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Field and laboratory determination of dynamic properties of natural soil deposits

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ABSTRACT: Field and laboratory shear wave velocity, shear modulus and damping data on natural soil deposits of Northern Greece are presented, discussed and compared. Field tests include cross-hole and SPT measurements, while laboratory tests include resonant column and cyclic triaxial tests. The soil samples covered a wide range from stiff clays, soft clays and silty clays to silt, silty sands and ancient debris-fill material. Shear modulus reduction and damping ratio increase curves do not always fall within the range of well known reduction curves. Field V_s and N-SPT values are rather well correlated. Laboratory V_s values were always below the field values.

INTRODUCTION

The evaluation of the dynamic properties of natural soil deposits is of prior importance in order to study the site response, to predict the ground motion and to proceed to seismic zonation.

The last few years it has been widely accepted that the amplification or the deamplification effects of surface sediments are controlled by the degree of nonlinear response of the specific site to a given input motion. The better understanding of the dynamic properties of some particular natural soils such as the Mexico City clays or the San Francisco Bay mud, together with the actual ground motion measurements during the Michoacan-1985 and the Loma-Prieta-1989 earthquakes, have been greatly contribute to show off the importance of local site conditions and especially the specific dynamic properties (G_{max}, strain dependent shear modulus and damping) of natural soils.

From the other hand experimental laboratory and field tests on rather typical homogeneous soils are poorly correlated with actual data for natural soil deposits. This fact make the use of typical modulus degradation curves (Seed & Idriss,1970; Sun et.al,1988) or the estimation of V_s, G_{max} from typical soil properties (Hardin & Drnevich,1972) a rather risky procedure if we wish to predict accurately the ground response at a given site for a specific seismic input motion. As a consequence it is more and more pronounced the need of field and laboratory data on various natural soil deposits.

The aim of the present research work is the presentation of some data describing the dynamic properties of typical natural soils from the area of Thessaloniki-Northern Greece. The field and laboratory test results are also compared with already known and widely used curves and relationships and some specific correlations are attempted between V_s field and laboratory measurements and N-SPT values.

TESTING PROGRAM

The testing program is a part of two wide research projects presently under execution a) the microzonation mapping of the metropolitan area of Thessaloniki which is the second most important city of Greece, capital of Macedonia, with more than 1.000.000 inhabitants and b) a research project oriented in the evaluation of the dynamic properties of typical Greek soils.

The data presented herein comprise field investigation and laboratory tests.

The field investigation comprise drilling, sampling, SPT testing and geophysical cross hole measurements.

The laboratory investigation comprise in a first stage conventional classification and typical geotechnical testing and in a second stage resonant column Long-Tor tests.

In total, data from nine sites are presented, together with resonant column tests from eleven undistributed soil specimens.

A wide variety of soils have been investigated. None of these soils can be classified as an homogeneous typical soil. More or less all are mixtures of sedimented soils, varying from hard-stiff clay with N_{30} SPT>100 and undrained shear strength $c_u >$ [illegible]

TABLE 1. Physical & mechanical properties of soil specimens

Αρ.δειγμ.		Διερχ. No200	WP	W	WL	IP	γ	γs	eo	Qu	UCS	Cross-Hole Vs	N (S.P.T.)
		(%)	(%)	(%)	(%)		(t/m3)	(t/m3)		(Kgr/cm2)		(m/sec)	
1	○	50	25	23.0	38	13	1.96	2.74	0.775	0.83	ML	-	22
2	▽	83	19	15.7	38	19	2.04	2.69	0.427	2.92	CL	-	91
3	□	87	14	17.5	27	13	2.17	2.65	0.448	0.94	CL	250	25
4	△	15	17	17.9	28	11	2.17	2.65	0.526	0.83	SC-CL	225	5
5	◇	87	19	23.2	44	25	2.07	2.69	0.530	-	CL	261	32
6	●	61	21	16.1	32	11	2.10	2.79	0.476	-	CL	372	23
7	■	42	19	25.7	40	21	2.13	2.71	0.744	3.70	CL	341	46
8	▲	92	25	28.4	60	35	1.92	2.73	0.700	3.35	CH	356	65
9	◆	40	26	14.3	47	21	2.14	2.69	0.442	5.80	CL	-	112
10	+	78	18	20.8	33	15	2.06	2.69	0.617	-	CL	212	7
11	▼	80	24	56.7	29	5	1.57	2.65	1.643	-	ML-OL	-	6

3.0kg/cm² to silty clay or clayey silt locally with sand, having N_{30}-SPT values as low as 5. Figures 1 & 2 present two typical soil profiles in two distinct areas of Thessaloniki. Table 1 gives the physical and mechanical properties of the eleven soil specimens where RC test have been performed.

Special attention must be given to the ancient debris-fill material which covers the central part of Thessaloniki and has an active history of 23 centuries. This material is extremely heterogeneous, locally and spatially, consisted of ancient construction materials, parts of ancient foundations, stones, gravels, clays etc. The depth below the actual surface varies from 1-2m up to 8-10m. Most of the modern buildings in the central, intra-muros, area of the city are founded directly on this formation. The importance of this surficial strata to the ground shaking is obvious but at the same time it is impossible to propose complete constitutive laws for this material. Our attention was focused to the estimation of a mean V_s value.

TESTING METHODS & PROCEDURES

The SPT tests were performed with the standarized test procedure using a 63.5kg hammer falling freely through a height of 0.76m, driving the standard Terzaghi sampling tube 30cm into the ground. No correction has been made to the SPT values either, regarding the energy ratio or the soil type and the depth of the penetration and the water table.

The cross hole measurements were performed in two adjacent boreholes spaced at 4-5 m cased with PVC tubes, properly cemented to the ground. A Bisson's shear hammer and a triaxial receiver geophone were used with an EG&G seismograph.

The laboratory investigation comprise essentially resonant column tests with the Drnevich Long-Tor resonant column apparatus. The tests were performed following the ASTM D4015-81, on 7.1x14.2 cm or 3.6x8.2 cm undisturbed specimens isotropically consolidated to several mean confining effective pressures. After primary consolidation the specimens were subjected to sinusoidal exci-

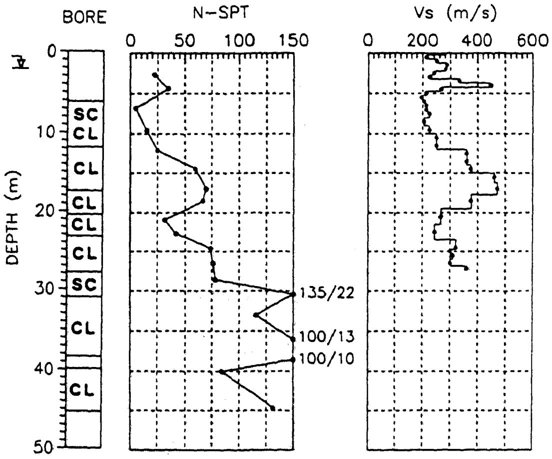


Figure 1. V_s and N_{30}-SPT profile at the shore area of Thessaloniki

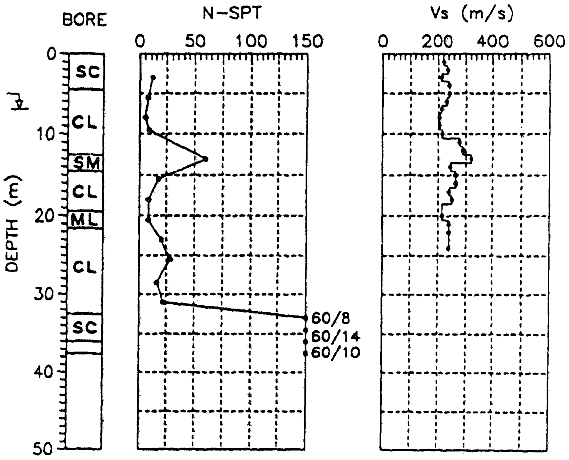


Figure 2. V_s and N_{30}-SPT profile at clay ey site

tation in both the longitudinal and torsional modes. Evaluation of the effects of time on modulus and damping of the soil was beyond the scope of this study. Nevertheless one single test on the specimen No.2 (Table 1) (hard clay, CL) for an effective confining pressure of 2.8kg/cm² showed a 20% increase on the shear modulus 48h after the comptetation of the primary consolidation.

A series of cyclic triaxial tests were conducted on intact specimens of the stiff clay formation. The shear moduli were obtained from the Young's moduli for the measured values of Poisson's ratio and they are plotted as function of the shear strain.

TESTING RESULTS & DISCUSSION

Figure 3 presents a typical RC test on the soft clayey silt specimen (SC-CL) (N-SPT = 5 blows/ft) for different levels of effective confining pressures. In the strain range above 10^{-3}% shear modulus increases with increasing effective confining pressure and decreases as shearing strain, γ, increased at all confining pressures. Damping ratio increases as strain amplitude increases and decreases as σ_0' increases. The effect of magnitude of confining pressure is less pronounced on D than on G. On the other hand the effect of γ on D is more pronounced than on G. The threshold strain at which the modulus begins to decrease with increasing strain varies from about 4.10^{-4}(%) at 144kPa to 2.10^{-3}(%) at 20kPa.

The change in modulus with strain amplitude is presented with the normalized shear modulus G/G_{max} vs the logγ in figure 4a for the clays and 5a for the silts and sands. The general tendency is for the normalized modulus curve to shift to the right while the shape of the curve remains about constant. In the same figures normalized curves from Seed & Idriss (1970), Sun et.al (1988) and for the Mexico clay and the S.F.Bay mud have also been included for comparison purposes. The range of all the cyclic triaxial tests on the stiff clay is shown in fig.5a. The comparison is quite satisfactory. The important scatter in the case of silts and sands (fig.5a) can be explained by the fact that non of these soils are pure silt or sand. For example specimen 4 (classified as SC-ML) presents a non insignificant plasticity (IP =11). Specimen 11 (ML-OL) a loose clayey silt of the shore area of Thessaloniki, presents similar behaviour as the S.F.Bay mud.

The effect of shearing strain amplitude on material damping D is shown in fig. 4b & 5b, for the clays and the silts-sands respectively. In general the measured damping ratio is rather high, even for very low shear strains and especially for the clays. For the sands and silts the measured values of damping are quite comparable with similar curves proposed by Seed&Idriss (1970) or for the S.F.Bay mud. The high damping values at low shear strains for the clayey soils have not been-as yet-fully understood and the whole problem is under study. One possible explanation could be the rather low void ratio (0.45-0.70) of all specimens and the anisotropy of their formation in relation with the type of test.

The variation of the low amplitude shear modulus G_0 with the effective confining pressure σ_0' is given for all RC tests, in fig.7. The scatter for the silts and sands is very high because of the complicate nature of these materials. For the clays the scatter is low and the proposed G_0-σ_0' relationships are reliable.

In fig. 6a,b,c some correlations are attempted between N-SPT values and the field and laboratory V_s data, the latest measured at the appropriate σ_0' value. We present correlation for the ancient debris - fill

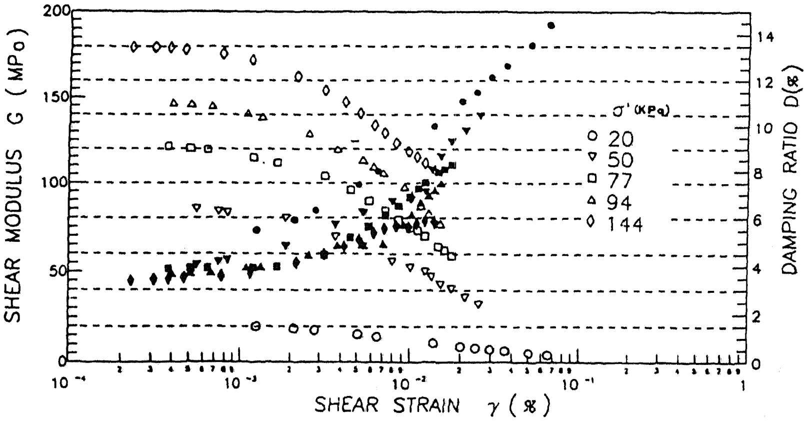


Figure 3. Typical resonant column testing. Modulus reduction and damping ratio increase with shearing strain amplitude at different effective confining pressures (specimen No.4)

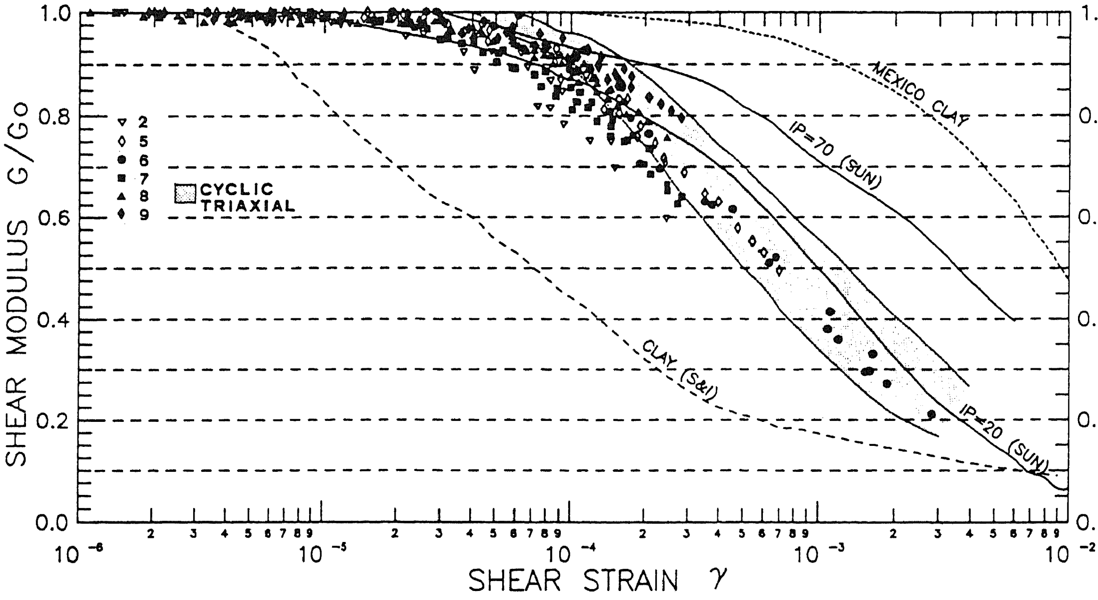


Figure 4a. Variation of normalized shear modulus with shearing strain for all clayey soils. Resonant column and cyclic triaxial tests.

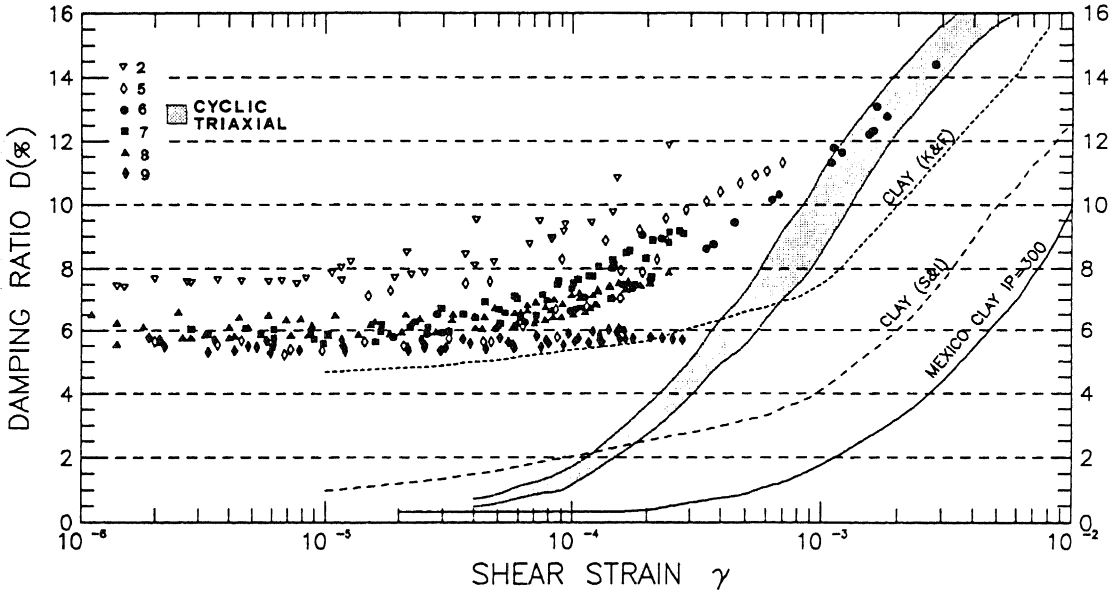


Figure 4b. Variation of damping ratio with shearing strain for all clayey soils. Resonant column and cyclic triaxial tests.

material, the silts & sands and the clays. In the same figure some well known relationships proposed by Imai & Tonuchi (1982) and Ohta & Goto (1976) are also included for comparison purposes. The most important remark is that the values of V_s determined by RC laboratory tests are lower than the cross hole field values. The great differences are attributed to: a) time effects, which generally increase the laboratory G_o and have not been included, b) the possible sample disturbance, c) the cross-hole technique which produce data at a much smaller strain than laboratory tests and d) the geophysical techniques which evaluate a much greater mass of soil and the actual heterogeneity

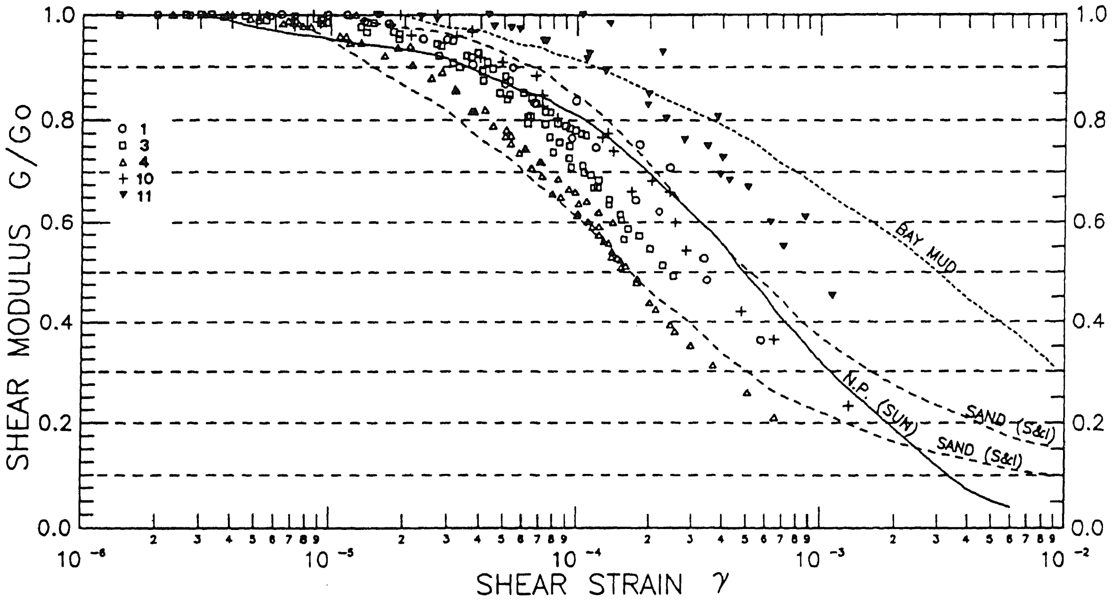


Figure 5a. Variation of normalized shear modulus with shearing strain for silts and sands. Resonant column tests.

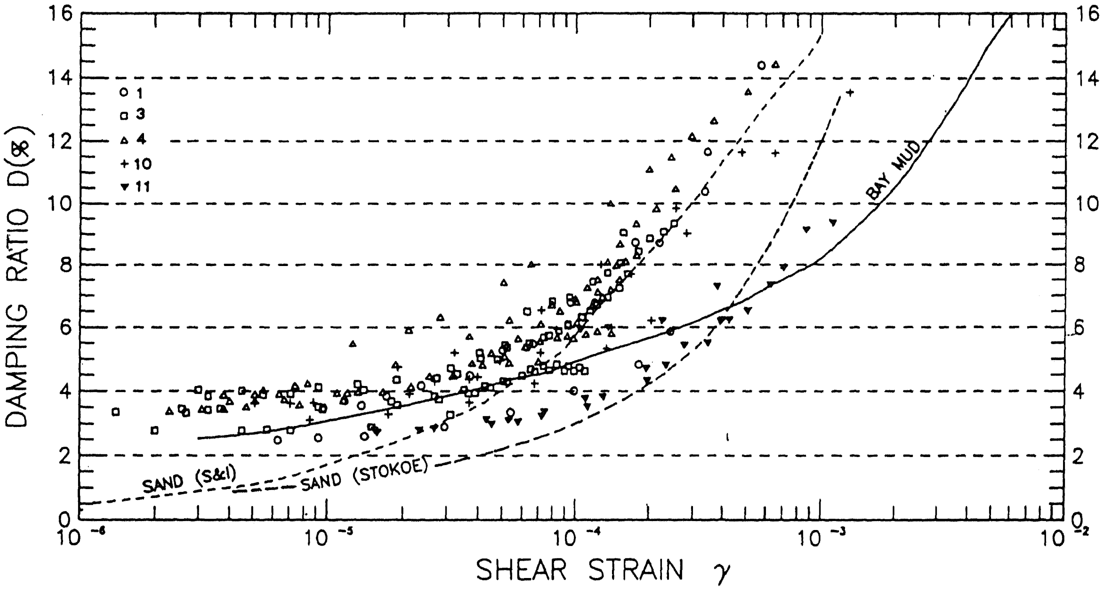
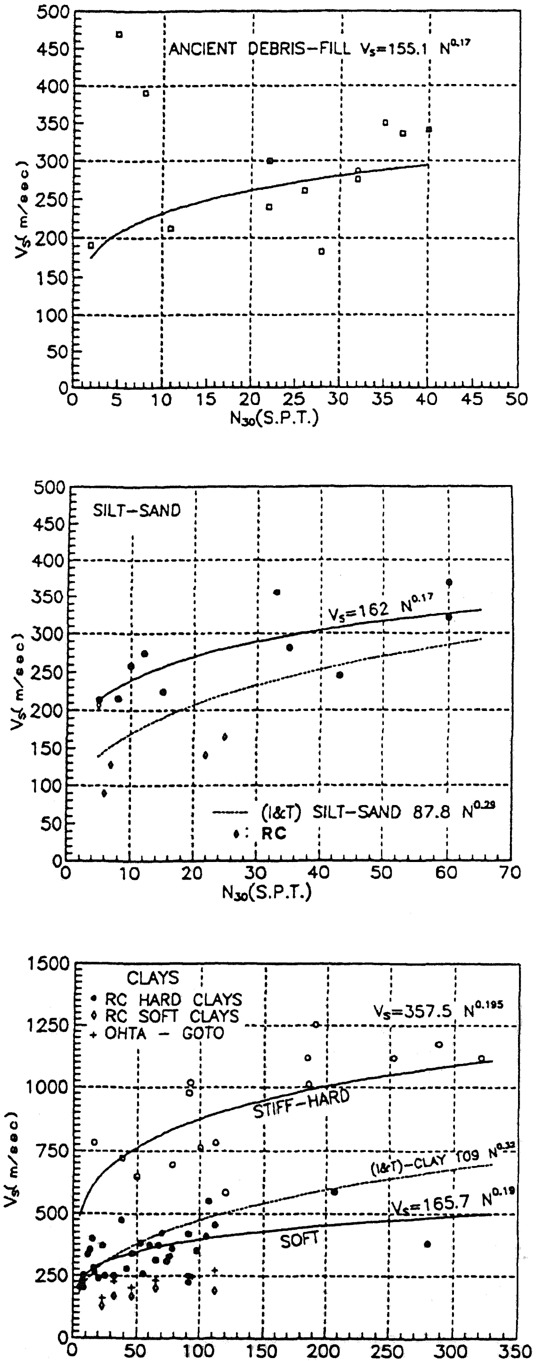


Figure 5b. Variation of damping ratio with shearing strain for silts and sands. Resonant column tests.

or/and anisotropy of the soil which has less influence than for laboratory RC tests.

CONCLUSIONS

Field and laboratory data (V_s,G-γ,D-γ) for natural soils are presented and discussed. The dynamic laboratory tests combined with field data contribute significantly to our present knowledge about the dynamic response of natural soils, which are mixtures of different type of soils, having a rather irregular granulometry. The results are compared with other results and show reasonably close comparisons. Further research



Figures 6 a,b,c. In situ (▫,o,●) and laboratory (RC-tests) (◊) measurements of V_S with the corresponding N_{30}-SPT values (uncorrected). a) ancient debris-fill formation, b) silts, sands and clayey silts, c) stiff hard clays and soft clays.

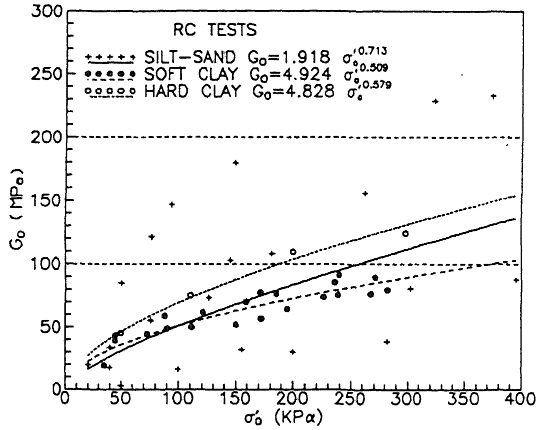


Figure 7. Variation of low amplitude shear modulus G_0 with the effective confining pressure.

work is needed, which is under way, in order to produce more data.

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