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SYNOPSIS Shanghai is located on the east coast of China at the mouth of the Yangtze river at the East China Sea. The alluvial soil deposit at this location is about 300 m deep with an upper soft soil stratum about 100m thick. A study of shear modulus G and damping ratio D of the soft soil stratum has been conducted using Drnevich Resonant Column Device. The test results have been compared with empirical formula for sands established by Hardin and Richart. New empirical relationships for the Shanghai silts and clays are presented.

INTRODUCTION

Though Shanghai is not a seismic area, there are several seismic sources within a range of 200 to 300 km. In recent years earthquakes have occurred in these areas and have had effects in Shanghai. Shanghai is situated at the mouth of the Yangtze River near the East China Sea, and is on deep alluvial soil with a thickness of 300 m. The top soil stratum is soft with a thickness of about 100 m. A study of the dynamic properties of the soft soils in Shanghai is an important component of seismic microzonation of the city, seismic hazard analysis and earthquake damage estimation. A typical profile of the soil strata in the Shanghai area is given in Table 1.

EFFECTS OF SHEARING STRAIN AMPLITUDE

Because the seismic intensity of Shanghai is set at 7 , the minimum strain amplitude in the resonant column test was 2×10^{-3}. Curves in Fig. 1 for silt and Fig. 2 for silty sand show the variation of G and D as a function of shearing strain amplitude, γ_d . It can be seen from the figures that the dynamic shear modulus G decreases non-linearly with increasing strain amplitude while the damping ratio increases non-linearly. This behavior of soils agrees with previous observations as reported by Anderson and Richart (1976) and Fei (1984) for example. When the shearing strain is less than 10^{-5}, the modulus scarcely changes and tends to a constant value, G_o or G_{max}. When the shearing strain amplitude is less than 5×10^{-5}, the change in damping ratio tends to be smooth.

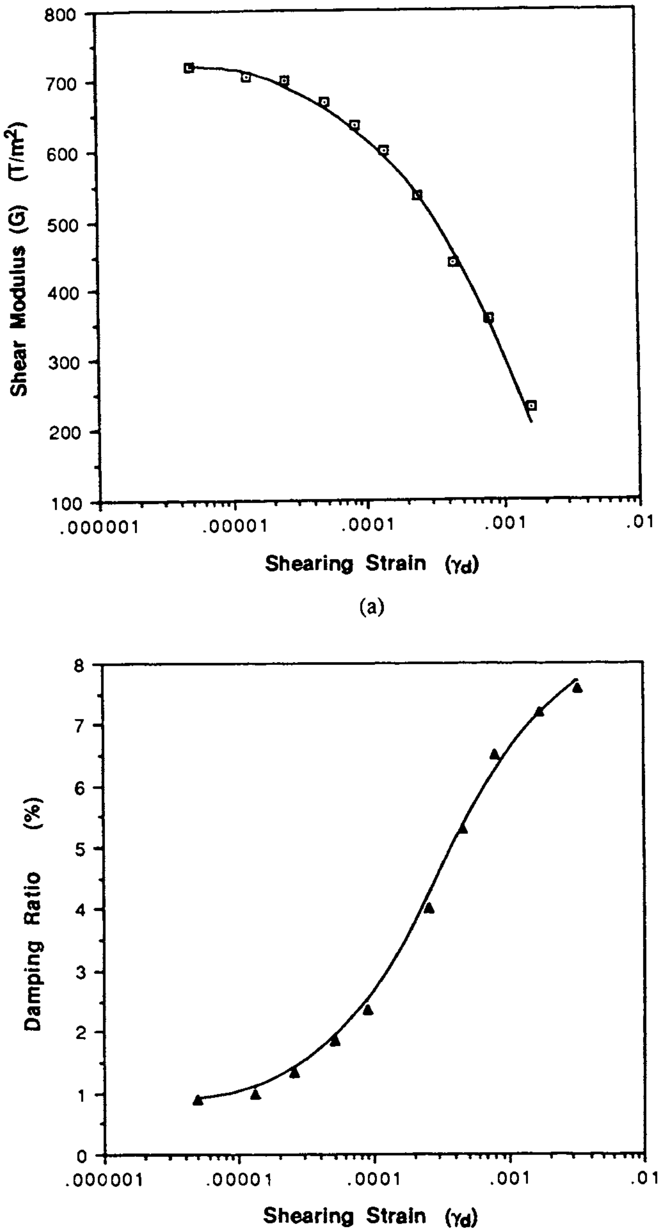
The maximum modulus, G_{max}, of the different layers are strongly affected by the soil type and the embedment, but the change of the maximum damping ratio D is not strongly influenced, being only 7.9% to 9.0%.

When the strain amplitude dependent shear modulus is divided by G_{max} (or G_o), it is seen that a smooth, concave downward curve is formed, Fig. 3a. When the strain amplitude is smaller than 10^{-5}, all the points are nearly on a straight line, but when the strain amplitude increases, G/G_{max} decreases non-linearly. When the strain amplitude is about 10^{-4}, curves for the modulus ratio of sandy soil and that of clayey soil clearly separate. This indicates that the classification of soil has no effect on

TABLE 1

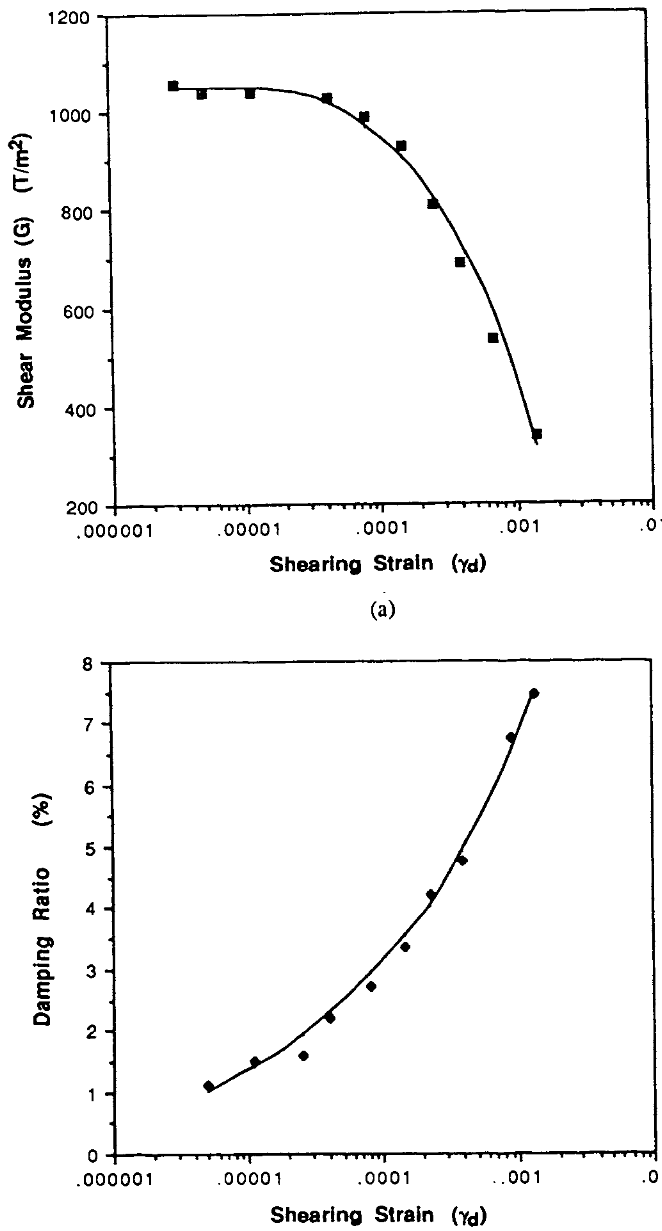
PROFILE OF TYPICAL SOIL LAYERS IN SHANGHAI

No.	Soil Description	Depth (m)	Void Ratio	Unit Weight (g/cm)	Shear Modulus (t/m)	Shear Wave Speed (m/s)
1	Fill	0.0	-	1.5	--	---
2	Yellow Clayey silt	1.7	0.97	1.84	2920	125
3	Gray Clayey silt with clay seams	4.4	1.13	1.77	4730	162
4	Gray mucky clay	13.6	1.46	1.69	2250	114
5	Gray loam clay	17.1	0.98	1.85	6560	186
6	Dark green loam clay	23.7	0.70	2.00	10870	231
7a	Yellow clayey sand	28.3	0.93	1.86	16870	298
7b	Yellow silty sand	34.2	0.92	1.86	18490	312
8	Gray yellow silty fine sand	40.0	0.84	1.87	24360	358
9	Indigo gray fine sand	60.0	0.84	1.87	31120	404
10	Gray med. coarse sand w/some gravel	84.9	0.84	1.87	32040	410
11	Brown grey clayey sand w/ silt	88.4	0.84	1.87	34000	423
	and sand	101.4				



(b)

Fig.1 Relationship between Shear Modulus or Damping Ratio and Shearing Strain



(b)

Fig.2 Relationship between Shear Modulus or Damping Ratio and Shearing Strsain

the modulus ratio for very small strain, but that it has a clear effect when the strain amplitude is large.

By regression analysis equations for the relationship between the shear modulus ratio G/G_{max} and the shearing strain amplitude γ_d were obtained:

Clay, $$\frac{G}{G_{max}} = \frac{1}{1374 \exp(\gamma_d) - 1373} \quad (1)$$
(t/m^2)

Sand, $$\frac{G}{G_{max}} = \frac{1}{802.8 \exp(\gamma_d) - 801.8} \quad (2)$$
(t/m^2)

The empirical relationship between the damping ratio D and the shearing strain amplitude can be expressed as:

$$D = 0.516 + 183.6 \gamma_d^{1/2} \quad (3)$$

When the shearing strain amplitude is large, the modulus ratio of sandy soil is slightly greater than that of clayey soil, see Fig. 3a.

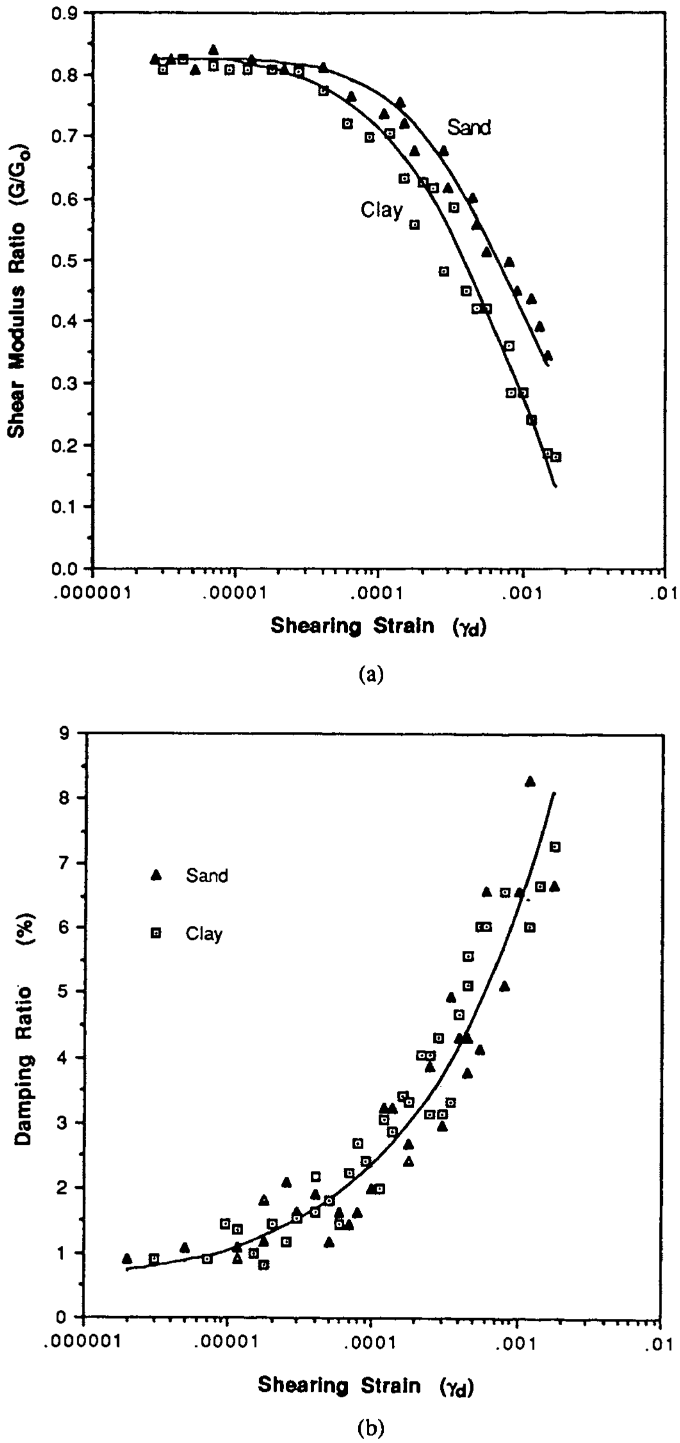


Fig.3 Relationship between Shear modulus Ratio or Damping Ratio and Shearing Strain

EFFECTS OF TYPE OF SOIL AND CONFINEMENT ON Gmax

Shear modulus is affected by many factors (Hardin and Black, 1968). For example, G varies with void ratio, e, average effective confining stress, σ_o', and shearing strain amplitude, γ_d. Damping ratio, D, also varies with γ_d and e, but the influence of σ_o' is small. For the Shanghai soils the values of G_{max} measured in the laboratory increased with increasing confining pressure and those measured in the field increased with increasing depth. In the paper by Hardin and Richart (1963) and in Richart, Hall and Woods (1970), the basic empirical relationship between G and e and σ_o' for angular sand and clay was expressed as;

$$\underset{(t/m^2)}{G} = A\,(2.97 - e)^2\,\underset{(t/m^2)}{(\sigma_o')^{1/2}} / (1+e) \qquad (4)$$

where $A = 326$ and

$\sigma_o' = (1 + 2\,Ko)\,(\gamma' H)/3$,

where Ko is the coefficient of lateral earth pressure,

γ' = the effective unit weight of the soil.

In a similar manner, the equations for different layers of Shanghai soils have been determined empirically from resonant column tests and can be expressed as:

For Yellow clayey silt,

$$Gmax = 394(2.97 - e)\ (\sigma_o')/\ (1+e) \qquad (5a)$$

For Gray mucky clay loam,

$$Gmax = 296\ (2.97 - e)\ (\sigma_o')/\ (1 + e\ ) \qquad (5b)$$

For Dark green clay loam,

$$Gmax = 295\ (2.97 - e)\ (\sigma_o')/\ (1 + e) \qquad (5c)$$

For Yellow clayey sand and silty fine sand,

$$Gmax = 703\ (2.97 - e)\ (\sigma_o')/\ (1 + e) \qquad (5d)$$

(In EQ. 5a - 5d, G_{max} and σ_o' in units of t/m^2)

COMPARISON WITH FIELD MEASUREMENTS

The average shear modulus and shear wave velocity of the various layers of a typical Shanghai profile using equations (5) are shown in Table 1. Their values are in general agreement with those obtained by seismic methods in the field. For two specific boreholes the shear modulus determined from shear wave velocity measured in the field and the shear modulus determined from equation (4) using "A" coefficients from equations (5) as tabulated in Table 2 have been plotted in Fig. 4. While most points show good agreement, some have large errors. It is though that most of the error came about because of changes in void ratio between the sampled soil and the in situ soil due to sampling disturbance. Also, for the clay or clayey silt near the surface, the field measured value was higher than calculated probably due to overconsolidation caused by desiccation, and overconsolidation was not taken into account in the empirical equations used here.

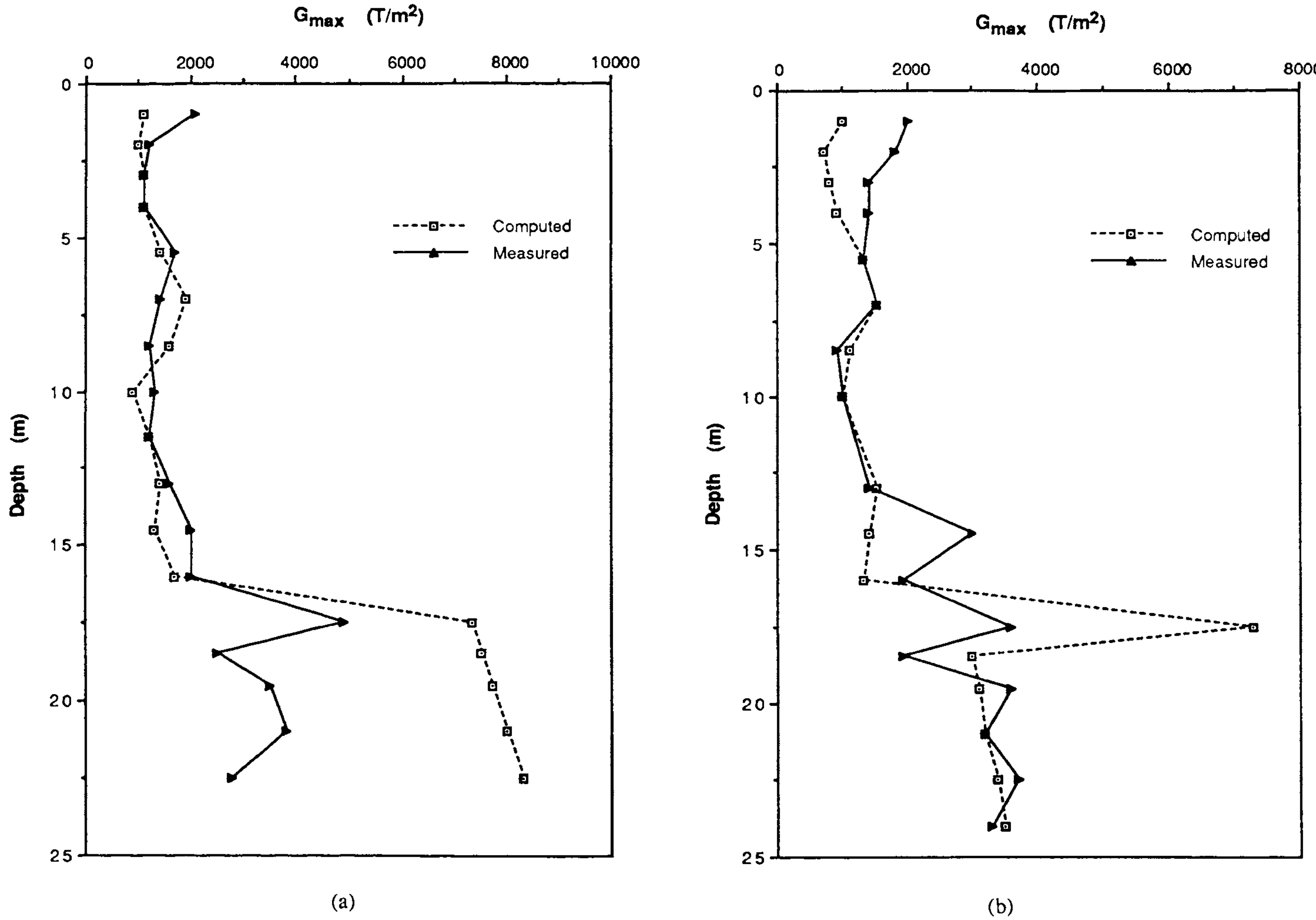


Fig.4 Shear Modulus Calculated from Eq.5 Compare with Shear Modulus from Field Shear Wave Measuring Test

TABLE 2

Values of Coefficient "A"

Soil Type	Hardin clay	From This Study Dark, Green loam clay	Clayey Silt	Yellow clayey sand, and silty fine sand
A measured	326	295	394	703
A proposed	326	300	400	700

CONCLUSIONS

The empirical relationships between G and , and D and γ_d obtained from resonant column testing of Shanghai soils exhibit conventional behavior compared to previous reports in the literature. The basic shape of the G vs γ_d is a hyperbolic relationship.

The maximum shear modulus of soil varies with specific soil type and equations of the Hardin type can be used to describe the Shanghai soils using "A" coefficients from Table 2.

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