SMALL-STRAIN TESTING IN THE UCLA NGI-TYPE DUAL-SPECIMEN DIRECT SIMPLE SHEAR (DSDSS) DEVICE

International Workshop on Uncertainties in Nonlinear Soil Properties and their Impact on Modeling Dynamic Soil Response

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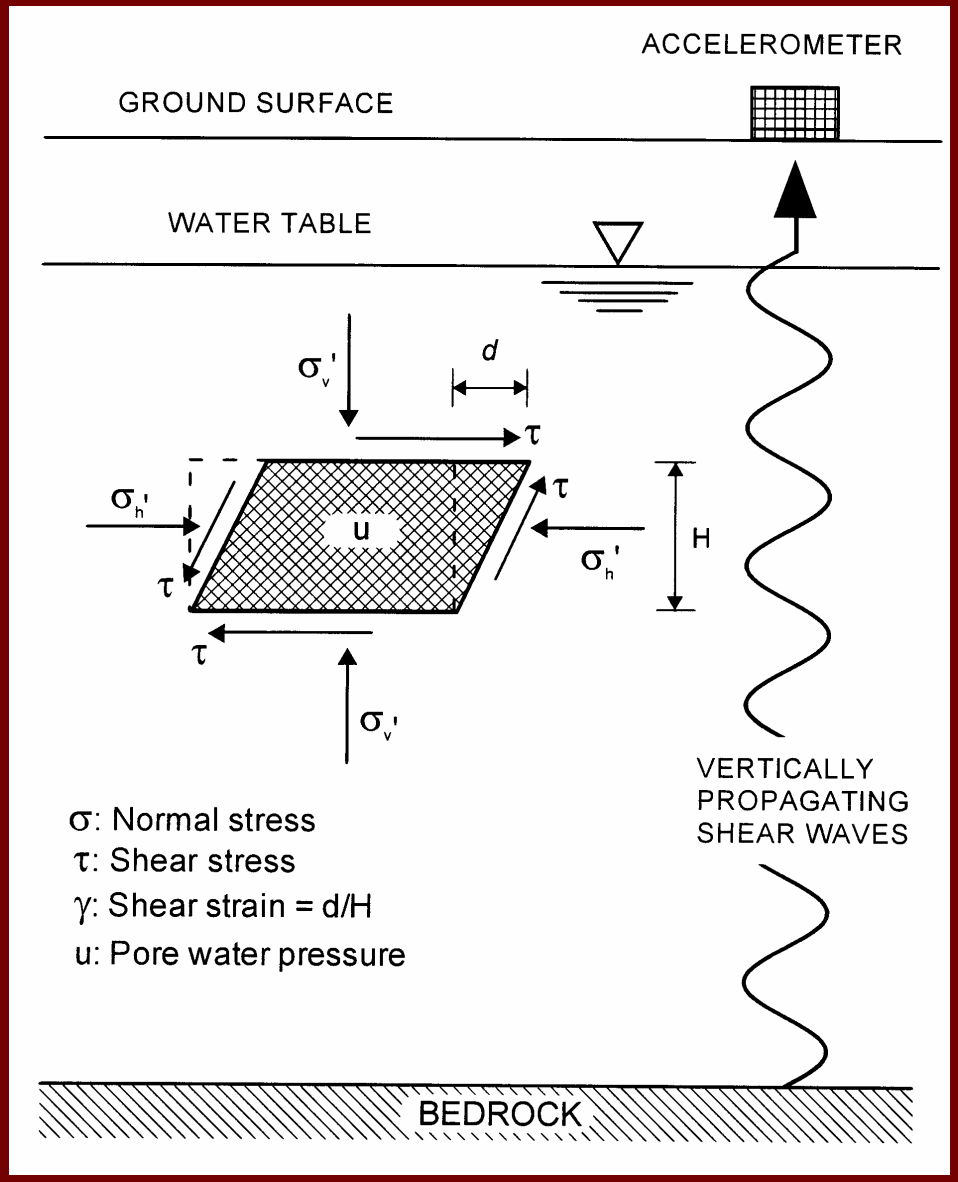
Capabilities of the DSDSS device

A device for small-strain direct simple shear testing, called the dual-specimen direct simple shear (DSDSS) device, was designed at UCLA in 1993 (Doroudian and Vucetic, 1995; 1998). With this apparatus, the cyclic stress-strain properties can be tested in the range from very small to very large cyclic shear strain amplitudes, γ_c.

- Secant shear modulus, G_s, can be determined with confidence at γ_c as small as 0.0002%,

- Cyclic loops can be clearly plotted and damping ratio, λ, comfortably obtained at γ_c= 0.0003%,

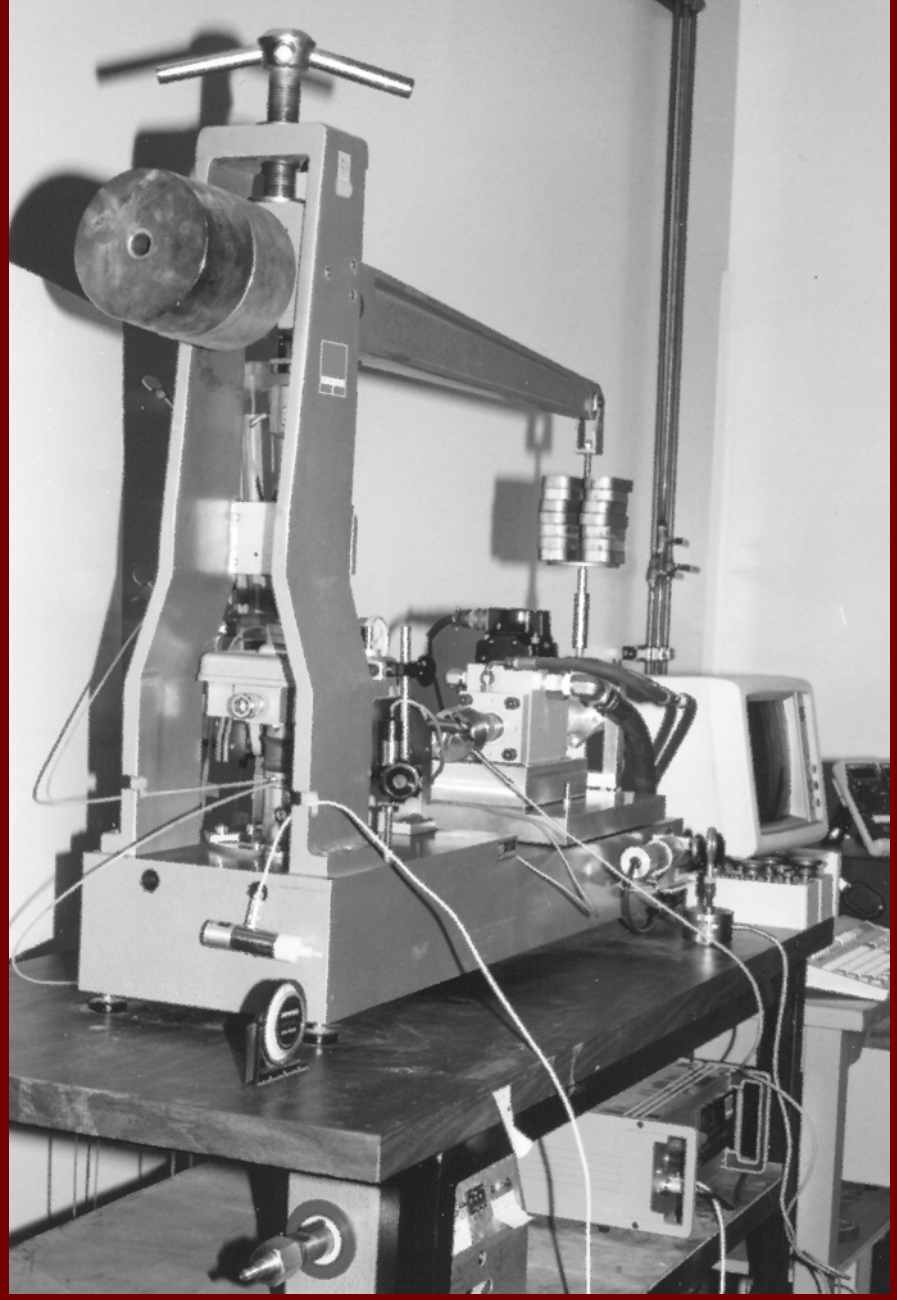
- On the other end of the γ spectrum, soil can be tested at large γ_c = 10 – 15%, or it can be brought to failure monotonically.



Usefulness of the direct simple shear testing

In a DSS test, the stress-strain conditions corresponding to those at level ground during earthquake can be simulated relatively well. The figure shows the state of a soi element during vertical propagation of shear waves.

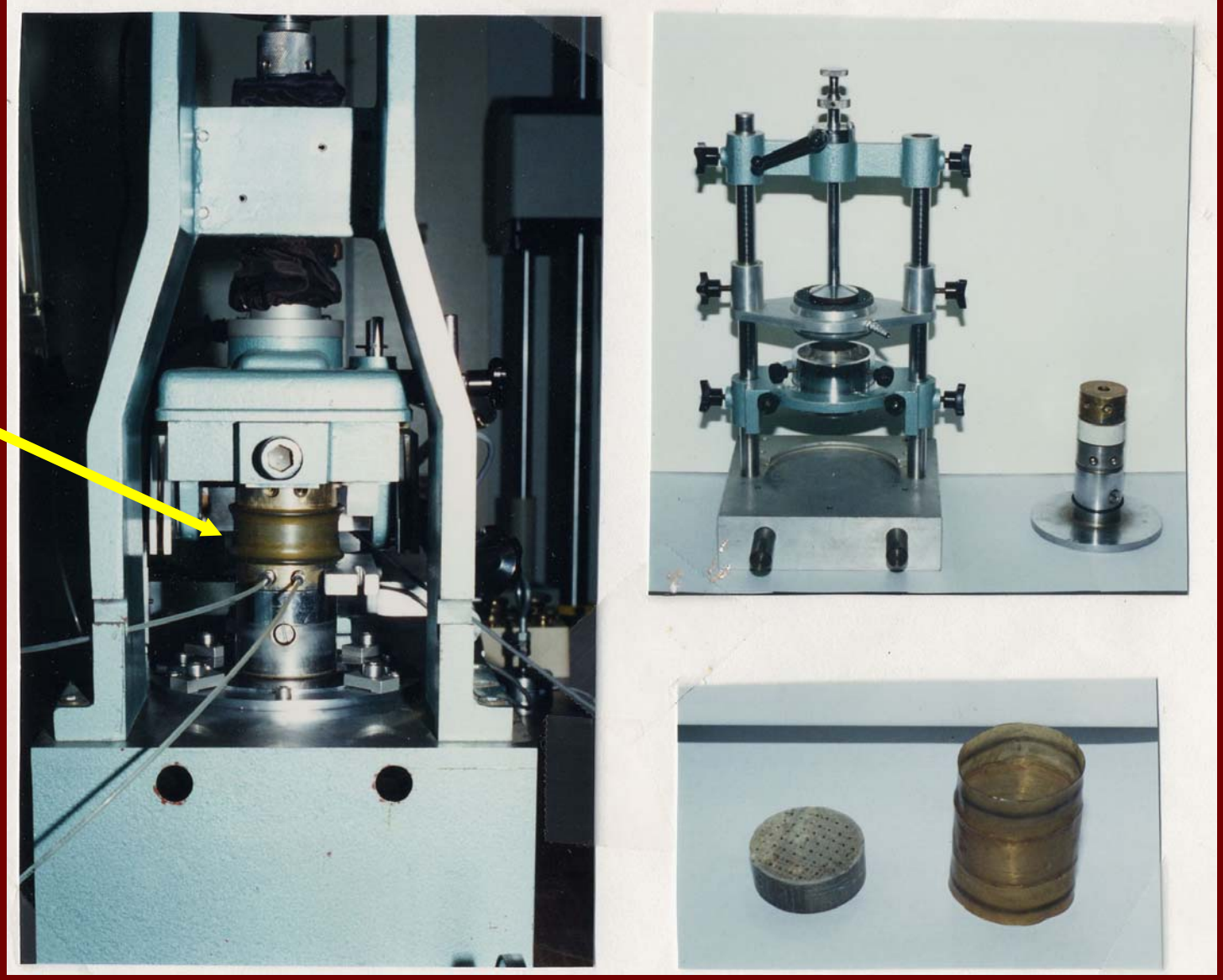
These idealized stress-strain conditions are similar to those of the DSS test specimen: on top of the existing consolidation vertical and horizontal stresses, cyclic shear stresses are applied.



Standard NGI-type of DSS device at UCLA

Standard DSS device

In the DSDSS device the specimen preparation, consolidation, and shearing procedures are in principle the same as those in the standard Norwegian Geotechnical Institute (NGI) type of DSS test. The tests conducted are the constant-volume, equivalent-undrained direct simple shear.



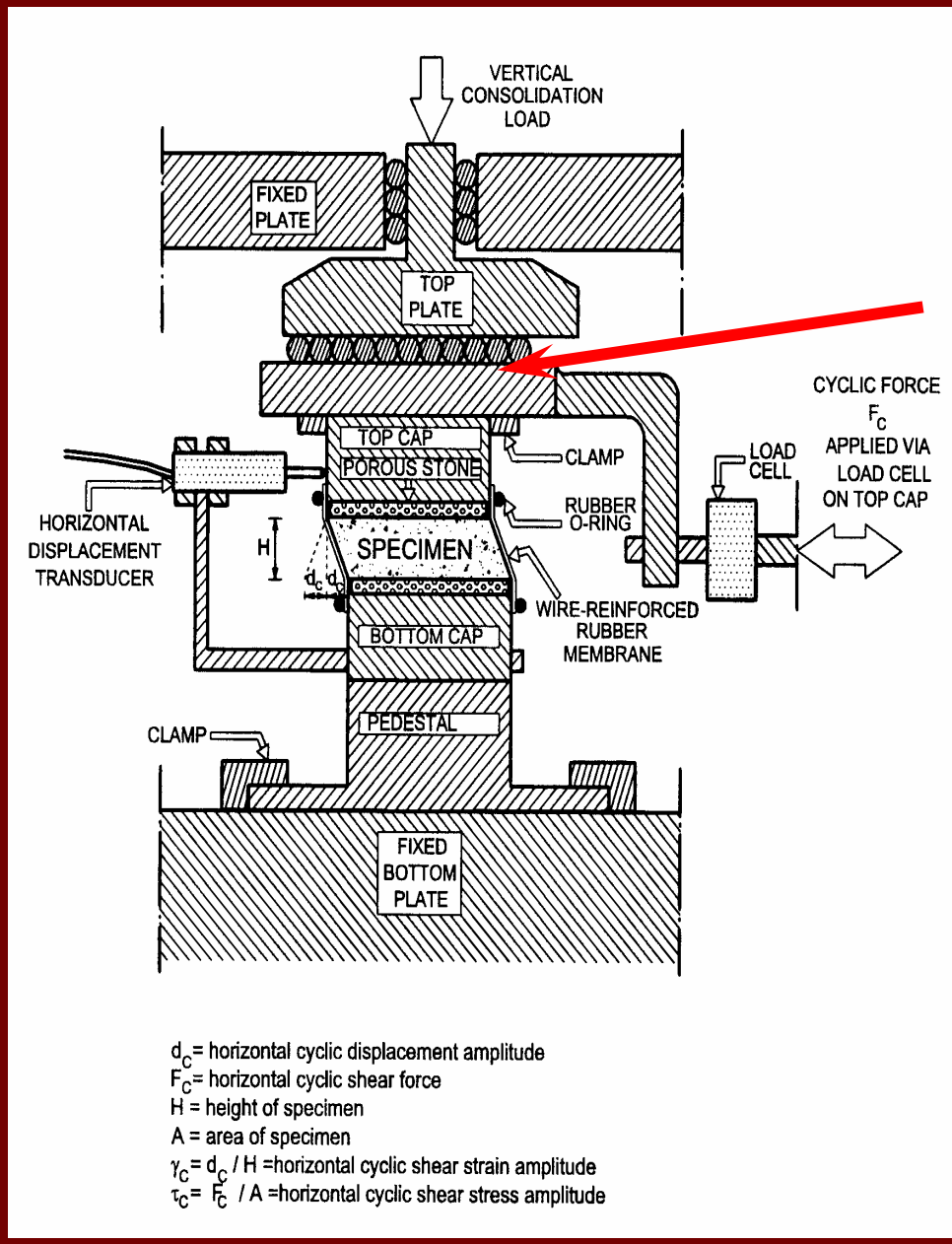
Specimen in the standard NGI-DSS apparatus, specimen trimming apparatus, a tested specimen, and a wire-reinforced rubber membrane

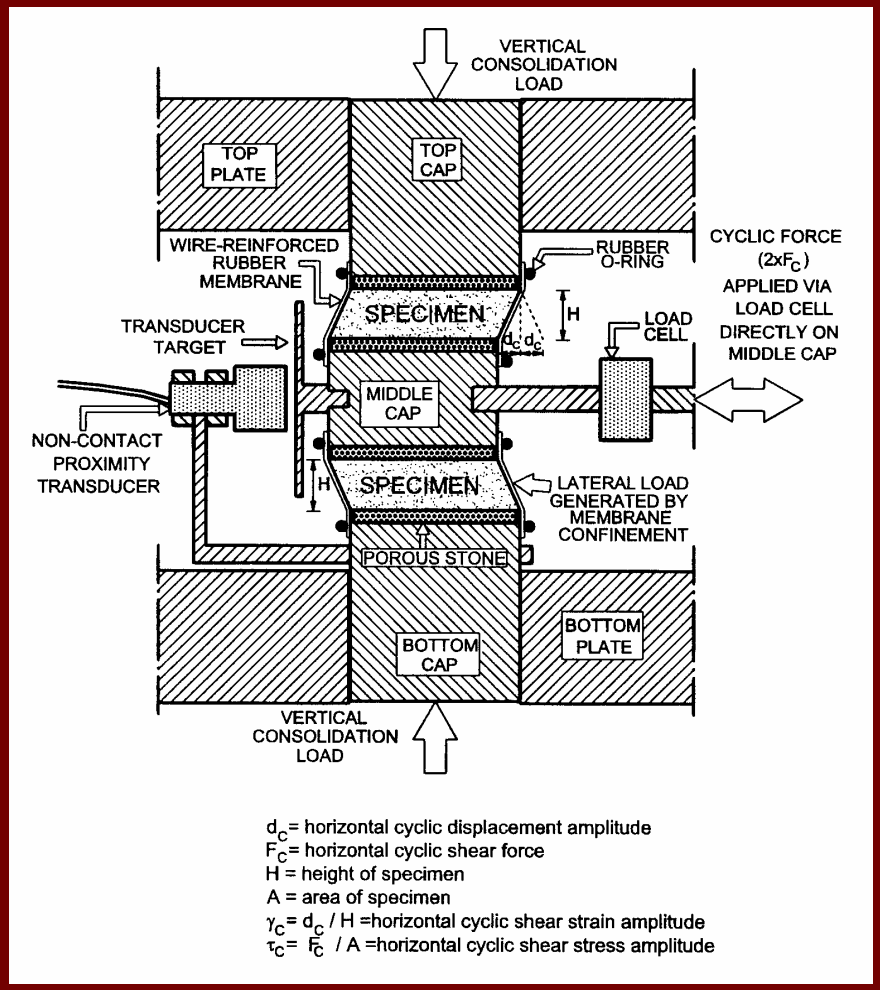
In the NGI-DSS and UCLA DSDSS tests the specimens have shape of short cylinder, usually 18 to 19 mm high and 66.7 mm in diameter.

The specimens are confined in wire-reinforced rubber membranes, the role of which are to greatly restrict and nearly prevent the radial deformations during consolidation and shearing, while allowing vertical and simple shear deformations.

The standard NGI-DSS trimming apparatus has been used for the trimming of intact DSDSS specimens of natural soil with minimal disturbance.

In the standard NGI DSS device, the small-strain testing cannot be successfully conducted. The friction of the top plate roller bearing, which is a part of the horizontal load cell record, is usually much larger than the shear resistance of the soil at very small cyclic shear strains, i.e., the strains in the order of γ_c=0. 01% – 0.0001% which are highly relevant in the geotechnical earthquake engineering and other soil dynamics disciplines.



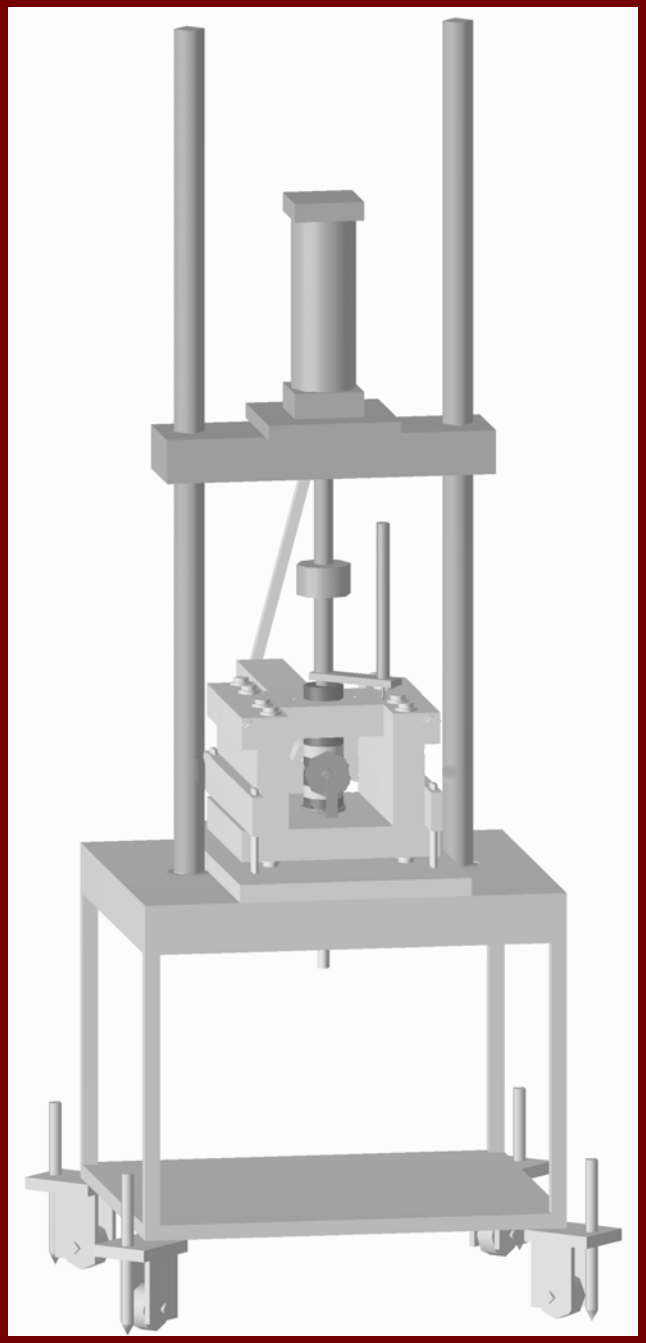


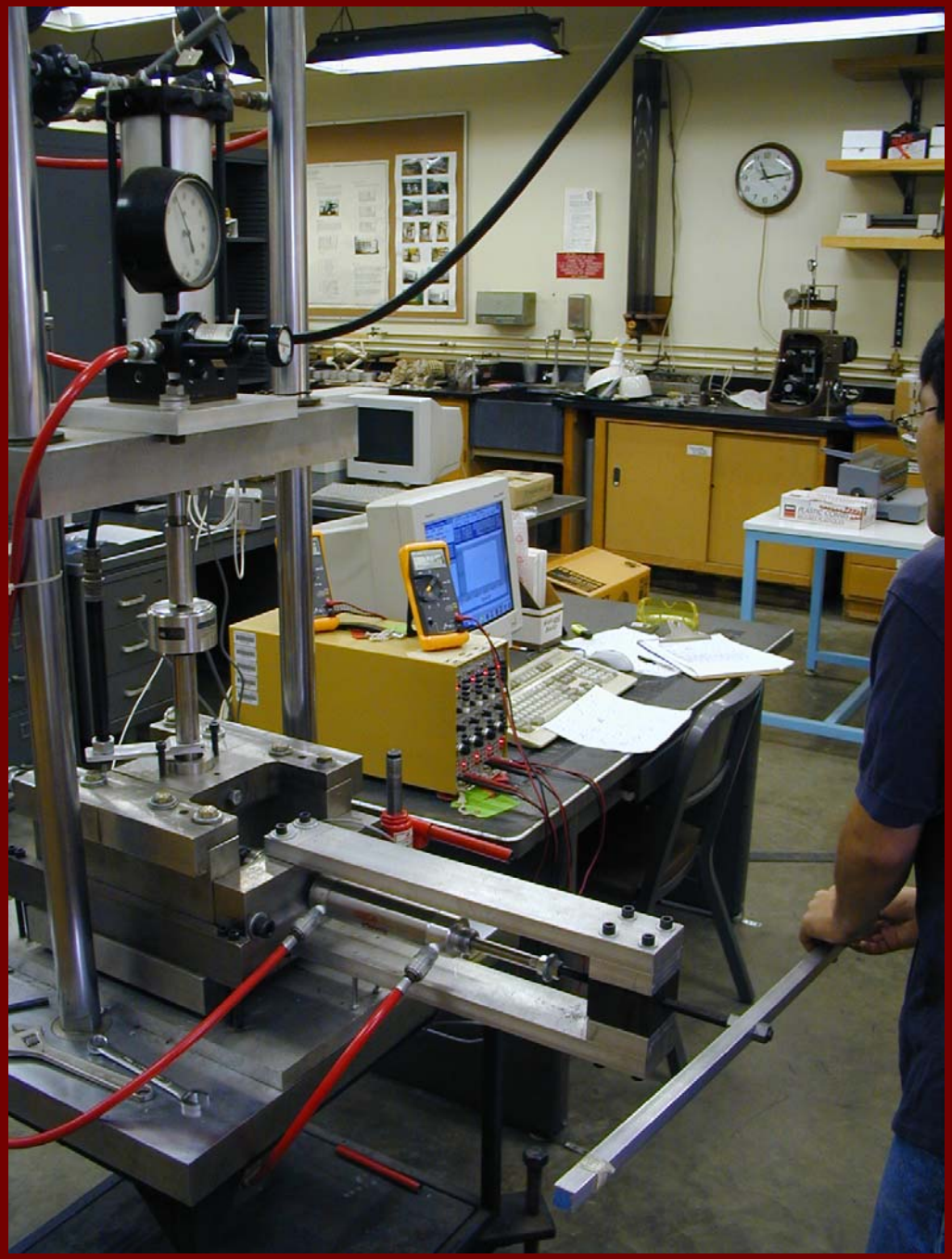
UCLA dual-specimen direct simple shear device (DSDSS) specimen setup

In the new DSDSS device this problem does not exist, because the entire horizontal shear force is transmitted directly to the soil (and also the membranes the shear stiffness of which is practically nonexistent at small strains).

<u>This is achieved by shearing simultaneously two parallel specimens of the same soil.</u>

Horizontal load is applied via the middle cap which “floats” between the specimens. In this way, only the soil resistance is recorded by the horizontal load cell.





To avoid false deformations and other errors, the setup is very stiff, made of thick steel components, and it is as symmetrical as possible

To avoid minute contact forces applied by contact displacement transducers, horizontal displacements between the middle cap and the top and bottom caps are recorded with high-precision non-contact transducers.

For precise measuring, recording, and processing of displacements and forces high-quality amplifiers, filters and data acquisition system are employed.

To avoid forces caused by vibrations of hydraulic, pneumatic or electrical motors, the cyclic or monotonic load is applied to the middle cap with the help of "human-controlled closed-loop system".

Historical notes:

In the original human-controlled closed-loop system of the DSDSS device, the component of which is on this photo the co-inventor of the device Dr. Macan Doroudian, load was applied in a very simple manner by just pushing the middle cap with hands, but rubber gloves had to be used to avoid electrical interference.

Furthermore, with the old load-application system it was not easy to fight the strength of the soil at large strains. The benefit of it was, however, that this was a system that allowed the operators (students and professor) to feel the strength of the soil, its yielding and eventual failure. This was always interesting and rewarding experience indeed.

Large shear strains are now applied in an elegant manner. Nevertheless, the DSDSS device is robust at large shear strains and gentle at small shear strains.

Typical DSDSS test results

Small-strain results on two clays:

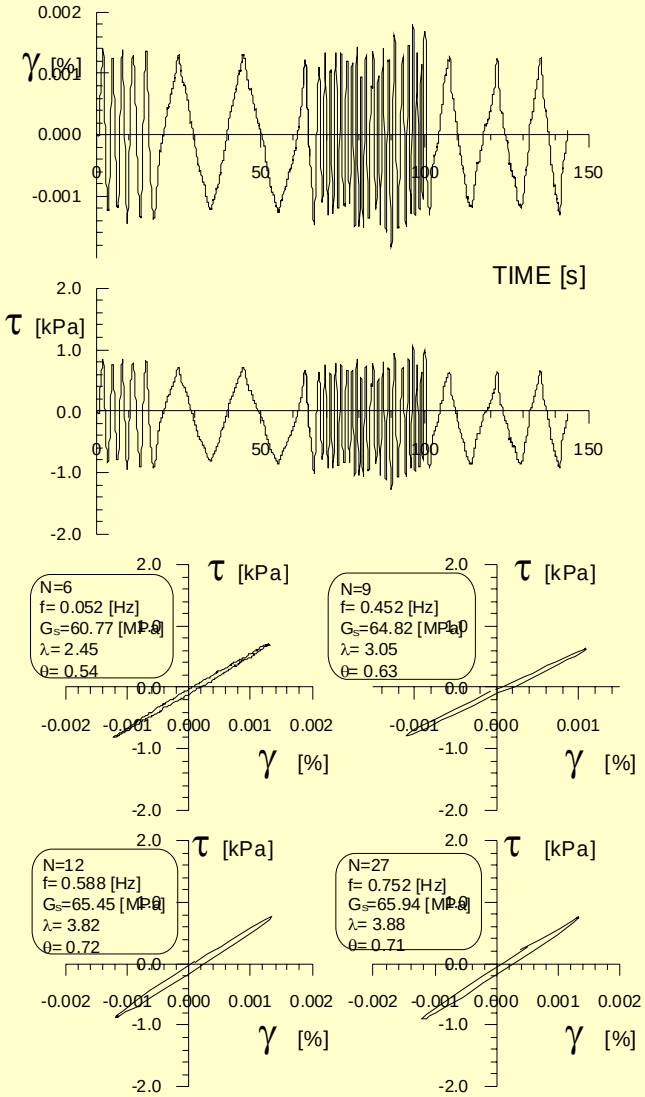


Fig. 9 Example of results of a cyclic step of Kaolinite-300 test results obtained on "undisturbed" laboratory-made clay

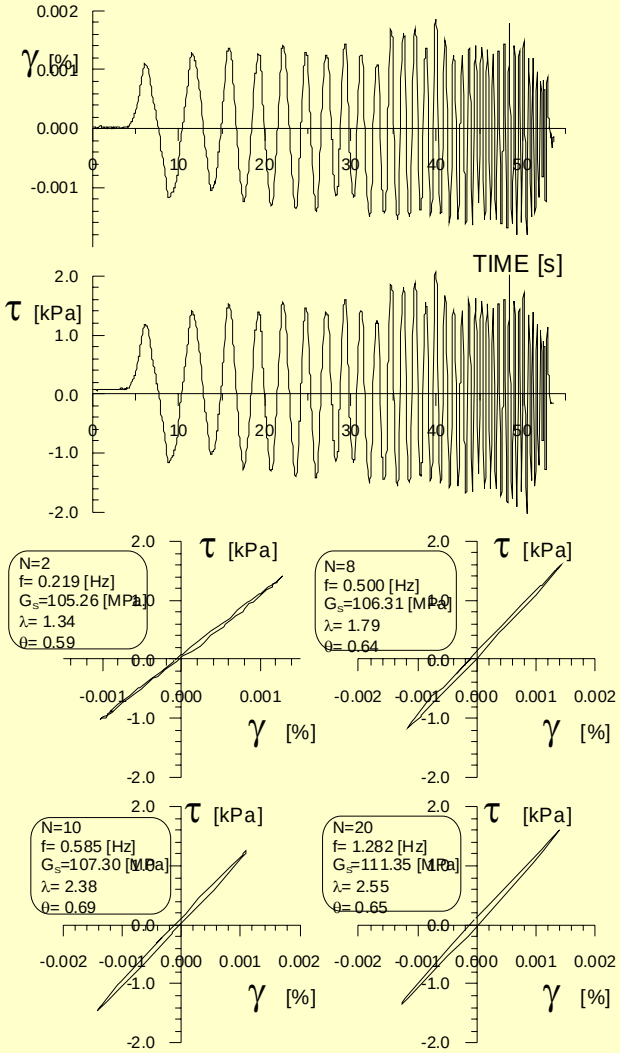
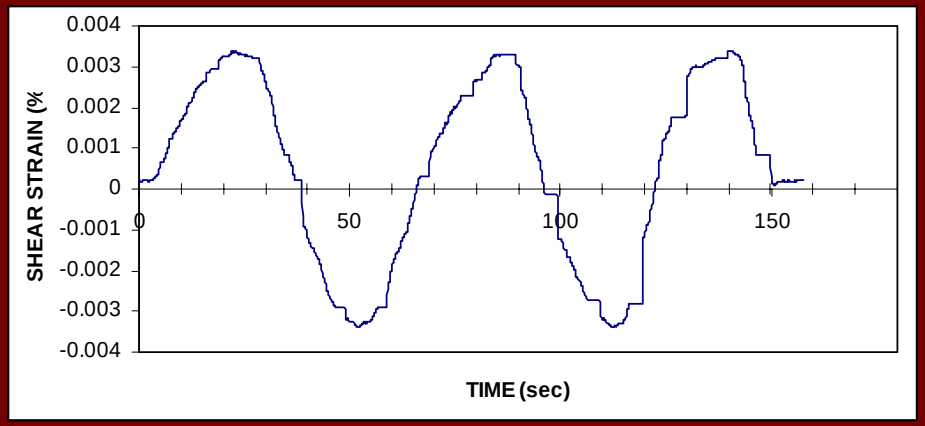
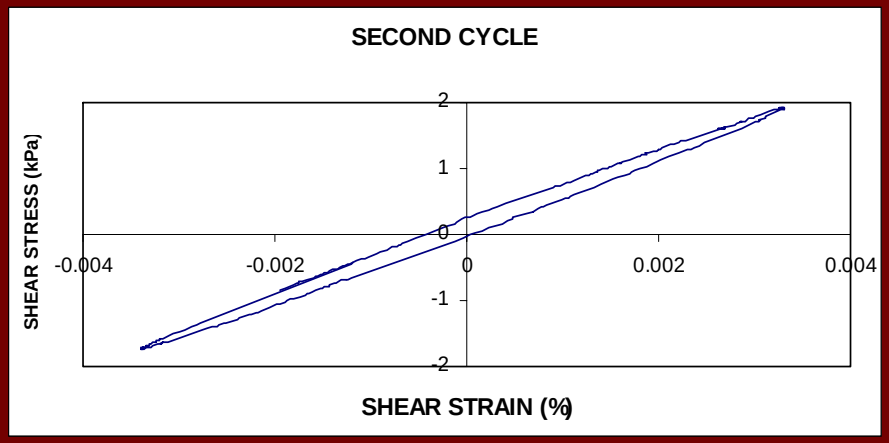


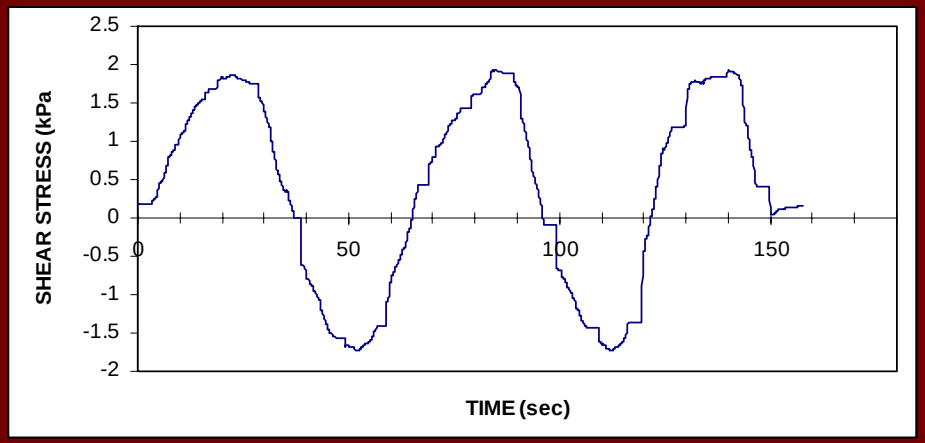
Fig.8 Example of results of a cyclic step of Augusta-857 test results obtained on "undisturbed" natural clay

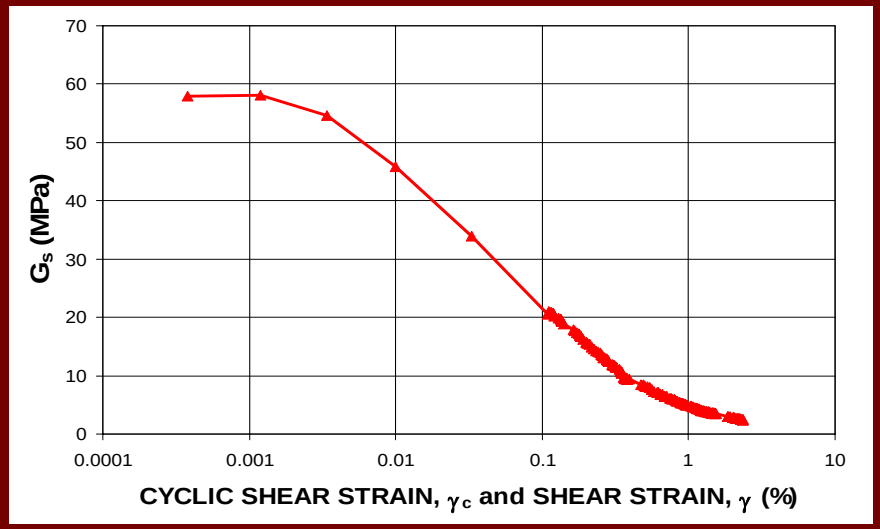
Typical combination of small-strain cyclic test followed by the monotonic loading to failure

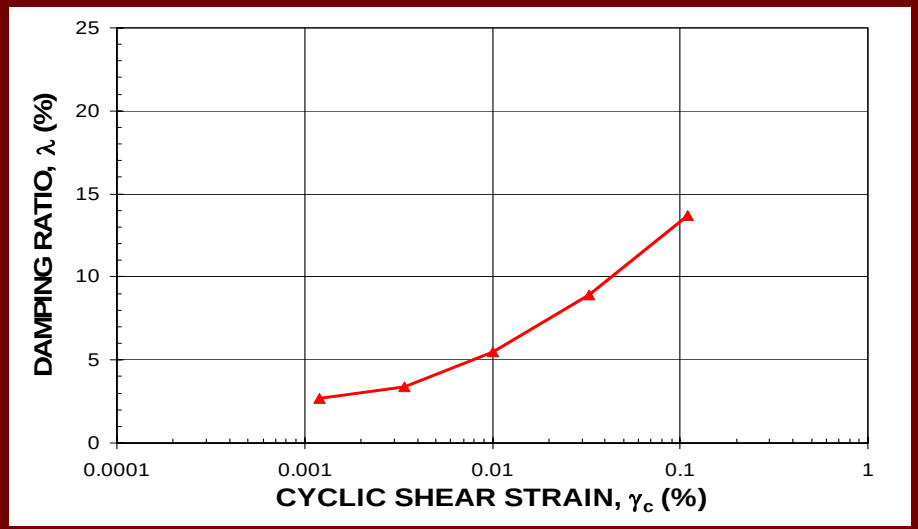
La Cienega, L2-2, 20.6-21.0 feet					
DSDSS TEST-STEP 4					
Type of soil: CL					
LL	27.3	PI	9.9	%Silt	-
e_o	0.554	S_o (%)	98.24	%Clay	-
$\sigma v'$ (kPa)	128	OCR	n/a	w (%)	20.15
γ_c (%)	0.003	H_o (mm)	19.71	G_s	2.70

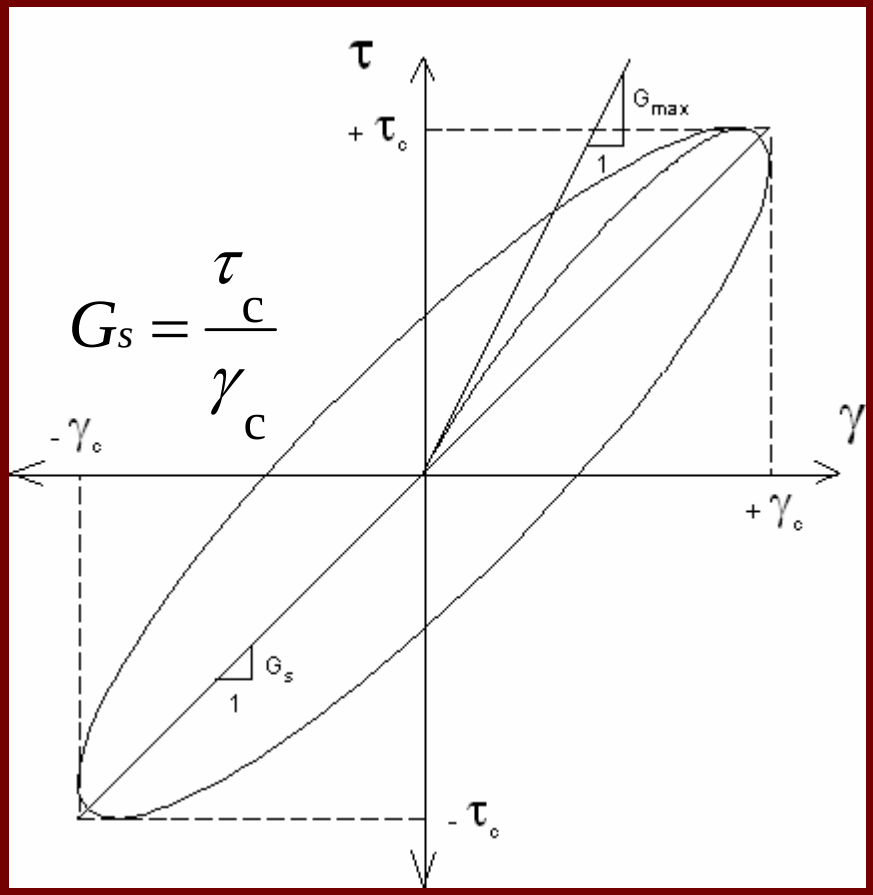


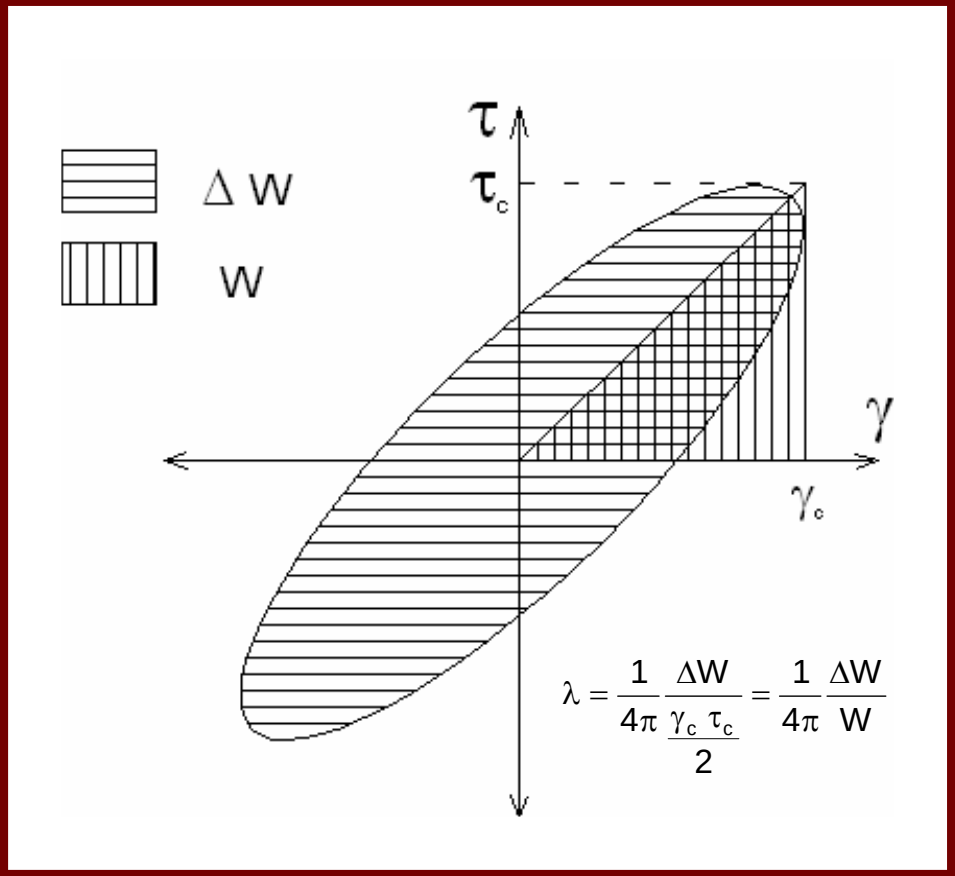




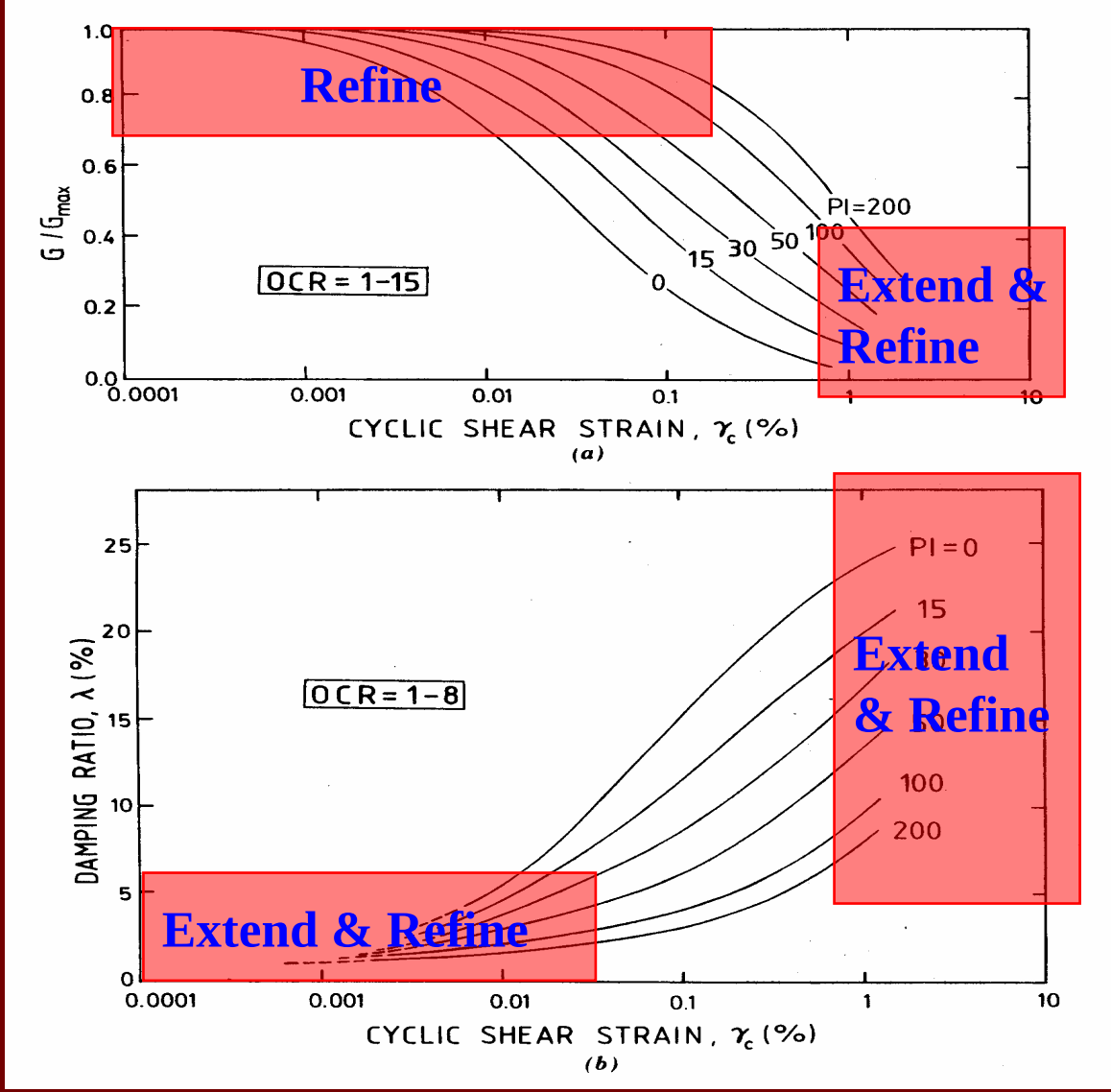




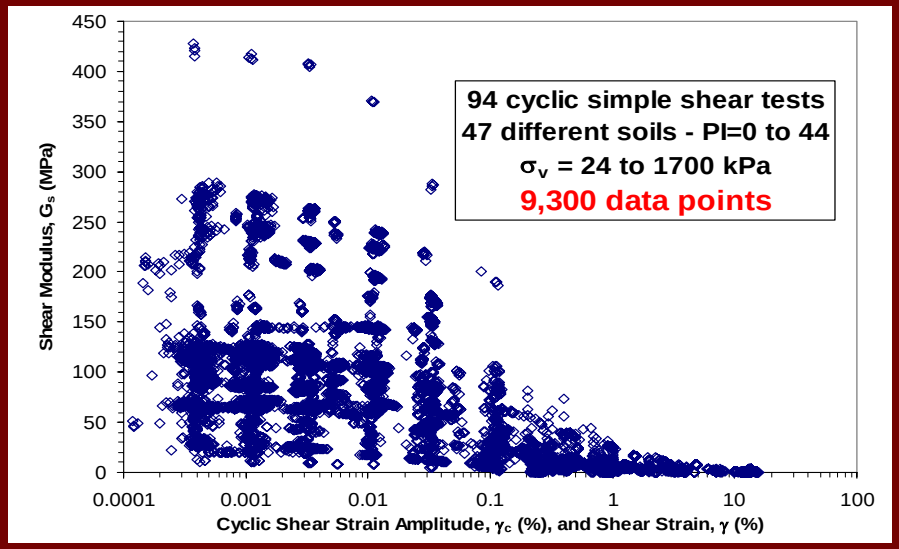


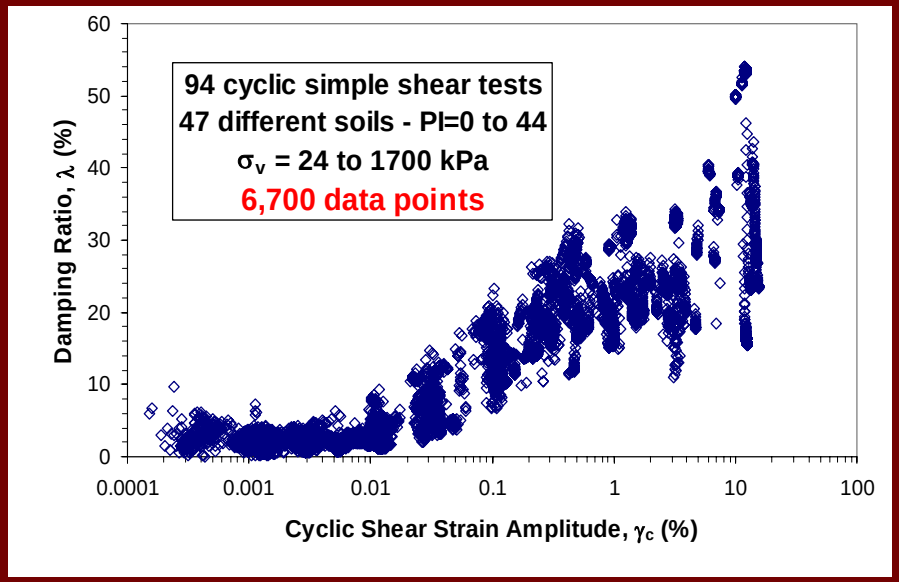


The new apparatus has been used mainly to test the equivalent damping ratio, λ, and secant shear modulus, G_s, and their variation with the cyclic shear strain amplitude, γ_c, in the form of the λ-log γ_c and G_s/G_{max}-log γ_c curves.

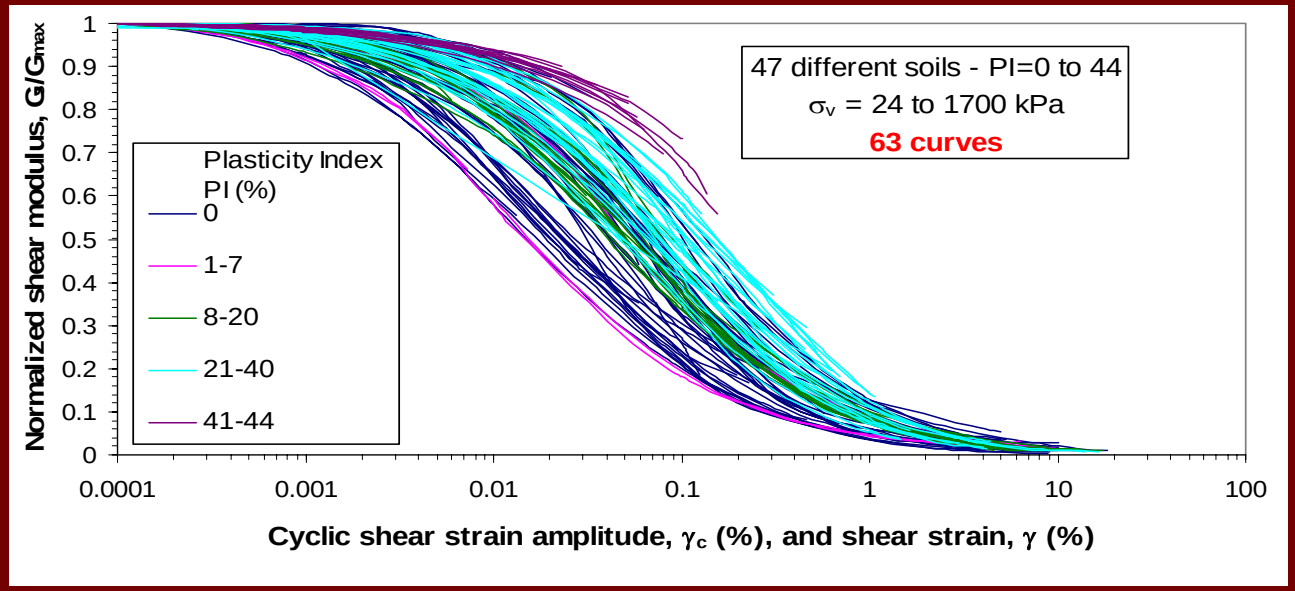


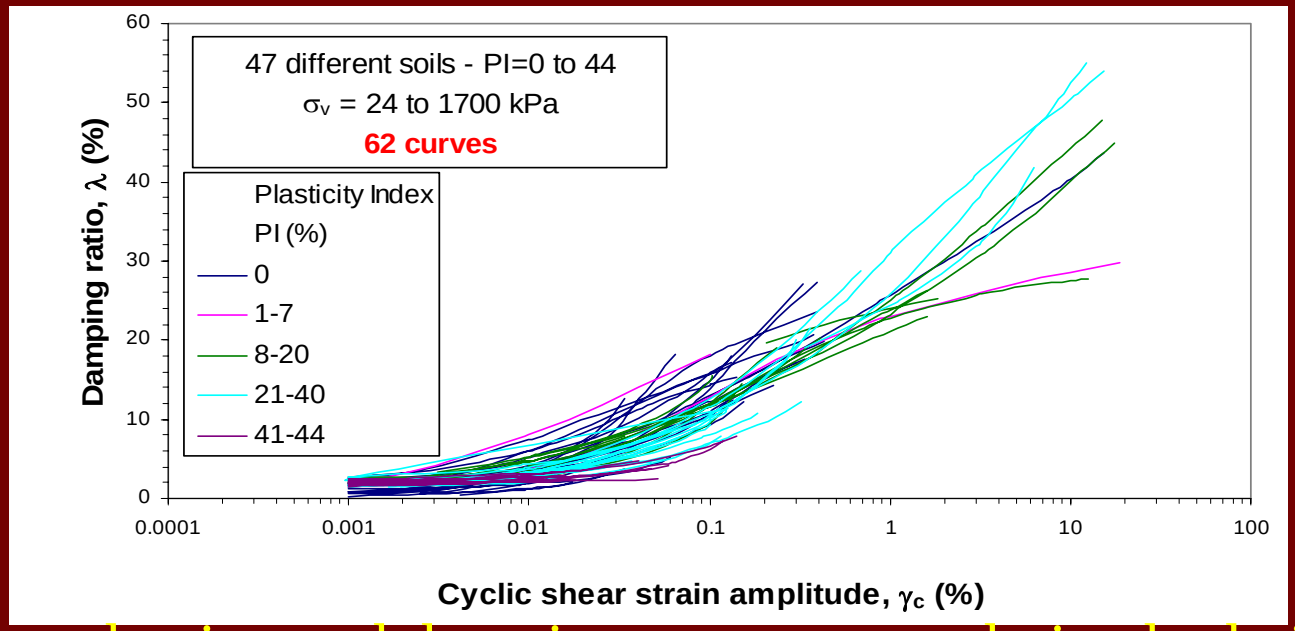
Main subject of the long-term research at UCLA was to refine and extend the average modulus reduction and damping curves suggested by Vucetic and Dobry (1991) to very small and very large γ_c.



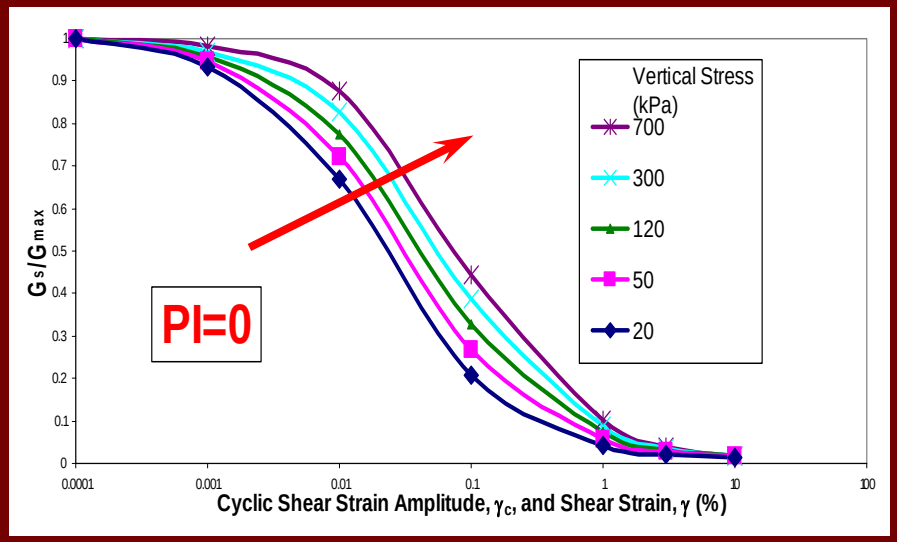


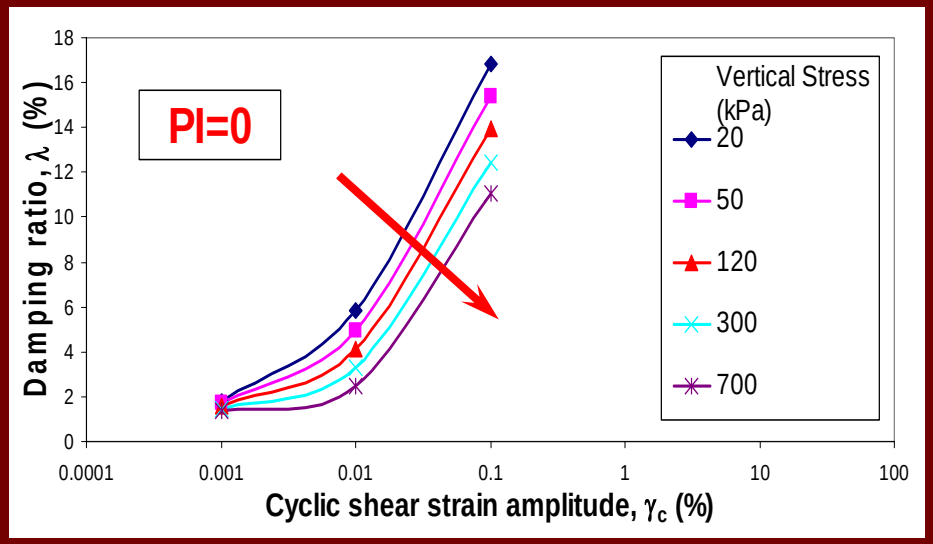
Over 160 cyclic tests were conducted on more than 60 soils, yielding enormous amounts of data. To analyze and compare these data systematically, a conveniently structured database with a <u>cyclic loop as elementary unit</u> was developed (Hsu and Vucetic, 2002). In the database every cyclic loop in each test is characterized by a series of relevant parameters. Using the database cyclic loops from different tests can be compared and manipulated to create instant graphical presentations of behavioral trends.

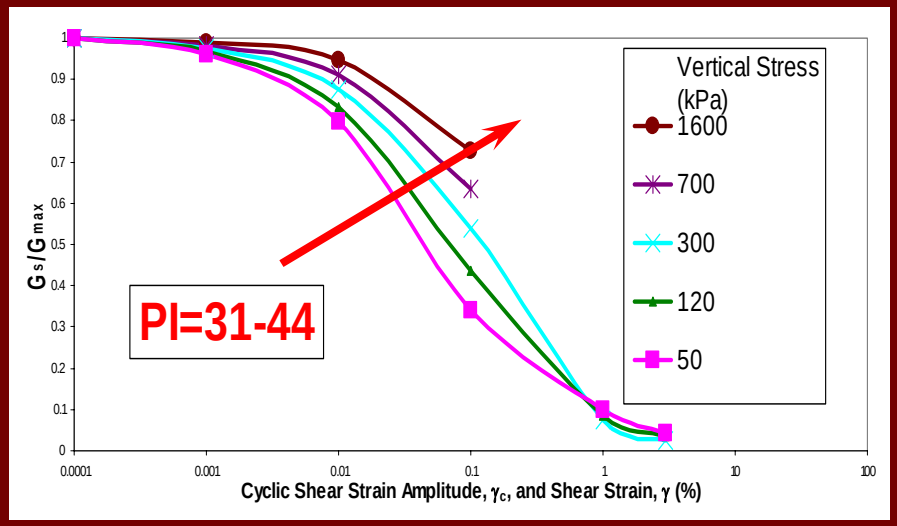


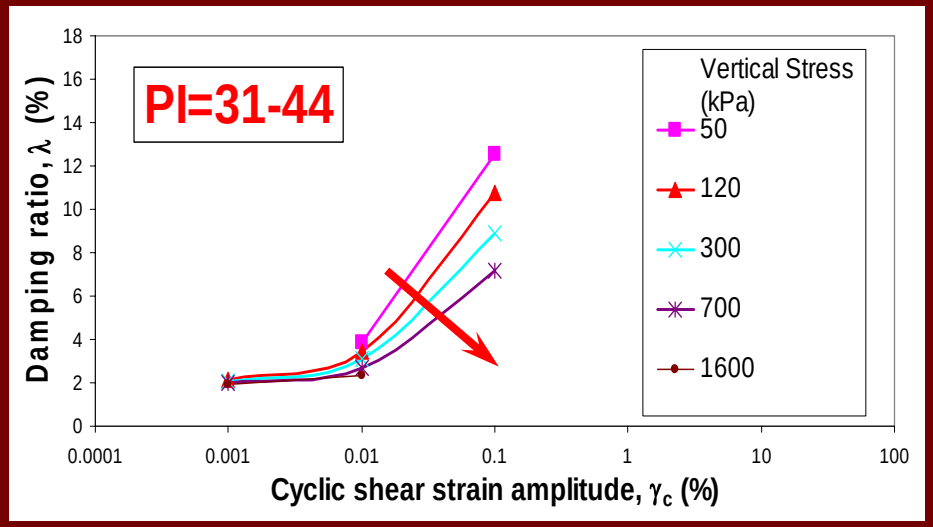


Modulus reduction and damping curves were derived relatively easily from the data points presented above using routines incorporated in the database (Hsu and Vucetic, 2002)

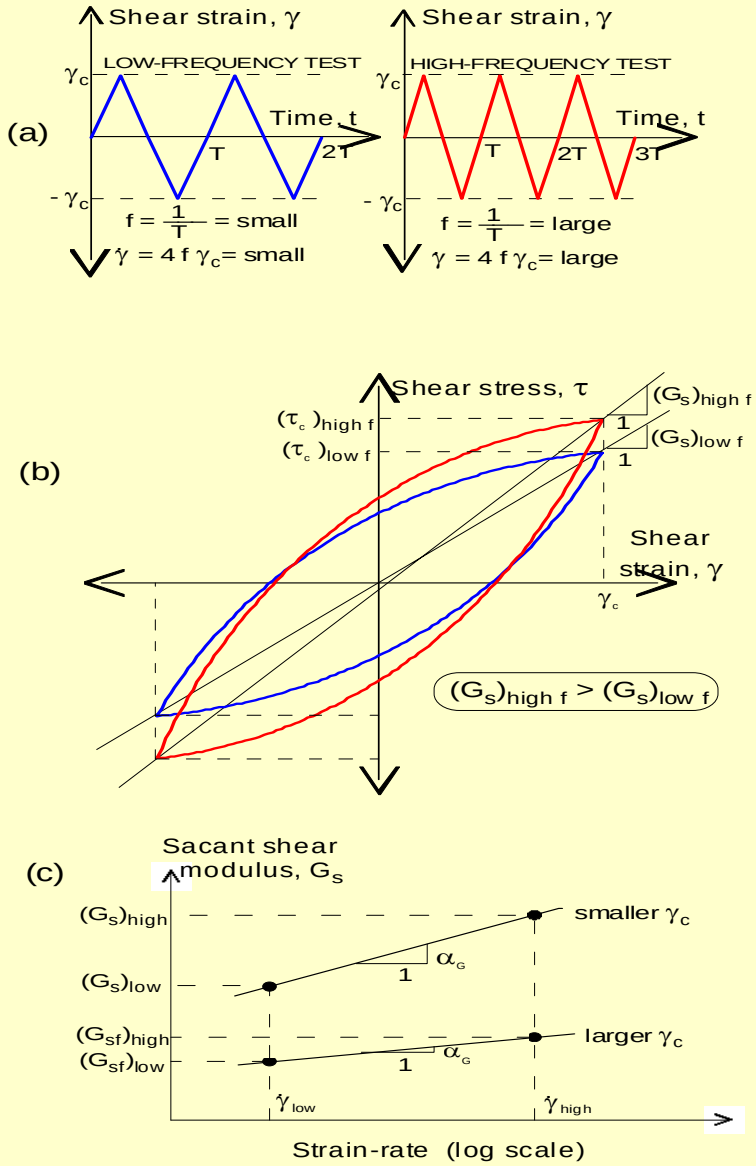






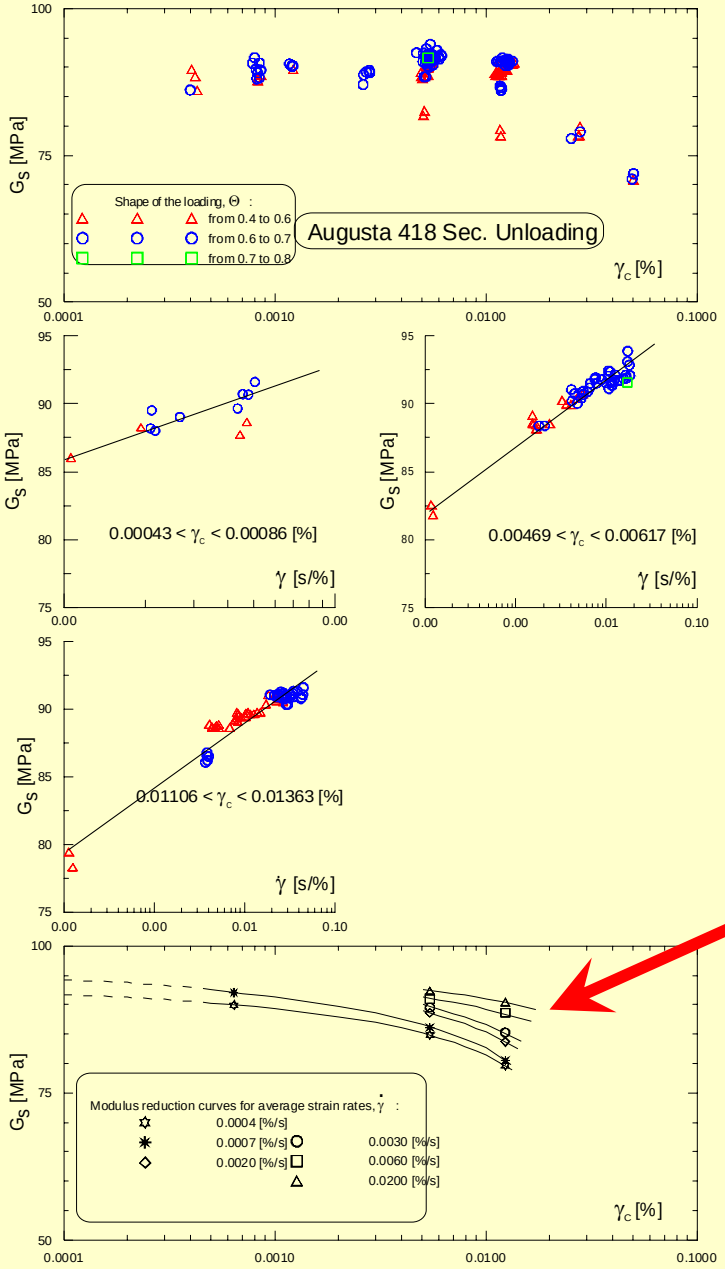


Effects of vertical stress on modulus reduction and damping curves were derived automatically from the database for selected ranges of PI (Hsu and Vucetic, 2002)



The effects of the rate of straining and frequency on modulus reduction and damping was investigated most extensively

(Matesic and Vucetic, 2003; Vucetic and Tabata 2003)



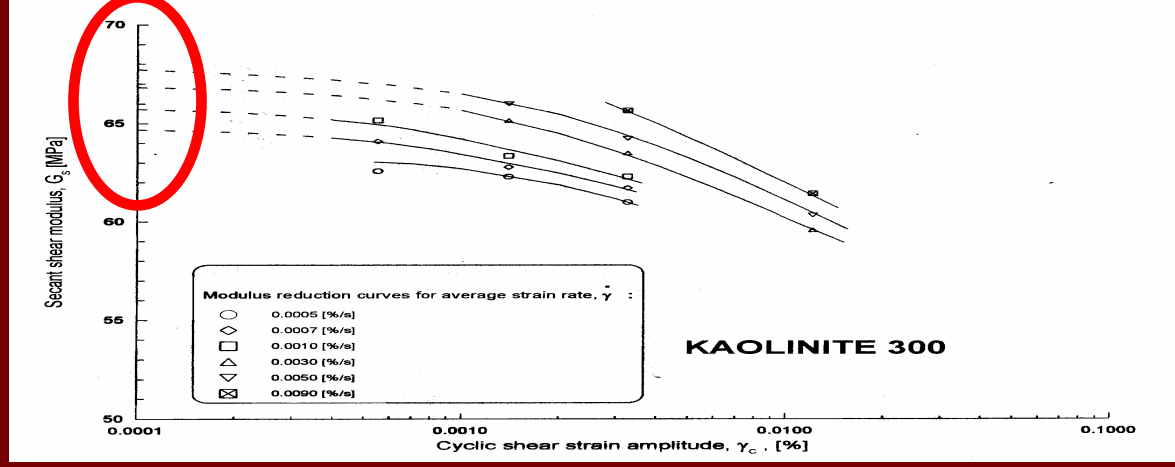
Using the database, the effect of the average rate of loading, *dγ/dt,* on secant shear modulus, G_s, in a high-plasticity clay was derived for selected ranges of cyclic strain amplitude γ_c.

Based on these data, the constant-strain-rate G_s-log γ_c modulus reduction curves were plotted.

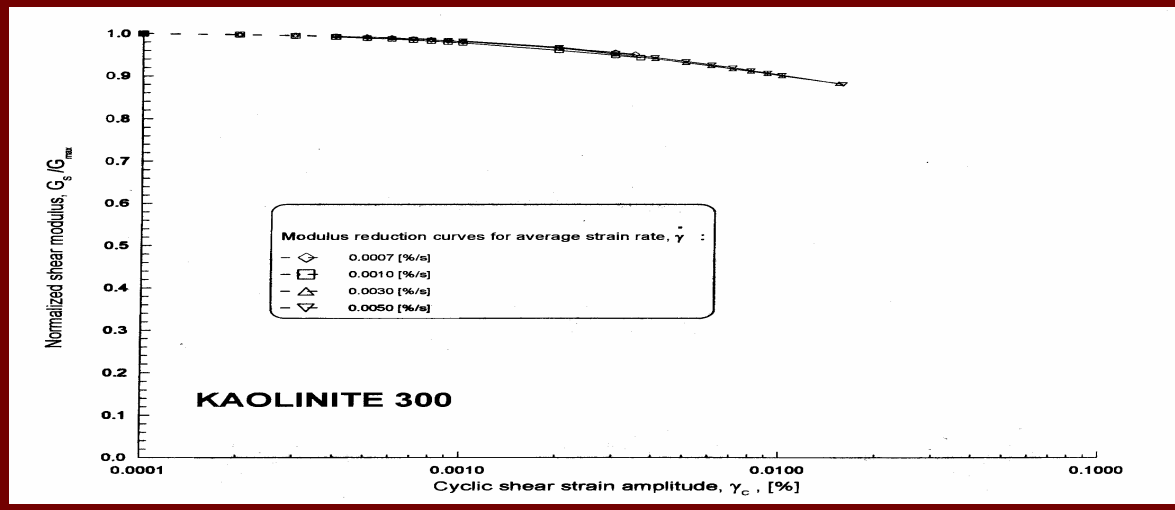
(Matesic and Vucetic, 2002)

In this way various effects and trends were studied:

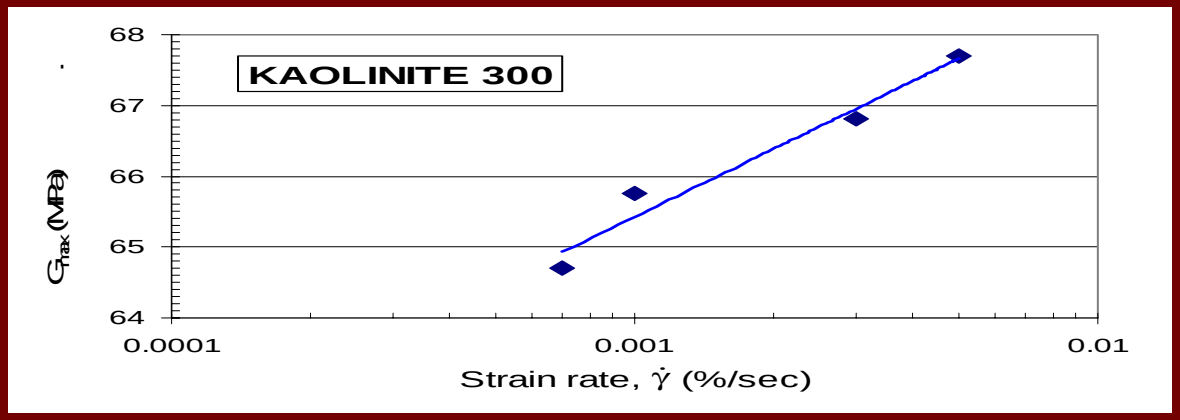
Effect of average strain rate on G_s -log γ_c curve (Matesic and Vucetic, 2003)



Effect of average strain rate on G_s/G_{max}- log γ_c curve (Matesic and Vucetic, 2003)



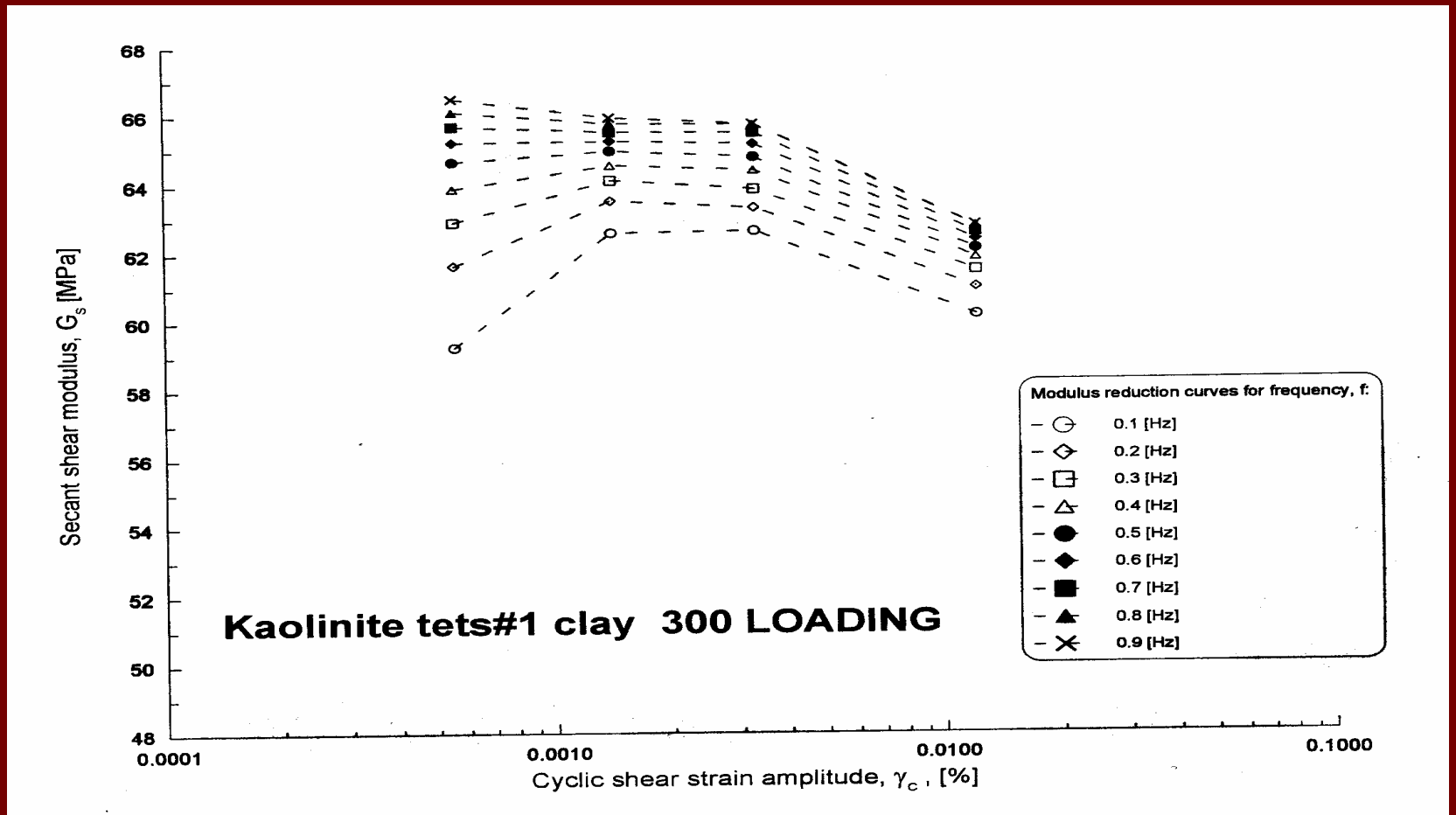
Approximate effect of average strain rate on G_{max} (Hsu and Vucetic, 2002)



One of the most interesting results is the effect of frequency on Gs-log γ_c curve obtained using DSDSS device

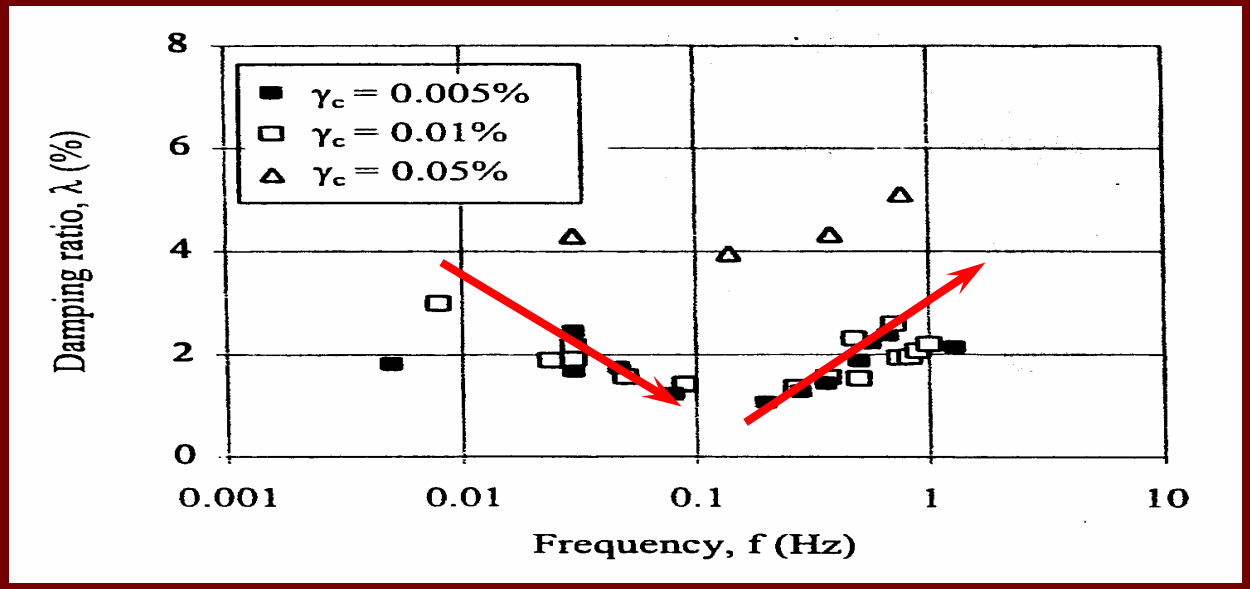
(Matesic and Vucetic, 2003).

It can be seen below that the Gs/Gmax-log γ_c curve can assume different curvatures if derived from cyclic tests conducted at the same frequency.

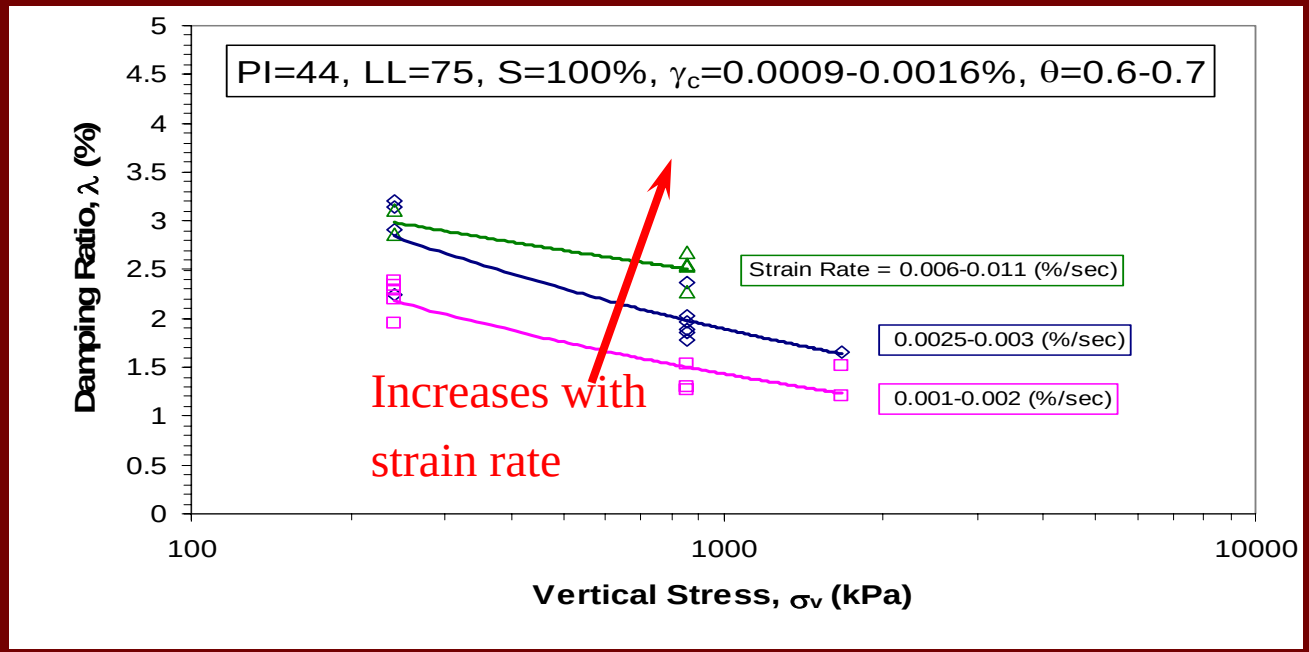


Another interesting result is complex effect of frequency, *f*, and vertical stress on damping ratio, λ:

Effect of *f* on λ at small-strains (Lanzo, Doroudian and Vucetic, 1999)



Effect of average strain rate and σ_v on λ (Hsu and Vucetic, 2002



Major publications containing DSDSS test results:

- Doroudian, M., and Vucetic, M. (1995), “A direct simple shear device for measuring small-strain behavior”, *ASTM Geotechnical Testing Journal*, GTJODJ, Vol. 18, No. 1, pp. 69-85.

- Doroudian, M. and Vucetic, M., (1998), "Small-Strain Testing in an NGI-type Direct Simple Shear Device," *Proceedings of the 11th Danube-European Conference on Soil Mechanics and Geotechnical Engineering*, Porec, Croatia, Publisher A.A. Balkema, pp. 687-693.

- Hsu, C-C., and Vucetic, M. (2002): “Dynamic and Cyclic Behavior of Soils Over a Wide Range of Shear Strains in NGI-type Simple Shear Testing Device”, *UCLA Reserarch Report* No. ENG-02-228, Civil and Environmental Engineering Department, University of California, Los Angeles, January, 267p.

- Lanzo, G., Doroudian, M. and Vucetic, M. (1999). “Small-Strain Cylic Behavior of Augusta Clay in Simple Shear”, *Proceedings of the Second International Symposium on Pre-failure Deformation Characteristics of Geomaterials - IS Torino 99*, Published by A.A. Balkema, Vol. 1, pp. 213- 219, Sept.

- Lanzo, G. and Vucetic, M. (1999): “Effect of Soil Plasticity on Damping Ratio at Small Cyclic Strains”, *Soils and Foundations*, Vol 39, No. 4, pp. 131-141.

- Lanzo, G., Vucetic, M. and Doroudian, M. (1997), “Reduction of Shear Modulus at Small Strains in Simple Shear”, *ASCE Journal of Geotechnical and Geoenvironmental Engineering,* Vol. 123, No. 11, pp.1035-1042.

- Matesic, L. & Vucetic, M. (2003), “Strain-Rate Effect on Soil Secant Shear Modulus at Small Cyclic Strains,” *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 129, No. 6, pp, 536-549.

- Vucetic, M., Lanzo, G., and Doroudian, M. (1998a), “Damping at Small Strains in Cyclic Simple Shear Test”, *ASCE Journal of Geotechnical and Geoenvironmental Eng.*, Vol. 124, No.7, pp.585-594.

- Vucetic, M., Lanzo, G., and Doroudian, M. (1998b), “Effect of the Shape of Cyclic Loading on Damping Ratio at Small Strains”, *Soils and Foundations*, Vol. 38, No. 1, pp. 111-120.

- Vucetic, M. and Tabata, K. (2003): “Influence of Soil Type on the Effect of Strain Rate on Small-strain Cyclic Shear Modulus”, *Soils and Foundation,* Vol. 43, No. 5, pp. 161-173.

- Vucetic, M, Tabata, K. and Matesic, L (2003). “Effect of Average Straining Rate on Shear Modulus at Small Cyclic Strains” *Proceedings, International Conference “Deformation Characteristics of Geomaterials”,* Lyon, 2003*”,* Editors: Di Benedetto et al., Publisher: A.A., Balkema, Lisse, pp. 321-328.

Summary and conclusion:

The DSDSS device is an excellent tool for the investigation of fundamental cyclic soil properties at very small and very large cyclic shear strains.

In this short presentation it has been indicated that there are still numerous issues in the domain of fundamental cyclic stress-strain behavior that need to be resolved through experimental investigations.

The complete resolution of these issues will greatly reduce many uncertainties in nonlinear soil properties and their impact on modeling dynamic soil response.

Acknowledgements:

The entire long-term study at UCLA using DSDSS device has been going on for last 10 years. It has encompassed cyclic testing in different research projects supported by different institutions. They are NSF, University of California Office of the President, Lawrence Livermore National Laboratory, Caltrans, PEER, Southern California Earthquake Center (SCEC), the University of Zagreb in Croatia, and the Okinawa International Exchange and Human Resources Development Foundation in Japan.

Support from all of these organizations is gratefully acknowledged.

The End