Discussion leader's presentation
Présentation par l'animateur des débats

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ABSTRACT: This paper includes both the initial presentation and the closure by the Discussion Leader of Discussion Session 1.1 on "Recent Developments in Laboratory Stress-Strain Testing in Geomaterials."

RESUME: Les présentations de l'Animateur de Séance de Discussion 1.1 intituleé "Lois de comportement des géomatériaux: développements récents", sont presentées dans cet article.

1 INITIAL PRESENTATION

Ladies and Gentlemen, Good Morning! My name is Ricardo Dobry, and I am the Discussion Leader of this session. We are following up the excellent presentation that Dr. Tatsuoka gave yesterday, where he proposed some topics for discussion; we have several excellent panelists who will be making short formal presentations; and we expect to have active participation and discussion from the floor throughout the session. Our panelists are: Prof. Di Benedetto, Prof. Shibuya, Prof. Lo Presti, Prof. Ladd (who is also our Session Chairman), and Prof. Graham.

What I want to do in this initial presentation is: first to give you some personal thoughts on the subject, and then propose a few discussion topics for the session, both to the panelists and to all of us present today, so that we can focus on a few key questions. Let me start with the discussion points proposed yesterday for this session by Dr. Tatsuoka:

1. Advantages and disadvantages of laboratory stress-strain measurements (compared with in-situ)
2. Relevant laboratory measurements
3. How to combine laboratory and field tests

EMPHASIS: non-linear soil stiffness in strain range 10^{-3}% to 1%

Of course, as soon as we start talking about soil stiffness at strains as small as these, we must necessarily talk also about shear wave velocity measurements in the field, V_s, about G_{max}, and about dynamic measurements in resonant column and other dynamic tests in the laboratory. In other words, we must necessarily refer to work people have been doing for 20 years or more with an eye to soil dynamics problems, as pointed out by both the speaker and the panelists in their presentations yesterday.

This experience on small strain and intermediate strain stiffness, originally developed for soil dynamics problems, should be an important reference point for evaluating static stiffness at those same strains. For example, Fig. 1 shows the reduction in secant shear modulus, G, with strain up to 1%, as a function of the Plasticity Index of the soil, PI, with high plasticity clays developing nonlinear behavior much slower than sands. This chart is based on many cyclic and dynamic laboratory tests, is extensively used for site response analyses in earthquake engineering, and it can be used as a starting point to evaluate static modulus in sands and clays in this strain range for problems involving static loading. One possible way of doing this is: first to measure the soil shear wave velocity, V_s, in the field with geophysical technique(s), and then estimate the secant $G = G_{max} (G/G_{max}) = \rho V_s^2 (G/G_{max})$, where ρ = soil mass density = total unit weight/g, g = acceleration due to gravity = 9.8 m/sec^2, and G/G_{max} is obtained from Fig. 1 at the appropriate shear strain.

Let me offer now several personal thoughts on the general subject of this session. Historically the interest on soil stiffness at small and intermediate strains has been limited to dynamic loads. Therefore, the testing techniques developed for the measurement of this stiffness are generally cyclic and/or fast (resonant column, cyclic triaxial, cyclic simple shear, cyclic torsional, and bender elements and similar techniques to measure V_s in the laboratory). As the interest increases on the static stiffness at small and intermediate strains, clarifying the effect o strain rate and cycling becomes important. Furthermore, the recent advances in stiffness measurements in static triaxial tests, and especially the measurements of local strain presented in his report by Tatsuoka, to eliminate the influence of bedding and compliance, which constitute a recent breakthrough, allow direct comparison between G in static tests and G from cyclic/dynamic tests at comparable strains. This is allowing for an accelerated progress in the development of a unified picture of both static and dynamic/cyclic stiffness at small and intermediate strains.

There are several distinctive characteristics of these dynamic measurements of the stiffness at very small strains, G_{max}

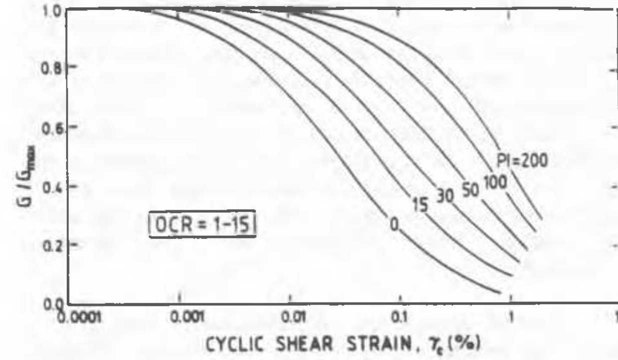

Figure 1
Secant modulus reduction curves for sands and clays from dynamic laboratory tests (Vucetic and Dobry, 1991)

= ρ V_s^2, both in the field and laboratory which are relevant to our discussion:

- Testing is nondestructive in the field and laboratory, and can also be done in a nonobstrusive manner when bender elements are used, which opens the possibility of combining G_{max} measurements with other tests (regular triaxial, simple shear, or consolidation tests, including measuring G_{max} at different times and stages of the static loading);
- We can measure in the field and laboratory a basic soil property (G_{max}, V_s) without the need for any special theory or assumption or empirical correction; and
- G_{max} is quite sensitive to sample disturbance and to even small amounts of cementation. This is in some sense "bad" when we try to determine G_{max} of disturbed samples in the lab and to extrapolate the results to the field, as it creates problems for us. But in another, very real sense, it is very good, in that measurement of G_{max} of samples both before and after reconsolidation, and its comparison with G_{max} field measurements, can give us a reliable measurement of the sample disturbance, and how far the small/intermediate small stiffness of the sample is from that in the field at various stages of the laboratory testing.

And now I would like to propose four discussion topics which incorporate the suggestions of Dr. Tatsuoka:

1. What have we learned about the influence of strain rate, cycling, cementation, and sample disturbance/ reconsolidation on soil stiffness at small and intermediate strains?

2. In relation to the soil parameters needed for classical settlement/stability problems: Can we quantify more exactly the effect of sample disturbance, or, conversely, can we develop in situ tests to measure directly the needed soil properties without the need for empirical corrections or correlations?

3. How can we take advantage of in situ and lab Gmax measurements for determination of intermediate and large strain soil properties?

4. What are important/needed advances in laboratory testing, including both small and large strains, as well as the needs of geoenvironmental engineering?

2. SESSION CLOSURE

We have learned today again that the world is complicated. The stress-strain behavior of soils at small/intermediate/large strains is affected at least by the following factors: (i) sample quality, (ii) cementation, and thus any degree of destruction we may have induced in the soil by our taking and manipulating the sample, (iii) the way we saturate the sample, (iv) reconsolidation, including the state of stresses we use (K_o versus isotropic consolidation), and (v) strain rate, and especially the effect of creep at very small strain rates, effect which should be carefully considered when using dynamically-measured G_{max} for static problems. Most of the panelists today referred to this last point. The factors listed above are all important when we try to evaluate deformation in the field under static loading using parameters based on laboratory measurements.

Several subjects and recommendations were brought upon by the panelists and by the informal discussion, related to stability problems, and especially to the evaluation of the situ shear strength of the soil. They include: (i) the role of piezocone and dilatometer in situ testing to define stratigraphy, and also their use as index tests, (ii) miscellaneous recommendations on the importance of the systematic use of radiography to evaluate sample disturbance, on the use of constant rate of strain odometer, and on CK_oU and automated triaxial testing, and (iii) the usefulness of normalized behavior in clay deposits and the role of SHANSEP. Clearly there is general agreement only on some of these issues, while others remain open questions that deserve further research.

Finally, the laboratory testing needs generated by geoenvironmental engineering considerations are important. Significant considerations here are the properties of unsaturated soils, effects of temperature, of large pressures, and of pore fluid chemistry, as well as the need for long duration testing.

In summary, I would like to list four aspects which, in my opinion, are key to the reliable use of both static and dynamic laboratory tests for the evaluation of deformations in the field under static loads, and which need further investigation. They are: the role of sample disturbance, the correlation between laboratory and field measurements of soil stiffness, the need for more comparisons between predicted and actual field deformation performance, and the role of numerical analysis of deformation.

REFERENCE

Vucetic, M. and Dobry, T. 1991. Effect of Soil Plasticity on Cyclic Response. Journal of Geotechnical Engineering, ASCE: 117(1):89-107, January.