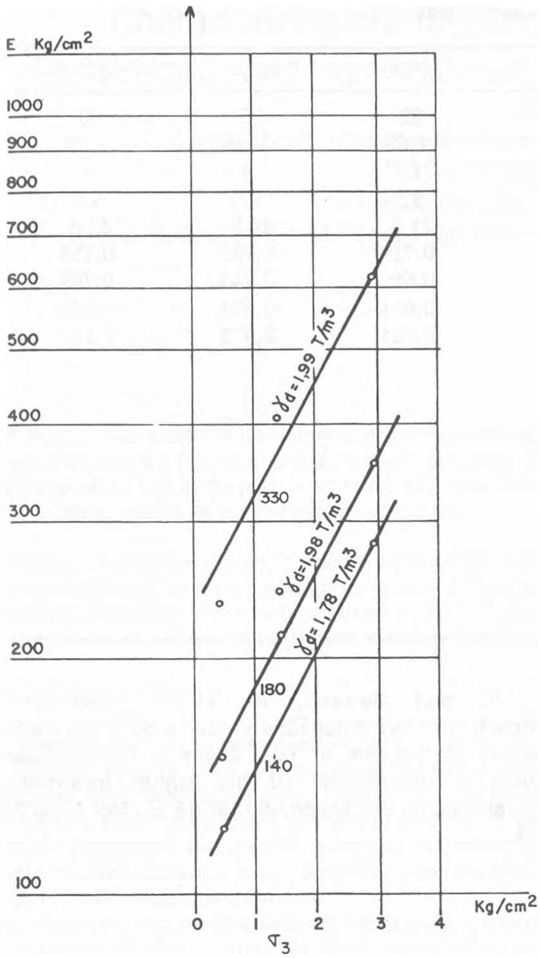

Figure 4. Variation of Young's moduly with the lateral stress applied to the remoulded sample for different values of the dry density.

Table VI. Deformation Modulus for σ_3 = 1 Kg/cm^2.

γ_d % P.M.	E Kg/cm^2
90	140
98,5	189
100	330

According to these relationships, the deformation modulus for each density at a confining pressure σ_3 = 1 Kg/cm^2, can be seen in Table VI.

5.6 Collapsibility

5.6.1 Types of collapse

It can generally be stated that a geotechnical material is collapsible when the modification of some state condition (pressure, temperature, moisture, etc.), brings about a change in the structure that reveals itself through a considerable reduction in volume, Uriel and Serrano (1970).

Many geotechnical materials are susceptible to collapse to a greater or lesser degree. For example, the "miga" sands in Madrid, compacted on the dry side with a low degree of compaction, undergo volume changes of the collapse type when they become moist, Corral (1979). However, rocks with very high isocompression pressures do collapse.

Some geotechnical materials are particularly susceptible to collapse. Such materials are loose sands, gypsiferous silts, loess, cemented clays and, in general, low density soils, and especially semi-saturated soils that are not very dense and macroporous soils.

The external conditions that induce volumetric changes can be diverse. In the case of loose sands, a dynamic force causes the collapse of a natural metastable structure. In the case of semi-saturated soils, a sudden increase in the degree of saturation brings about a reduction in volume. This is what happens to loess and some clays and gypsiferous silts. A third potential cause is the stress change, which, with the failure of the bonds that maintain the natural structure, leads to another one that is denser and more stable. Some gypsiferous silts, sensitive cemented soils and macroporous rocks could be included in the last group.

For the purpose of studying the behaviour of collapsible materials, they can be classified into two groups:

Group I:

Materials in which there is a sudden change in the effective stress-deformation relationship for a certain collapse pressure, without the final resistance of the material being reached. It is thus the case that the collapse is only caused by stress changes for effective pressures. Clays or cemented silts and highly porous rocks belong to this group. For example, when they are tested at a constant moisture, a considerable modification in the compressibility module can be detected when the effective pressures reach a certain level.

Group II:

Materials in which, without the sudden appearance or when the conditions that cause the collapse are constant, no change in the stress-strain relationship takes place. Such is the case for loess or some of the gypsiferous clays. If they are tested at a constant moisture, continuous curves are obtained, without angularity for this relationship. However, with saturation, a considerable volumetric change takes place, probably due to an increase in the pore pressure, which, in turn, cause the material's shear strength to be used up. A stress-strain relationship does not necessarily have to exist, given that the structure change can be different, depending either on the what the moisture velocity is the stress state prior to such moisturising.

Almost all collapsible materials have characteristics which fall into both group categories, but it is generally the case that only one of the groups has a predominant effect.

The degree of collapsibility is a function of the ease with which the natural structure of the material can be transformed into a denser material, and that is why the collapse phenomenon can be more clearly detected in low density materials.

The collapse of the compacted silts used for the anti-contamination barriers at Ascó N.P.P., belong to Group II.

5.6.2 Collapse of compacted silts

Determining the collapse of compacted silt was of special interest, because these silts in their natural state have a loose structure, and the settlements that took place as a result of the Group II collapse, were over 35% for loads of 6 Kg/cm^2.

The collapsibility of silts subjected to a load, were determined by edometric tests in which the sample was submerged under different load conditions, collapse of Group II.

The results obtained can be seen in Table VII. The settlement that is caused by the collapse of silts placed with a high moisture, are low, below 0.4%, even with low densities, about 90% of the Modified Proctor density.

In the case of silts with a humidity of 2% below the optimum Modified Proctor level, but with low densities, about 80% of the Modified Proctor level, the collapses that occurred were equal to or greater than 3%.

Table VII. Results of the collapse tests

Ref.	M-1	M-2	M-3	M-4*	M-5*	M-6*
γ_d %PM	85	90	90	82	79	80
γ_d gr/cm^3	1,69	1,79	1,89	1,62	1,56	1,59
P Kg/cm^2	0,5	1	1,5	1,5	3	6
W_i %	16,8	16,3	13,8	9,5	9,6	9,6
W_p %	20,9	18,3	15,3	21,3	22,9	22,6
e_i	0,656	0,571	0,550	0,719	0,785	0,753
e_{Fd}	0,643	0,558	0,532	0,659	0,746	0,709
e_{FW}	0,639	0,555	0,527	0,681	0,694	0,649
S %	0,243	0,192	0,326	0,825	2,978	3,511

e_i = initial void index
e_{Fd} = void ratio under load P
e_{FW} = void ratio under load P with flooding

$$S = \frac{e_{Fd} - e_{FW}}{1 + e_{Fd}} \, . \, 100$$

* = Sample of silts in natural state

CONCLUSIONS

Two anti-contamination barriers, one horizontal, on the surface, and the other vertical, around the perimeter, were constructed for a nuclear power generator, in order to isolate it.

These silts consisted of 37% carbonates, 1.6% gypsum, 13% sands and 48% quartz and others.

The silt-content is 77% and the clay-content 13%.

The maximum density obtained with the Modified Proctor test power, was 1.98 gr/cm^3, with an optimum moisture of 11.4%.

These compacted silts had a low permeability $K \leq 5.10^{-6}$ cm/sec., which guaranteed that the anti-contamination barriers would fulfil the purpose for which they were constructed.

The cohesion is zero and the angle of friction $\varphi \geq 34°$ in saturated samples. The failure load for the compacted silts, as a function of the "in situ" placement density and the confining pressure, can be seen in Table IV.

Young's modulus corresponds to a confining pressure of σ_3 = 1 Kg/cm^2 and obtained from samples of different densities, is as follows:

γ_d (% P.M.)	E Kg/cm^2
90	140
98,5	180
100	330

When moisture levels are 5% above optimum moisture, the collapsibility is low.

When moisture levels are 2% below this optimum moisture and densities are 80% of the Modified Proctor level, the collapsibility is high when the silt is subjected to loads above p = 1.5 Kg/cm^2.

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