Cyclic stress history effects on small-strain shear modulus of silt

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1 Introduction

Silts are susceptible to liquefaction shown by field performance data during earthquakes. The cyclic behavior of silts has been investigated only on a very limit scale. Adequate information on dynamic soil properties, especially the small strain shear modulus G_{max} ($\gamma<10^{-7}$%) and the damping ratio, is essential in the seismic response analysis. However, only the contribution of effective stress reduction to G_{max} degradation is considered during cyclic loading, and that of soil fabric change during cyclic loading is neglected. A multi-use triaxial apparatus with bender element system was used to investigate the influences of seismic cyclic loading history on G_{max} of soils in this paper.

2 Test Program

The mechanism of G_{max} of saturated silt under the influences of seismic cyclic loading was investigated, meanwhile that of G_{max} without such influences was investigated for comparison.

The bender element system was shown in Fig. 1. One element vibrated to generate shear waves; shear waves propagated through the sample and vibrated the other element. The shear wave velocity V_s in the specimen can be calculated from the wave travel time t and the known separation L between the bender elements as $V_s=L/t$. And according elastic theory, the small strain shear modulus can thus be calculated as $G_{max}=\rho V_s^2$ for a known material density ρ.

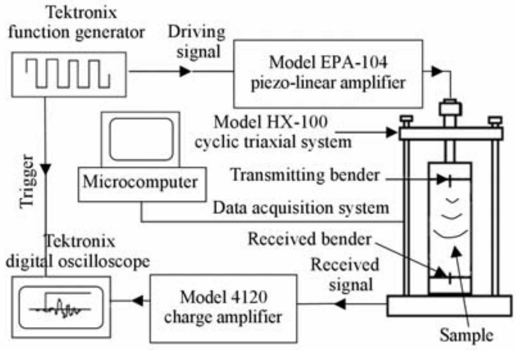

Fig.1 Schematic of triaxial system with bender element

The grain-size distribution curve of the tested silt was presented in Fig. 2, and the properties of this material were as following: specific gravity d_s=2.67g/cm^3, liquid limit w_L=35.4%, and plasticity index I_p=11.5 according to China's Standard for soil test method (GB/T50123-1999).

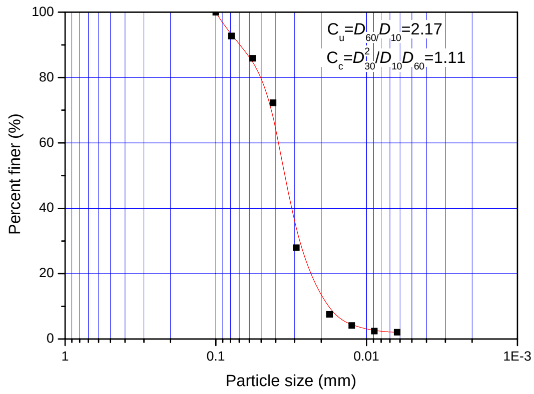

Fig.2 Grain distribution curves of tested silt.

Saturated specimens of 39.1 mm in diameter and 80 mm in height were sampled with the moist tamping method. The tested procedure was shown in Fig. 3. In cyclic loading tests, samples were consolidated isotropically for 12 hours, and shear wave velocity was measured for G_{max0}. Then they were subjected to a few number of 1 Hz uniform amplitude cyclic stresses; and the shear velocity for G_{max}, residual pore water pressure and residual strain were recorded at the intervals between cyclic loading procedures until the cyclic failure occurred.

3 Test Results and discussion

The modified test data were plotted in normalized G_{max} versus normalized mean effective stress σ'_m in Fig. 4. The plots were located in a narrow band, and no evident overconsolidation effect on G_{max} was observed. These results were consistent with those presented in previous study (Petraikis & Dobry, 1986) showing that G_{max} is ultimately a function of the effective confining pressure and void ratio function $F(e)$ (surrogate for the particle contacts) for cohesionless soils. Then the following approximation for G_{max} could be fitted as Hardin et al. curve:

$$G_{max}=520P_aF(e)(\sigma'_m/P_a)^{0.43} \tag{1}$$

Where $F(e)=1/(0.3+0.7e^2)$ and P_a is the atmospheric pressure for tested silt, and in Eq. (1) stress were expressed in kPa.

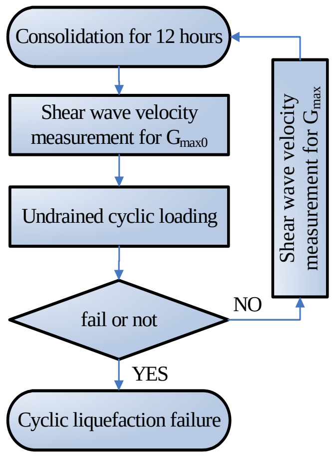

Fig.3 Cyclic test procedure flow chart.

Time effect and interval effect were not obviously, and that was consistent with formal study (Zhou & Chen, 2005). The test results during cyclic loading test were plotted in Fig. 5 and Fig. 6, normalized by initial small shear modulus G_{max0} and initial mean effective stress σ'_{mo}. Fig. 5 and Fig. 6 shown the effect of cyclic density and shear stress (*CSR*=cyclic shear stress

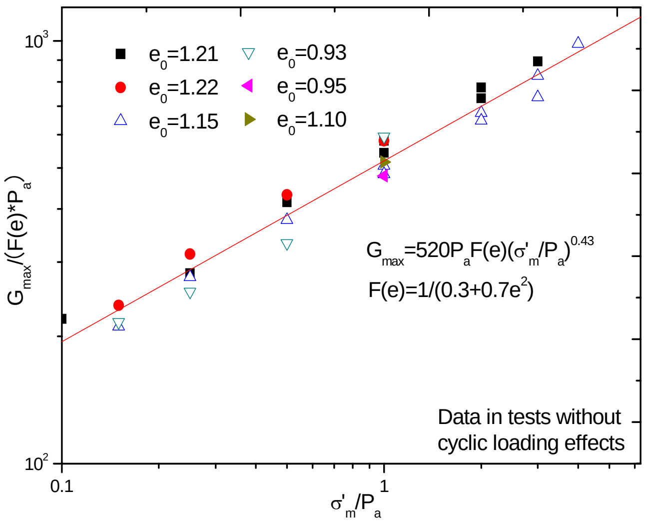

Fig.4 Dependence of $G_{max}/F(e)*P_a$ on normalized confining pressure

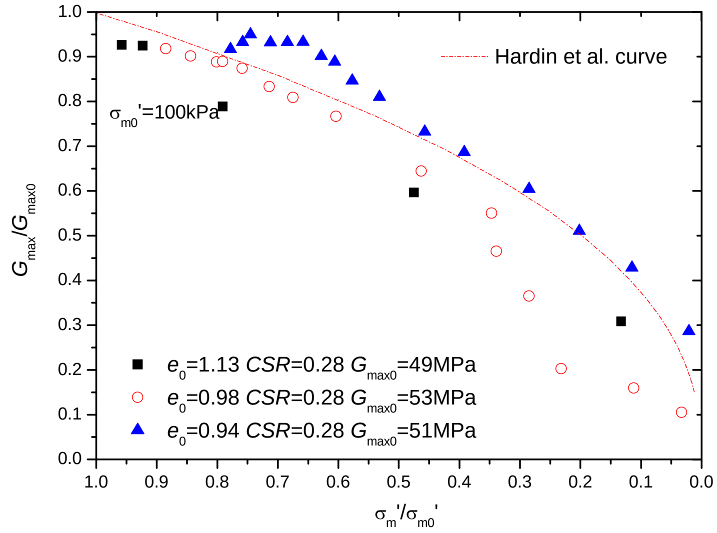

Fig.5 Dependence of the modulus reduction on density.

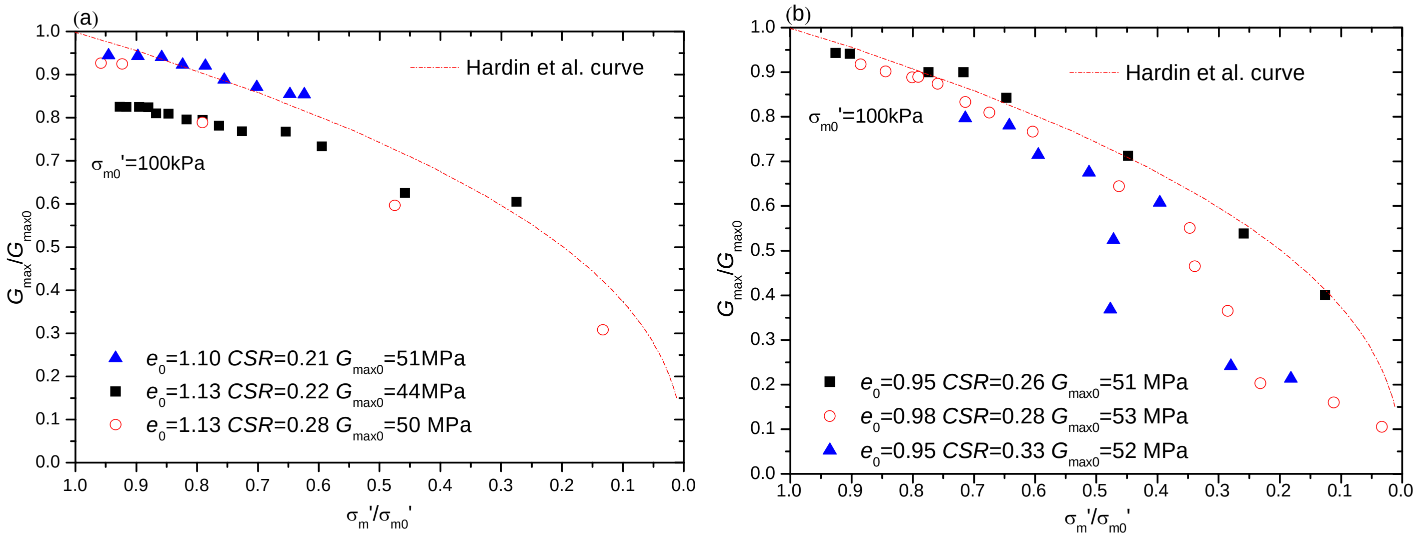

Fig.6 Dependence of the modulus reduction on *CSR*.

amplitude/initial mean effective stress) on modulus reduction separately. Fig. 5 indicated that density is an important index to influence the further reduction of G_{max} during cyclic loading. Under the same *CSR*, the further reduction of G_{max} was inclined to occur in relative lower density sample. The cyclic shear stress influences the small shear modulus during cyclic loading obviously (shown in Fig. 6). And it should be noted that in Fig. 6 a tendency could be figured out, that for a given sample at the approximate confining pressure and density, the higher the cyclic shear strain was applied, the larger modulus reduction could be obtained. Under the relatively high cyclic stress, the relatively stable contacts formed under long confinement duration are replaced by softer and unstable contacts due to particle re-orientation, which contributes to further reduction of G_{max}.

4 Conclusions

In the present study, the small strain shear modulus of saturated silt was investigated throughout the undrained cyclic triaxial tests with the bender element system, and further reduction of G_{max} different from Eq. (1) was observed. The density is an important index influencing G_{max} during cyclic loading. And the cyclic stress level influences the G_{max} obviously. The relatively high amplitude cyclic loading resulted in not only reduction of effective stress, but also the further reduction of G_{max}.

Reference

1. Hardin B.O., Black W.L... Vibration modulus of normally consolidated clay (closure). Journal of the Soil Mechanics and Foundations Division, ASCE, 1969, Vo1.95, No.SM6:1531-1537 2. Petraikis E., Dobry R.. A self consistent estimated of the elastic constants of random array of equal spheres with application to granular soil under isotropic conditions. NY: Resselaer Poly technic Inst., Troy; 1986 (Rep. No. CE-86-04) 3. Yan-guo Zhou, Yun-min Chen. Influence of seismic cyclic loading history on small strain shear modulus of saturated sands. Soil Dynamics and Earthquake Engineering, 2005(25):341-353