Contribution for the knowledge of mechanical characteristics of contaminated dune sand with gasoline

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Abstract: Portugal, country of the Southwest of the Europe, has extensive areas of granular lands constituted by sands of dunes that are located next to the coast. The unsustainable development of the society has lead to the intensive occupation of these lands. As consequence sometimes arise contaminated soils where are or can be built buildings or other structures. Therefore, this work presents some results of a group of classic tests in the ambit of the Soils Mechanics (identification, compaction, direct shear and oedometer), in the sense of acquiring sensibility concerning the way as these soils behave when they are contaminated with gasoline.

Keywords: dune sand, resistance and compressibility characteristics, contaminated soil.

1   INTRODUCTION

The area of dunes sands in which this study is developed, is about 40 km^2 (Figure 1) and along the entire Portuguese coast we can find hundred of square kilometers of this kind of soils. They are usually with an intense urban occupation. These soils have been studied in the scope of the Soil Mechanics in the classical sense (Ferreira Gomes, 1992, Ferreira Gomes and Ladeira, 1995). This study is especially dedicated to investigate the mechanical properties of these soils when they are contaminated with gasoline.

The soils in study are extremely recent (Modern), and are still in a continuous formation in some zones. The most nearest to the coast can achieve daily accumulations of 10 cm of height in very windy days. The interior zones are usually in a more stable situation in relation to erosion/deposition due to the protection of the forest (pine forest). These soils make part of the geotechnical unity "Duns sands " of the Geotechnical zoning maps of urban and suburban area of Aveiro - Portugal (Ferreira Gomes,

1992). The most frequent thicknesses range from 8 to 12 meters. They present a whitish-brown colour and they are essentially composed by sands of quartz ($\approx 65\%$) and feldspar ($\approx 33\%$) of fine to medium grain size, and with some black particles of very fine sand ($\approx 2\%$).

Figure 1 *Location of the studied area–Aveiro region – Portugal*

Regarding the geotechnical classifications, they present the particularity of always be classify as SP, according to the Unified System, and frequently as A-3(0) according to the AASHO Classification. Nevertheless some sands are classified as A-1b(0), because they have a grain size slightly bigger. These last ones are located in the neighborhood of the beaches areas. The physical parameters of these soils obtained from several tests, are present in Table 1.

Table 1 *Main physical parameters of the dune sands in Aveiro Region (Ferreira Gomes and Ladeira, 1995).*

Parameters		Variation
Density particles - Gs		2.62 - 2.67
Natural total unit weight - γ_N (kN/m^3)		15.2 - 20.1
Natural dry unit weight -γ_{dN} (kN/m^3)		14.6 - 16.7
Natural water content (%)		1 - 22
Compaction energy E = 27 kg.cm/cm^3	Maximum dry unit weight - γ_{dmax} (kN/m^3)	17.5 - 18.0
	Optimum water content (%)	9.5 - 14.2
Resistivity - R (Ohm.m)	Sands with low water content (above water table)	800 - 5000
	Sands with some water content (above water table)	350 - 800
	Saturated sands (under water table)	100 - 350
Seismic velocity- V$_p$ (m/s)	(above water table)	175 -750

From dynamic penetration tests, type DPL (Dynamic penetration light) and based in relations between NP (number of blows) and other geotechnical parameters, Ferreira Gomes and Ladeira (1995) developed the graphic on Figure 2. This graphic presents the evolution of the friction angle with the depth, in minimum density and medium density situations, knowing that this last situation is more probable to happen in the nature. Example of typical tests are presented in Figure 3, where it is possible to see that the evolution of NP is of the type "mountain teeth", although the lithology is strictly the same in depth, that is, uniform sands.

From direct shear tests (CD) in deformed saturated samples, with the same vertical stresses in shear phase and consolidation phase, curves of "shear stress versus horizontal displacement" with a very soft maximum were obtained. The friction angle obtained from maximum shear stresses ranges from 30 to 33 degrees with null cohesion. From triaxial tests of the type CID, in saturated sands, at similar conditions to those in the direct shear test, the tension/deformation curves obtained are similar to those obtained in the shear direct tests. Although they present a more pronounced maximum, the friction angles are 1 to 2 degrees above to those obtained in the same samples in the direct shear tests.

In relation to the compressibility the soils in study seem not to present great settlements problems. However Ferreira Gomes and Ladeira (1995) made some studies in that area. From the traditional oedometer tests, in saturated moulded samples with low density in the oedometer rings and stresses between 0.05 and 3.2 MPa, and using the classical methodology based in the theory of Terzaghi consolidation, they obtained for the parameter t$_{90}$ (time for reach 90% of the primary consolidation) values less to 1 minute and values of C$_c$ (compression index) between 0.04 and 0.09. The settlements that occur in these soils are practically instantaneous, being almost in simultaneous with the placement of the loads. Therefore, the soils settlements that can occur in these soils will be the result of the Young`s Modulus (E$_s$) and the Poisson's coefficient (ν).
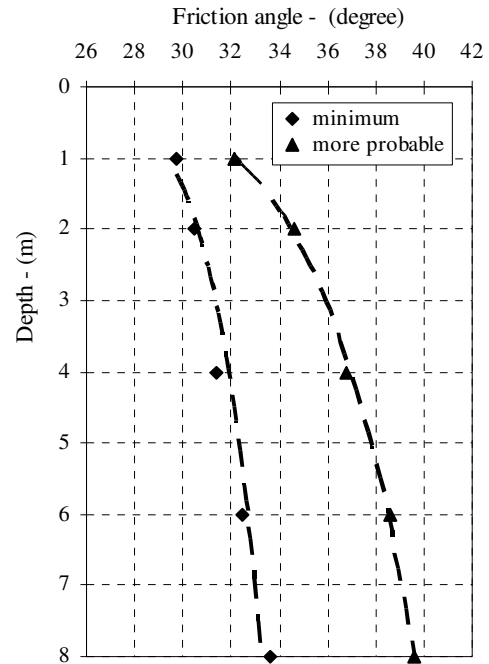

Figure 2 *Friction angle -ϕ versus depth for dune sands in situations in that are considered levels of very loose dune sand (minimum) and in more probable situations of medium density (From Ferreira Gomes and Ladeira, 1995*
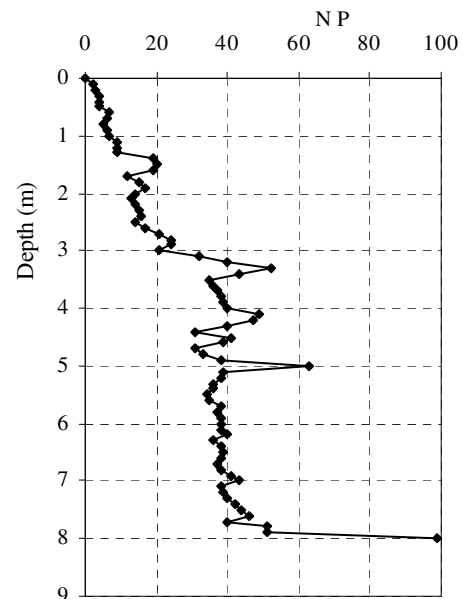

Figure 3 *DPL typical obtained in geotechnical unity of dune sands (Ferreira Gomes,1992).*

From "*in situ*" tests and based on the correlations obtained between geotechnical parameters, Ferreira Gomes and Ladeira (1995) have established for these soils the following relations: i) $q_c = 455\ D$; and ii) $q_c = 2462\ D$ (D, depth in meter, and q_c, cone resistance of CPT test, in kPa), for situations of minimum and more probable parameters, respectively. Using the Trofimenkov propose (1974, in Ferreira Gomes and Ladeira, 1995) in the transformation q_c in E_s ($E_s = \alpha q_c$; $\alpha = 3$) we can obtain the minimum and more probable variations of E_s in agreement with the following: $E_s = 1365\ D$ to $7386\ D$ (D, in meters, and E_s in kPa).

Finally, about deformability, for these soils, Ferreira Gomes (1995) through triaxial tests CID established: $E_s = 34.4 + 135\ \sigma_c$, when σ_c is the σ_3 stress in the triaxial test, and $\mu = 0.35$ as medium value and standard deviation of 0.05.

2 TESTING PROGRAME AND RESULTS

Initially, basic tests were made with the propose of characterize the main identification and physical parameters of the dune sands, in other words, 3 grain size tests and 2 compaction tests of Proctor type with different energies. The results are represented in Figure 4 and 5 respectively. They are essentially sands of medium grain size, without fine particles. In relation to the compaction they present curve of type "S" with maximum dry unit weight for water content near the saturation point (w=10-12%) and also in the situation of dry sand dunes (w = 0%), besides presenting minimum in w=4.5-6.5%.
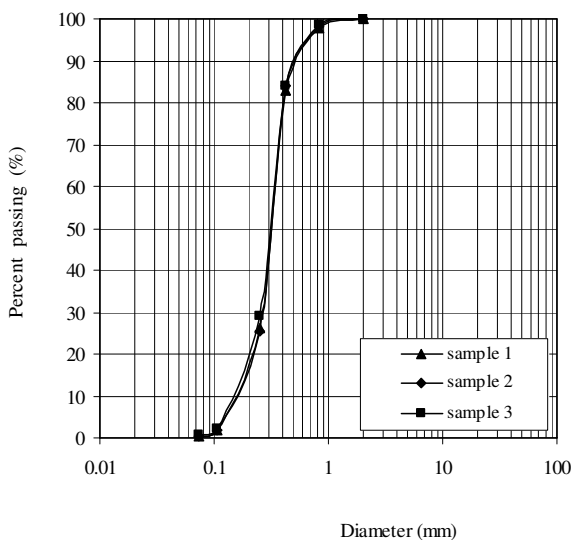

Figure 4 *Grain size distribution curves for dune sand in study.*

After the basic tests, shear strength tests (Direct shear tests) and compressibility tests (Oedometer tests), in saturated sands with water and with gasoline were also done. The aim is to discover the influence of this pollutant in the mechanical properties of these soils. The specimens tested were moulded with 5% content water and placed in the test cells with a unit weight corresponding to a low density.
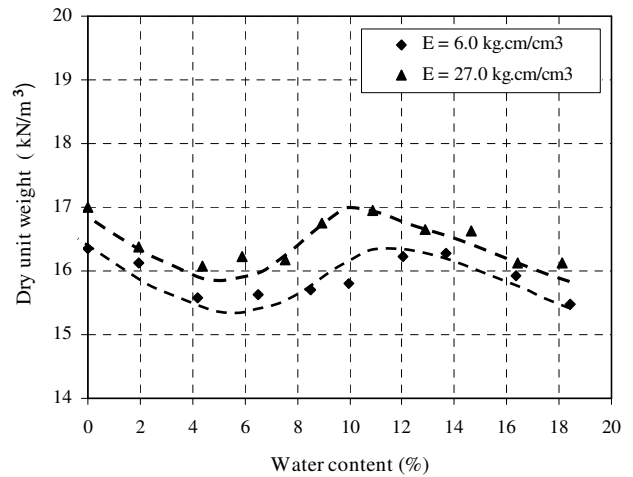

Figure 5 *Compaction curves for dune sands with different energies(E).*

The direct shear tests were performed on specimens always subjects to a preload of 30 kPa and were organized in 3 groups in agreement with the following:

i) tests with specimens subject to immediate saturation with water in a test, and gasoline in another test. In the consolidation and shear phase, were made two tests with instantaneous saturation of the specimens, one with water (*IS-Water*) and other with gasoline (*IS-Gasoline*);

ii) tests with specimens subject to the saturation during 1 week with water in a tests and gasoline in another one. In the consolidation and shear phase, were made two tests, one with water (*1week S- Water*) and other with gasoline (*1 week S – Gasoline*);

iii) tests with 2 days of saturation with gasoline following by 2 days without gasoline (*2 Days S–Gasoline & 2 Days Ingasoline*); the consolidation and shear phase was made with gasoline residual moisture.

The consolidation phase only last about 30 minutes, being followed the shear phase. The speed of the test in the shear phase was of 1.0 mm/minute. The tests were carried out on 4 specimens with vertical stresses of 44.6, 80.0, 150.7 and 327.0 kPa in consolidation phase, being the same vertical stresses of shear phase, that is, were tested always normally consolidated specimens. A shear circular box was used with an area of 28.27 cm^2.

Typical results of the tests for group i) mentioned above are presented in figure 6. It can be seen that the specimens were tested in a loose density sands situation. All the other tests presented curves approximately similar.

The results of the shear tests, in terms of maximum stresses and respective friction angle are represented in Figure 7. It is verified in the dune sands contaminated with the gasoline that they present always a friction angle lower than the one obtain in the sands not contaminated. The situation of larger

difference (1.4 degree) is in the case of the tests in specimens with instantaneous contamination and tested just after the primary consolidation is verified (in times inferior to 30 minutes). It must also be stressed the situation of the sand that was temporarily with gasoline (situation iii) and was tested only with the residual moisture of the contaminant, and that also presented a very low value of the friction angle, equal to that verified with contaminant in saturation for a long time.
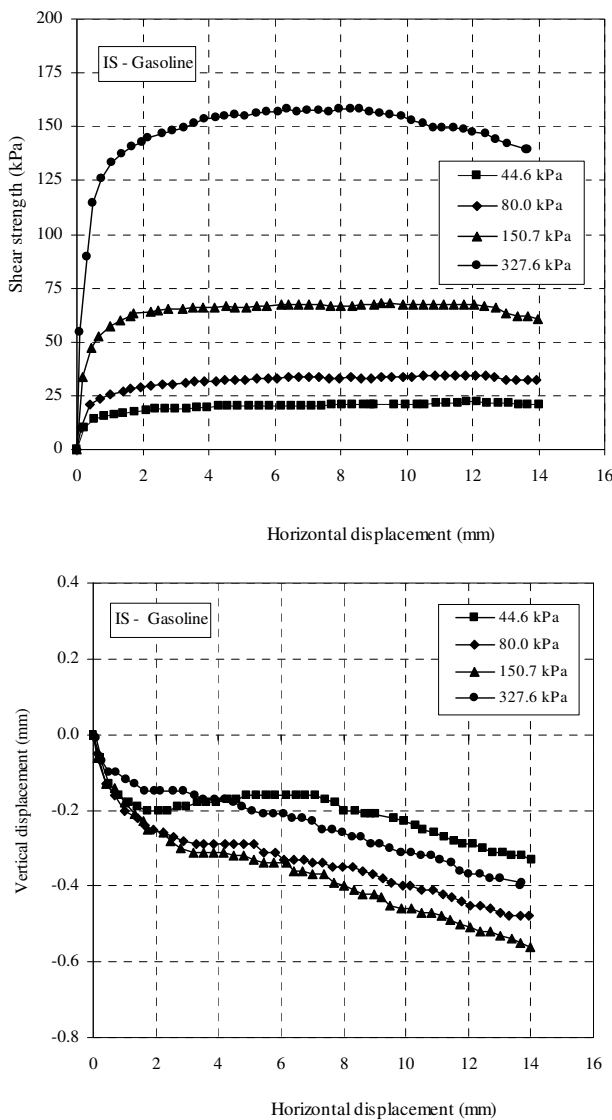

Figure 6 *Typical results of direct shear tests in dune sand with instantaneous contamination with gasoline.*

In relation to the oedometer tests the specimens were always subjects to a preload of 9 kPa and they were organized in 3 groups in agreement with the following:

> i) tests with specimens subject to immediate saturation with water in a test and gasoline in another test, continuing immediately the load phase; tow tests were made with instantaneous saturation, one with water (*IS-Water*) and other with gasoline (*IS-Gasoline*);
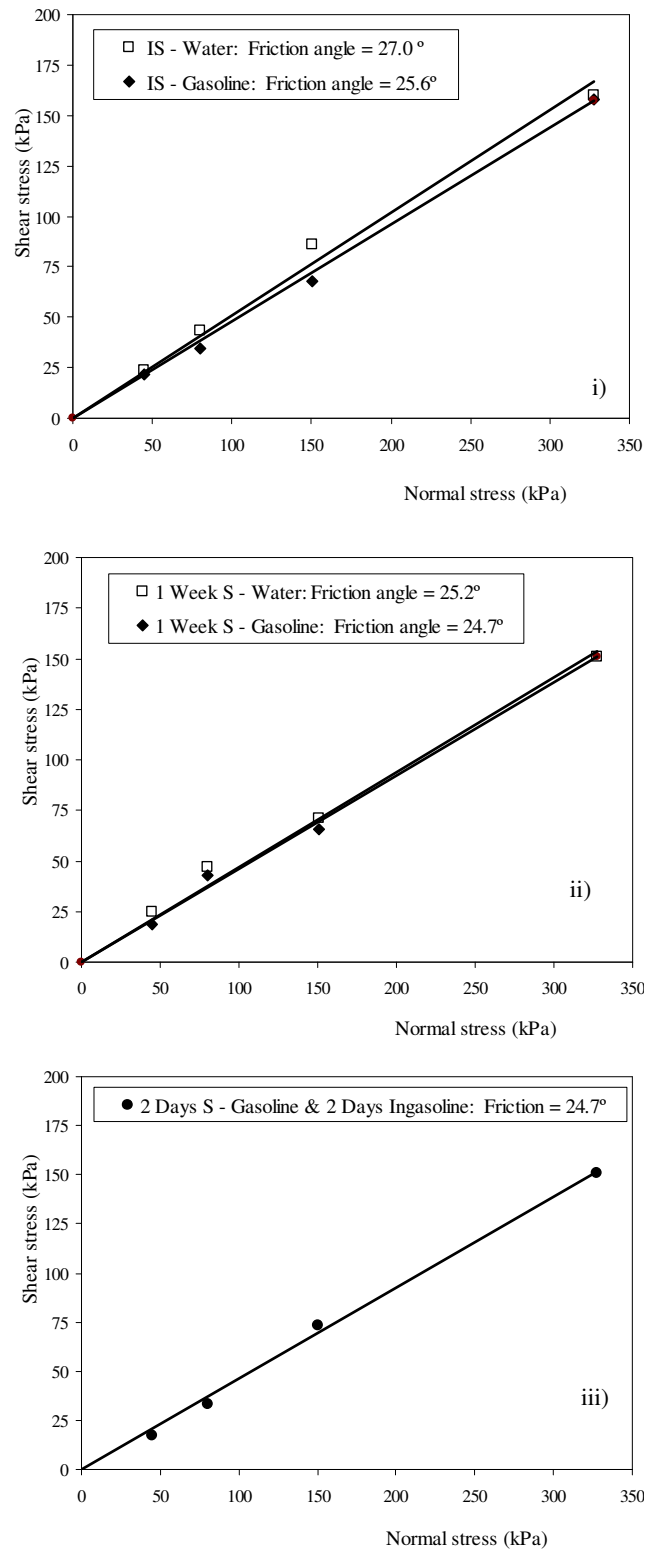

Figure 7 *Failure envelopes from maximum stresses and respective friction angle from the different direct shear tests performed on samples i) saturated instantly with water (IS-Water), and with gasoline (IS-Gasoline); ii) saturated for 1 week with water (1 Week S -Water), and with gasoline (1 Week S - Gasoline); and iii) saturated temporarily for 2 days with gasoline for later this to be removed and the shear tests carried out with residual contaminant, on dune sands.*

ii) tests with specimens subject to the saturation during 1 week with water in a test and gasoline in another test, continuing the load phase only after that period of time; two tests were made in this situation, one with water (*1 Week S - Water*) and other test with gasoline (*1 Week S -Gasoline*);

iii) tests with specimens subject to the saturation with gasoline during 2 days, being followed 2 days without gasoline; two tests were made, one with a specimen with residual moisture (*2 days S –Gasoline: air*); and the other, saturated with water (*2 days S – Gasoline: water*).

Were used oedometric cells with 31.75 cm^2 of area and 2 cm of thickness, applying constant stress of 25 kPa duplicated at each 12 hours until to reach about 3200 kPa. The Figure 8 presents the normalized void ratio (e/e$_0$, with e$_o$ the initial void ratio) versus normal stress (σ_n) and still the Compression index (C$_c$) for different specimens tested.

Of these results, it can be said that due to the low values of C$_c$, that the dune sands present, these are always of low compressibility, contaminated or not. Anyway the soils in contact with the gasoline in saturation or even residual moisture of this contaminant, always present values of C$_c$ slightly greater than the values of the not contaminated soils. That situation is believed that should be related with the greasy lubrication effect of the particles of the dune sands, turning them more slippery and more inclined to deform.

The results of the oedometric test were used to obtain the coefficient parameters of volume compressibility (m$_v$), the coefficient of consolidation (C$_v$), and the coefficient of permeability (k) (Lambe and Whitman, 1979).

The evolutions of these parameters for the several load levels on the dune sands in the different situations without and with contaminations are represented on Figure 9.

Looking at those results it is verified that m$_v$ in the beginning of the loading decreases very quickly with the increase of normal stress, taking very low values for all the situations where normal stress is superior to 100 kPa, that is, m$_v$ < 2x10^{-2} cm^2/kg when σ_n > 100 kPa.

The coefficient of consolidation decreases almost linearly with the increase of the normal stress, taking values between 190x10^{-7} m^2/s and 230x10^{-7} m^2/s. Generally, it was in the contaminated soils that the lowest values were obtained and in the non-contaminated soils that the highest values were obtained.

Finally, it can be said that the coefficient of permeability, also decreases almost linearly with the increase of normal stress, when both axes of the graph are in logarithmic scale (Figure 9). It can be seen that the values obtained for k range from 10^{-6} m/s to 2x10^{-4} m/s.
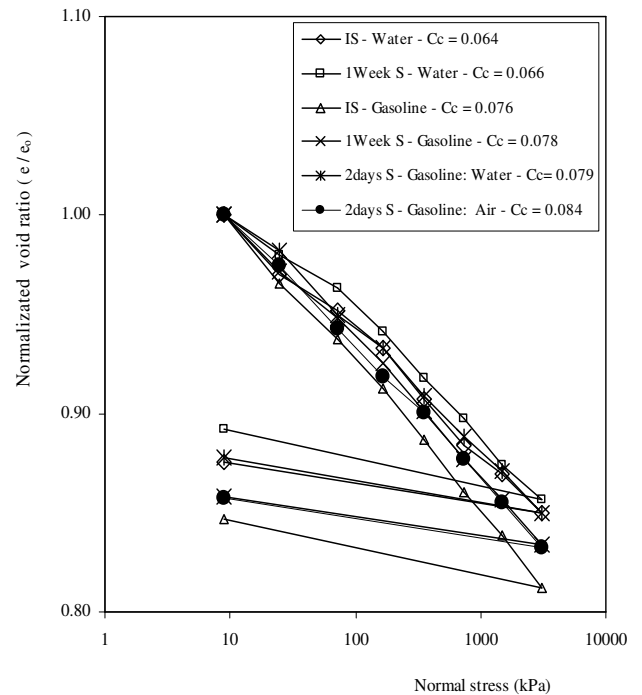

Figure 8 *Compressibility curves and compression index (C$_c$) of different oedometer tests performed in samples in different situations, without and with contamination of gasoline, on dune sands.*

3 FINAL NOTES

From the studies performed in the dune sands of recent age on the Portuguese coast one can highlight the following:

- the dune sands are essentially fine to medium grain size soils and occur *"in situ"* with low to medium density and sometimes very loose, being essentially of nature quartz-feldspar;

- from shear strength tests, when the soils are contaminated with gasoline, the friction angle (ϕ) is lower than the values obtained in saturated sands with water without contamination. The maximum difference is 1.4 degrees, that is, the contaminated sand show a friction angle 5.2 percent lower; the lower friction angle obtained in the contaminated sands was of 24.7 degrees;

- from compressibility tests of the oedometric type it is verified that the dune sands in study increase the compressibility when they are contaminated, in spite of that decrease is insignificant. The saturated sands with water without contamination present a compression index (C$_c$) in the order of 0.065 that increase slightly when they are contaminated. The maximum value obtained was 0.084.
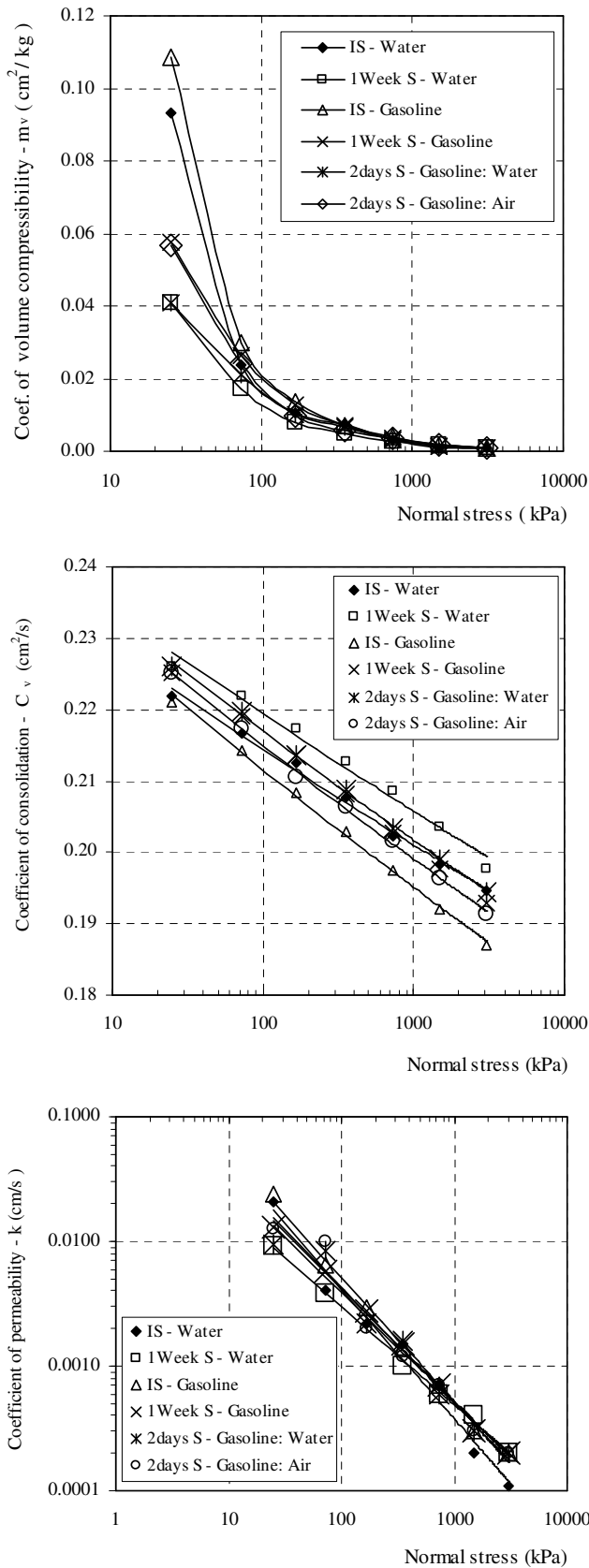
The lower mechanical properties of the contaminated dune sands could be explained by the greasy lubrication effect of the particles of these soils in the presence of the gasoline. On the other hand, as the soil particles are inert there are no chemical reactions between these particles and the gasoline

Anyway, the final notes and conclusions presented in this paper should not be generalized as it is necessary to perform more tests in other situations of contaminations, and in other kind of soils.

Finally, it must be pointed out the difficulties to perform tests with contaminated soils with gasoline and their derived. It is not easy to ventilate the laboratories in such a way that the health of the investigator could not be threatened. Another difficult is the attack capacity of the gasoline on some materials, as for instance, on the latex of membranes used in triaxial tests, breaking them when in contact with them, and that hinders the execution of this type of tests.

ACKNOWLEDGEMENT

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Figure 9 *Coefficient of volume compressibility, coefficient of consolidation, and coefficient of permeability versus normal stress from oedometer tests, in samples in different situations without and with contamination of gasoline, on dune sands.*