Flexible Pavements, Gomes Correia (ed.) © *1996 Balkema, Rotterdam. ISBN 90 5410 523 2*

Resilient behaviour of soils

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ABSTRACT: This study examine the resilient behaviour of sands, silts and clay for different moisture conditions and various stress paths. The analysis of data from repeated load triaxial tests carried out on these recompacted soils has enable to test different models and validate their hability to predict resilient response of soils.

1 INTRODUCTION

The soils beneath pavements and the unbound aggregate layers of road construction are subjected to a variety of stresses and pore water pressures. The levels of these stresses pressures are very different from the conditions usually considered in geotechnical engineering problems.

The conditions peculiar to the soils and aggregates in or under pavements are as follows:

a) normal stresses in unloaded pavements are very low;
b) pore pressures are small in magnitude and frequently negative;
c) the materials are often partially saturated;
d) traffic loading applies repeatedly rotated stress field to the soil or aggregate.

In order to be able to design and analyse pavement structures it is necessary to quantify the stiffness properties of the lower layers of the construction. Many models have been proposed for this (some of which are covered in this paper) but, because of the complexities outlined above, they have generally been developed for simplified cases.

It is the purpose of this paper to study the effect of stress level and water content especially in resilient behaviour of two fine grained soils. For this purpose a test program was undertaken at the "Laboratório Nacional de Engenharia Civil" using Seine and Marne silt (LIM) and the London Clay (LOC).

Many of the findings will also be applicable to other soils but discussion of this is beyond the scope of this paper.

2 BACKGROUND

2.1 Cohesionless soils

The conventional manner to relate the stiffness response of a cohesionless soil with stress level is by means of the Kθ model (Hicks 1970) represented by the following equation

$$M_r = K_1\, \theta^{K_2} \qquad (1)$$

where M_r = elastical modulus; θ = first invariant of stress tensor; and K_1 and K_2 are material constants. This model has been applied by Gomes Correia (1985) over a wide variety of stresses paths in the compression zone.

Whereas the Kθ model may reasonably predict shear strains in response to both cycling axial and radial stresses, it may not be very accurate to predict volumetric strains as has been stressed by Gomes Correia (1985). It was for this reason that other models have been improved, like Boyce (1980) model and a variant to this model, which is represented by the following equation

$$\varepsilon_v = \frac{p^n}{K_1}\{1 - \beta(\frac{q}{p})^2\} \qquad (2)$$

$$\varepsilon_q = \frac{p^{n_1}}{3\ G_1}\ \frac{q}{p} \qquad (3)$$

where:

$$\varepsilon_v = \varepsilon_1 + 2\ \varepsilon_3 \qquad (4)$$

$$\varepsilon_q = \frac{2}{3}\ (\varepsilon_1 - \varepsilon_3) \qquad (5)$$

$$p = \frac{\sigma_1 + 2\ \sigma_3}{3} \qquad (6)$$

$$q = \sigma_1 - \sigma_3 \qquad (7)$$

ϵ_1 = axial strain; ϵ_3 = radial strain; p = mean normal stress; q = deviator stress; and K_1, G_1, n, n_1 and β = constants obtained experimentally.

This model has been applied successfully by Gomes Correia (1987) to predict the resilient behaviour of two sands (Fontainebleau sand - SFB - and Barreiro sand - BS). Table 1 summarizes the identification characteristics and the constants of the model.

The stress paths used in that study and a typical adjustment of the model are presented in Figures 1 and 2.

2.2 Fine grained soils

For fine grained soils the resilient behaviour is stress dependent and influenced by the water content or suction. Loach (1987) and Gomes Correia (1985) used two different models for unsaturated compacted fine grained soil represented by the following equations

$$M_r = A\ (\frac{p'_0}{q_r})^B\ q_r \qquad (8)$$

$$M_r = A\ (\frac{p'_0}{q_r})^B \qquad (9)$$

where p'_0 = mean normal effective stress or the suction at zero confined stress; q_r = reapeted deviator stress; and A and B are materials constants.

These models are discussed in Dawson and Gomes Correia paper presented in this section and they propose a new model represented by the following equation

$$M_r = C + A\ p'_0 - B\ q_r \qquad (10)$$

3 TEST PROGRAM

The test program for studying the resilient behaviour of fine grained soils was performed as for the granular materials in the following way: firstly a large number of a greater cyclic loading (80000 cycles) were applied (conditioning) until stabilization of permanent deformations, and then a number of different stress-paths were

Table 1. Identification characteristics of Fontainebleau sand (SFB) and Barreiro sand (BS). Constants of the model.

Soil	Characteristics						Modified Proctor		Model parameters (*)				
	% < #200	D_{50} (mm)	w_L (%)	PI (%)	G	Classification	γ^{max}_d (kN/m^3)	w_{opt} (%)	$1/K_1$	n	n_1	β	$1/3G_1$
SFB	4	0.2	NP	NP	2.64	A-3(0) SM	16	5.5	265.52	0.41	0.53	0.11	26.15
BS	12	0.4	27	17	2.67	A-2-6(0) SM	21	8.0	200.47	0.42	0.31	0.13	126

(*) ϵ_v and ϵ_q are in microstrain and p, q in kPa.

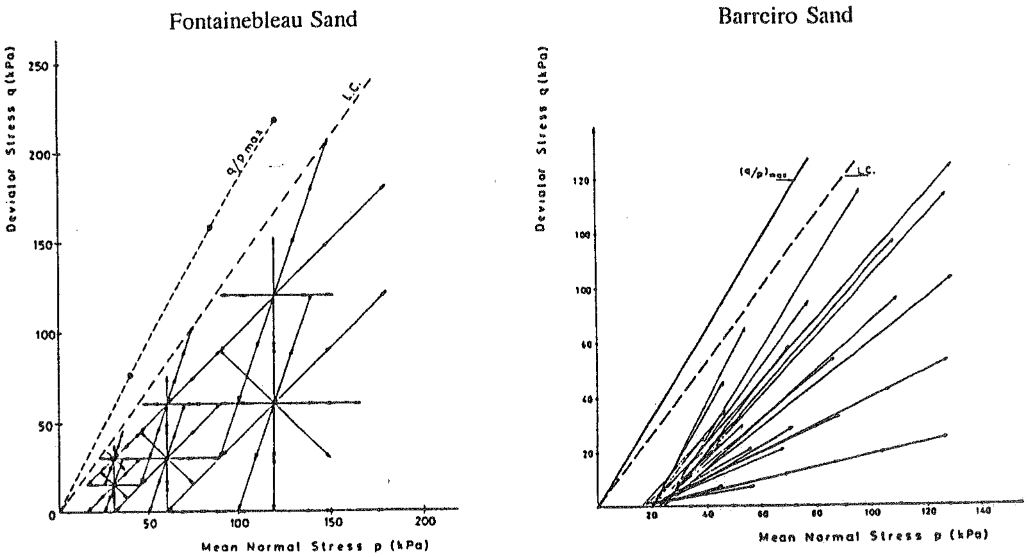

Fig.1 Stress paths used in the study of resilient behaviour of two sands (Gomes Correia, 1987)

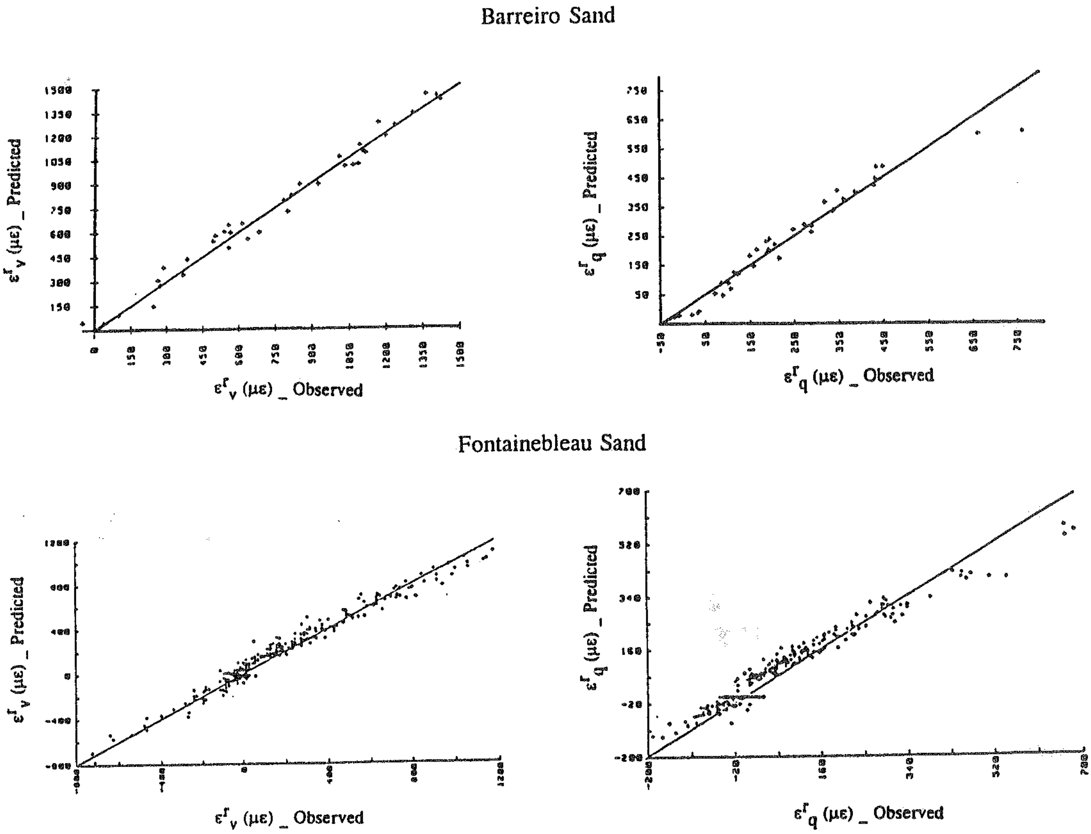

Fig.2 Adjustement of Boyce modified model for two sands (Gomes Correia, 1987)

applied. These stress-paths are presented in Figure 3. The test procedures were presented in a previous paper.

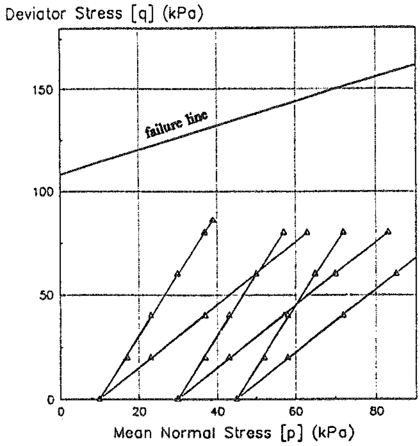

Fig.3 Stress path used for the study of fine grained soils

4 MATERIALS

The soils used for this study were a Seine & Marne silt (LIM) and the London Clay (LOC). A summary of their identification characteristics and compaction is presented in Table 2.

Table 2. Identification characteristics and compaction of Seine & Marne silt (LIM) and London clay (LOC)

Soil	Characteristics					Normal Proctor	
	% < μ2m	w_L (%)	PI (%)	G	Classification	γ^{max}_d (kN/m^3)	w_{opt} (%)
LIM	29	37	16	2.69	A-6 CL	17.6	17
LOC	61	76	51	2.69	A-7-6 CH	15.2	25

5 APPARATUS AND SAMPLE PREPARATION

The triaxial repeated loading apparatus at "Laboratório Nacional de Engenharia Civil" (LNEC) is a servo controlled hydraulic system. This equipment is able to apply both axial and confining repeated pressures. The deformation measurements are done by LVDT attached at the specimen and facilities exist to volume measurements and suction control and measurement. The computer control and data acquisition hardware used is a Hewlett Packard 3852A data acquisition unit and Hewlett Packard 900 series 300 computer. The software for data acquisition was written by LNEC. A sketch of the equipment is shown in Figure 4.

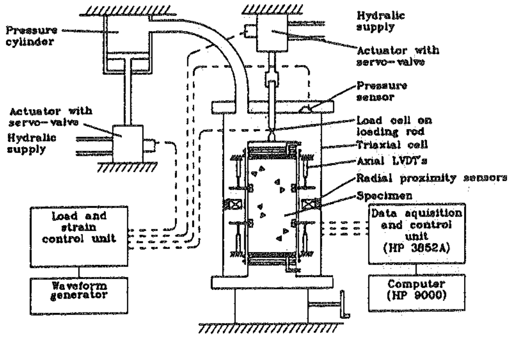

Fig.4 Triaxial servo hydraulic equipment at LNEC

The specimen preparation is done by Proctor compaction at three different water contents (w_{opt}-2%; w_{opt}; w_{opt}+2%). In order to obtain for each material the same density at different water contents the compaction energy is changed.

6 RESULTS

The resilient behaviour is generaly influenced by the conditionning. This is intended to simulate the behaviour during construction.

A typical result of the conditioning is presented in Figure 5 and it is observed that in all tests the sample approached a steady state response condition.

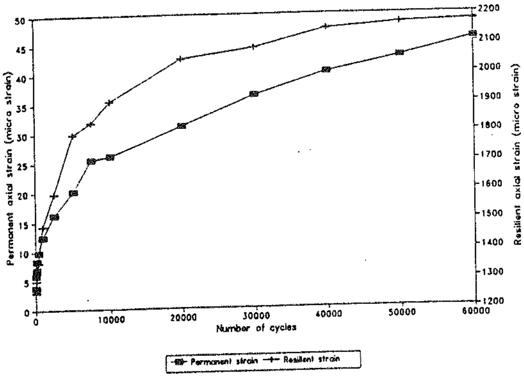

Fig.5 The resilient and permanent behaviour during conditioning

The resilient data for silt shows that for a low water content (w_{opt}-3%) the material have a nearly elastic behaviour practically independent of the initial confining stress and of the effect of cycling the confining pressure (Figure 6). However, this behaviour changes for samples compacted at optimum water content or greater, mainly due to the influence of the initial confining stress (Figure 7).

The resilient behaviour of London Clay is much more stress dependent for the range of moisture content used in tests (Figures 8 and 9).

For each moisture content some of the previously referred resilient models were tested and it was verified that the model presented by Dawson and Gomes Correia, in this section, produces the best adjustement. A typical result of model hability to predict resilient response is shown in Figure 10 and the coefficients of the model for each material and moisture conditions are presented in Table 3. The model was not applied to the silt at a moisture content of w_{opt}-3% because in this condition the material has practically a constant modulus (Figure 6).

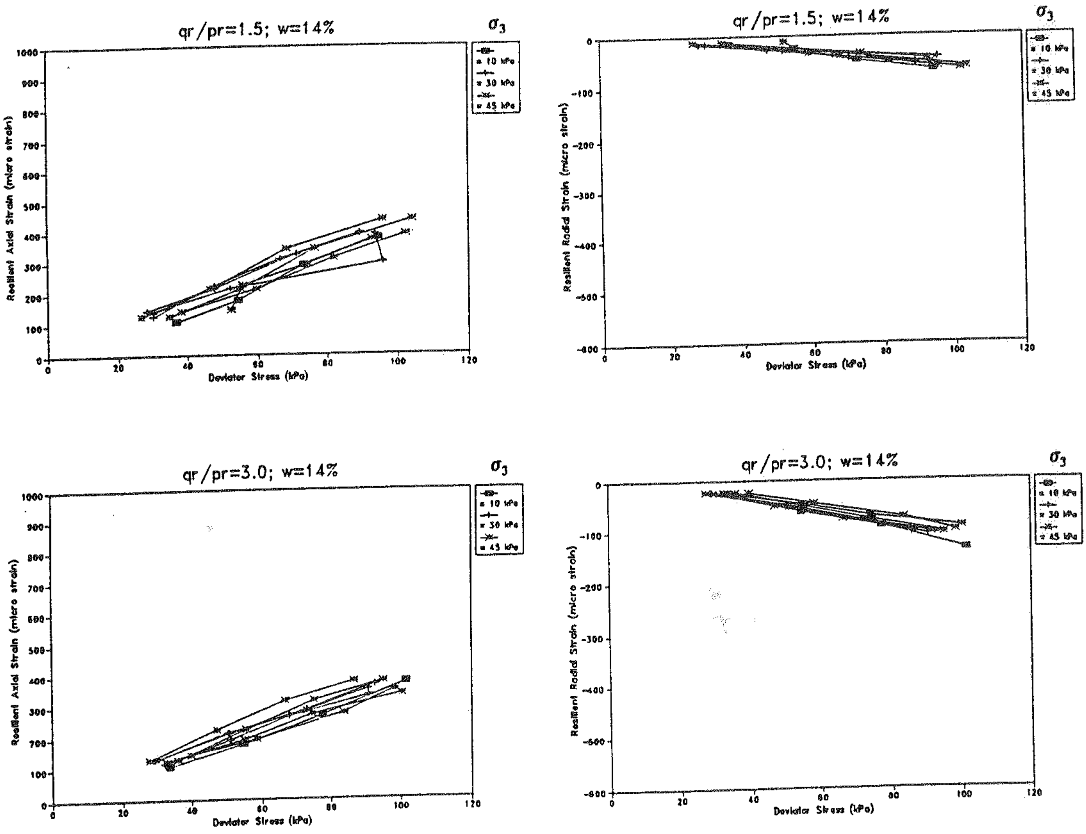

Fig.6 Resilient behaviour of silt for a moisture state of w_{opt}-3%

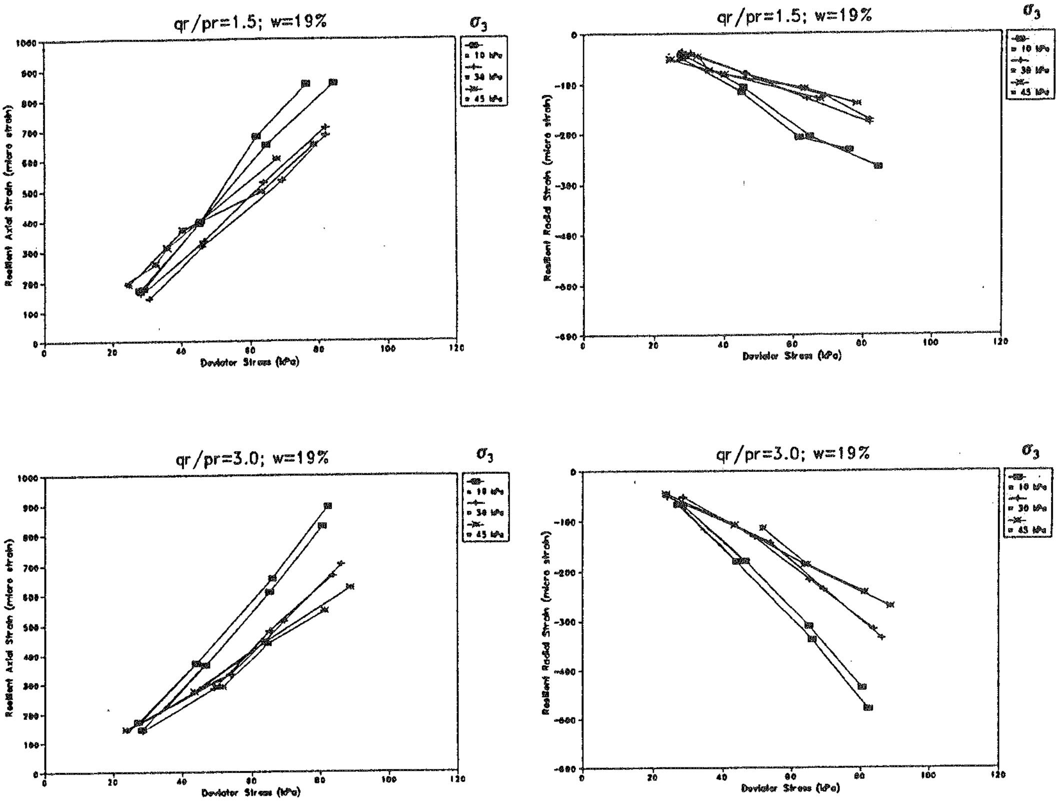

Fig.7 Resilient behaviour of silt for a moisture state of $w_{ópt}+2\%$

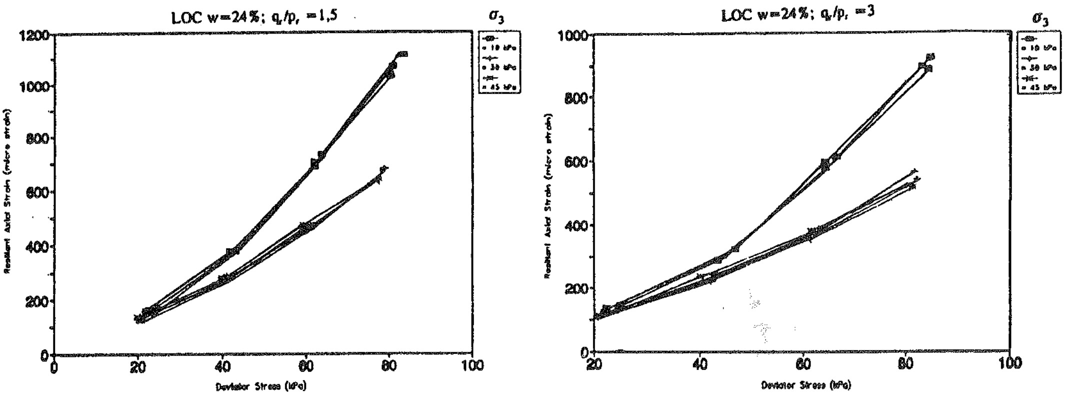

Fig.8 Resilient behaviour of London Clay for a moisture state of $w_{ópt}-1\%$

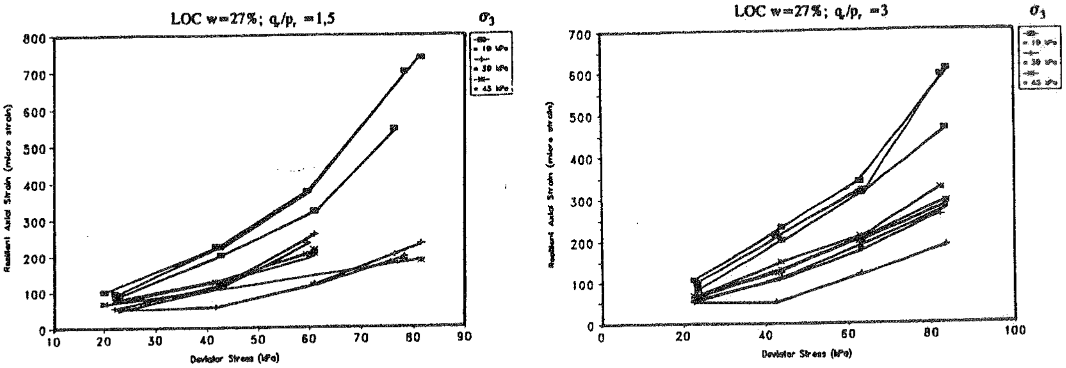

Fig.9 Resilient behaviour of London Clay for a moisture state of $w_{opt}+2\%$

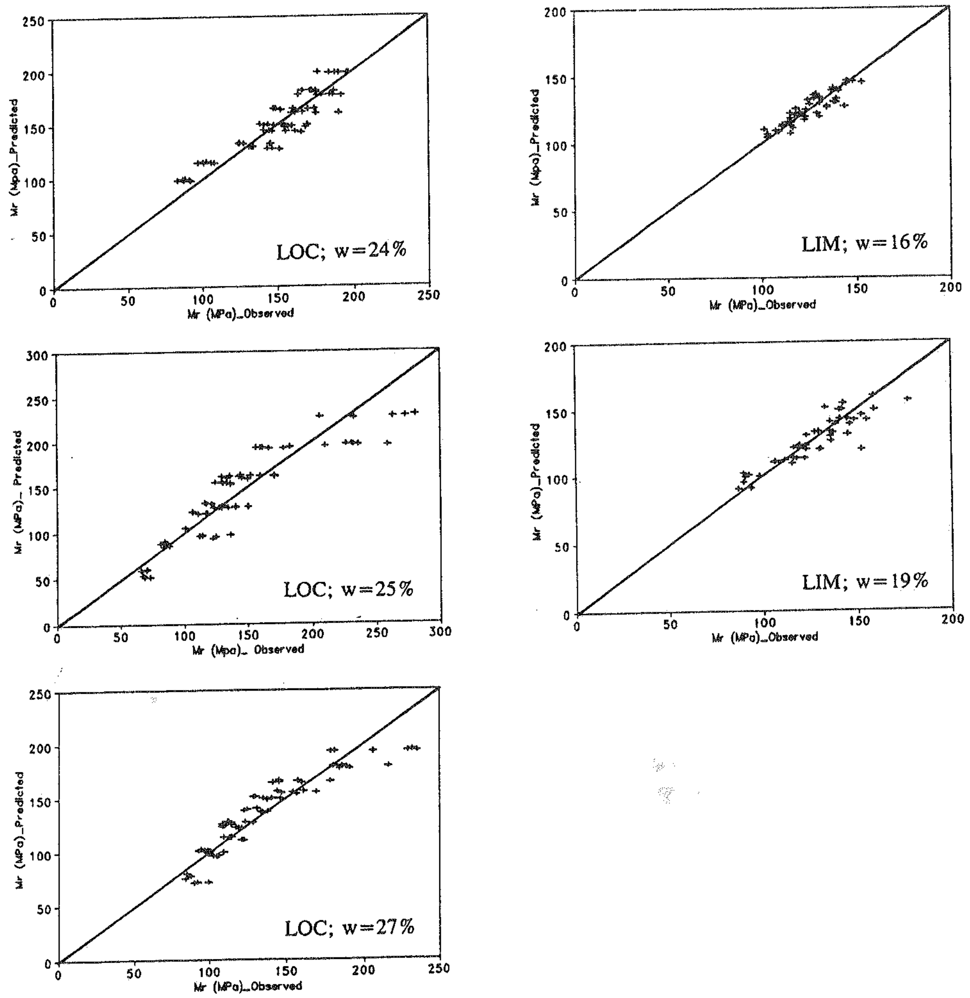

Fig.10 Adjustment of the resilient model to the experimental results of silt and clay soils

Table 3. Coefficients of the model and moisture conditions of Seine & Marne silt (LIM) and London clay (LOC)

Soil	Specimen compaction characteristics		Model adjustement					Resilient characteristic modulus (MPa)
	w (%)	γ_d (kN/m³)	A	B	C	r^2	N	
LIM	14 (w_{opt}+3%)	16.9	-	-	-	-	-	200
	16 (w_{opt}-1%)	17.2	82.6	0.93	-0.29	0.80	46	128
	19 (w_{opt}+2%)	17.3	120.4	1.13	0.54	0.86	45	122
LOC	24 (w_{opt}-1%)	15.2	153.5	1.38	0.85	0.84	72	144
	25 (w_{opt})	14.9	170.3	2.00	1.72	0.82	72	127
	27 (w_{opt}+2%)	15.5	176.4	0.99	1.38	0.84	72	123

r^2 - correlation coefficient; N - number of observations.

The parameter B of the model shows that, for the silt at moisture content of w_{opt}-1%, the modulus tends to increase slightly with the deviator stress. So the softening of fine grained soils with the increase of deviator stress is not a general behaviour but it depends on the initial conditions, mainly on the water content.

Using a characteristic stress path of q_r=60kPa for initial constant confining pressure of 30kPa a characteristic resilient modulus is calculated by the model and the values presented in Table 3.

Based in these results a relationship between resilient behaviour and water content is presented in Figure 11. It is obvious that stiffness decreases with moisture content which is more important for the silt than for the clay as has been reported elsewhere.

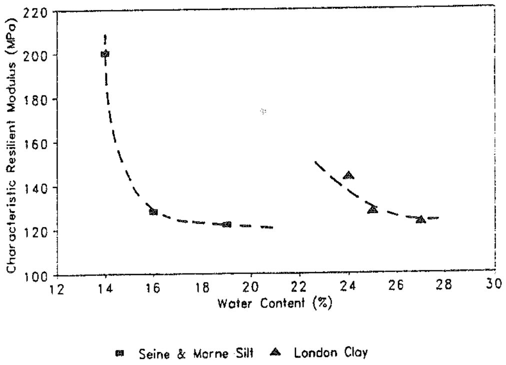

Fig.11 Influence of the water content in the resilient behaviour

The Poisson ratio is not very stress dependent and based in the results obtained we can propose for practical use a value between 0.2 and 0.3 for a water content below w_{opt} and a value between 0.4 and 0.5 for moisture greater than w_{opt}.

REFERENCES

Boyce, J.R. 1980. A non linear model for the elastic behaviour of granular materials under repeated loading. Soils under cyclic and transient loading. Vol.1. Rotterdam, Balkema.

Dawson, A.R. & Gomes Correia, A. 1993. The effects of subgrade clay condition on the structural behaviour of road pavements. Euroflex, Lisbon.

Gomes Correia, A. 1985. Contribution to the study of deformability of soils under cyclic loading (in French). Doctor Engineer Thesis. École Nationale des Ponts et Chaussées, Paris.

Gomes Correia, A. 1987. Contribution to the study of deformability of soils under cyclic loading (in Portuguese). Thesis presented at LNEC, Lisbon.

Hicks, R.G. 1970. Factors influencing the resilient properties of granular materials. PhD Thesis, University of California, Berkeley.

Loach, S.C. 1987. Repeated loading of fine grained soils for pavement design. PhD Thesis, University of Nottingham.