Discussion Session 1.1 / Séance de Discussion 1.1
Assessment of deformation properties including time and rate effects
L'Evaluation des propriétés de deformation incluant les effects de temps et de vitesses

D.J.DeGroot – *University of Massachusetts, Amherst, MA, USA*
J.C.Santamarina – *Georgia Institute of Technology, Atlanta, GA, USA*

ABSTRACT: This paper presents a summary of topics addressed during Discussion Session 1.1 *Assessment of Deformation Properties Including Time and Rate Effects.* The three primary topics selected for discussion included: quantification and mitigation of sample disturbance, strain rate effects, and static liquefaction. The paper highlights the contributions to the discussion session of the discussion leader, discussion panel members, and the general audience.

RÉSUMÉ: Cet article constitute un résumé des sujets discutés pendant la séance de discussion 1.1 L'Évaluation des propriétés de déformation incluant les effets de temps et de vitesse. Les trois sujets principaux choisis incluaient: l'énumération et la mitigation du remaniement de l'échantillon, l'éffet de la vitesse de déformation, et la liquéfaction statique. L'article souligne les contributions de l'animateur des débats, des participants invités, et de l'audience à la séance de discussion.

1 INTRODUCTION

This paper presents a summary of the topics presented and discussed during Discussion Session 1.1 *Asscssment of Deformation Properties Including Time and Rate Effects.* The session members were as follows:

Chairman: Dr. I. Vanicek, Czech Republic
Discussion Leader: Dr. D.J. DeGroot, USA
Session Reporter: Dr. J.C. Santamarina, USA
Panel Members: Dr. S. Leroueil, Canada
Dr. G. Mesri, USA
Dr. D. Lo Presti, Italy
Dr. M. Lipinski, Poland

Following the opening remarks by Chairman Vanicek, Discussion Leader DeGroot introduced three issues that were selected as the primary topics for the discussion session: quantification and mitigation of sample disturbance, strain rate effects, and static liquefaction. The panelists addressed these topics with short presentations after which the discussion was opened to the general audience. The paper is organized by the topics noted above and brings together the different contributions from the discussion leader, discussion panel members, and the general audience.

2 SAMPLE DISTURBANCE

DeGroot indicated that visual detection of sample disturbance can be done by x-ray techniques but that methods to quantify sample disturbance needs to be more widely implemented in practice. Currently, some quantification methods are: volumetric change during recompression to the in situ state of stress (Andresen and Kolstad 1979), specimen quality designation (SQD; Terzaghi et al. 1996), residual pore pressure or suction, determination of G_{max}, and assessment of $\Delta e/e_0$ at the in situ state of stress as a function of overconsolidation ratio (Lunne et al. 1997). Lo Presti pointed out that sampling with a Shelby tube can cause 50% reduction in G_{max} in silts and 80% in soft clays. Several panel members expressed support for method of measuring volumetric change during recompression for quantification of sample disturbance.

The ability to collect high quality samples with the Laval and Sherbrooke block samplers was highlighted by DeGroot. However, Jamiolkowski (Italy) noted that these samplers are not commonly used in practice and that other techniques could be used instead, such as sharp edge samplers. Jardine (UK) emphasized the importance of operator safety when handling sharp-edge samplers, and indicated that suction at the bottom of the sample can be readily avoided by adding an airline at the tip of the sampler.

Leroueil noted that each sampling technique causes a certain level of strain for a given soil. This strain imposed during sampling must be compared against the strain a soil can take in order to understand the level of sampling disturbance that is caused. Following Clayton et al. (1998), he recommended: to avoid inside clearance when sampling soft clays, to use low wall thickness to diameter ratio (less than 1/40), and to maintain a cutting edge between 5° and 7°.

Mesri highlighted that the issue of sample disturbance must be analyzed within the more general context of data gathering and interpretation. In particular, present correlations were developed with specimens gathered using traditional sampling techniques; therefore, they will loose validity when better sampling and mitigation techniques are used.

Two methods are currently used to mitigate the effects of sampling disturbance: the NGI recompression technique proposed by Bjerrum (1973) and recompression above the in situ state of stress followed by data interpretation in terms of normalized parameters or SHANSEP as proposed by Ladd and Foott (1974) at MIT. Lo Presti advocated the use of the NGI technique to avoid consolidating above the in situ state of stress.

3 STRAIN RATE EFFECTS

DeGroot introduced the general topic of strain rate effects and asked if it is possible to quantify the connection between strain rate effects and soil structure. He noted that liquidity index is one such parameter and suggested that Burland's (1990) framework using intrinsic soil properties could also be used. DeGroot also asked the panel what are the practical implications of strain rate effects in geotechnical engineering practice.

Leroueil addressed the effect of strain rate on strength, compressibility and residual strength, and highlighted that while strain rate effects are significant, they are often neglected in practice. He made the following observations and supported them with data and case histories:

- The effective strength friction angle is almost independent of strain rate in normally consolidated (NC) soils, yet, the strength envelope lowers when the strain rate decreases in overconsolidated soils (OC) clays. On the other hand, the undrained strength increases 10% per log cycle of strain in both NC and OC soils. This explains the higher undrained strength measured with the self-boring pressuremeter, as compared to that measured in the laboratory.
- The preconsolidation stress typically increases by 10% per log cycle of strain rate (Cao et al, 2001). Thus, given the low strain rates in situ (e.g., under embankments), the in situ compression curve is often below the laboratory curve, and larger primary consolidation settlements should be expected in situ.
- The residual strength, in terms of tanϕ' increases about 2% to 3% per log cycle of strain and it has virtually no effect on the factor of safety. However, it appears that the rate of displacement is very sensitive to factor of safety: data show that the strain rate can decrease by two orders of magnitude when the factor of safety increases by about 5%.

Finally, Leroueil observed that strain rate effects appear not to be significantly affected by microstructure.

Mesri confirmed that strain rate affects deformation parameters, and addressed the issue of whether the relationship between effective stress and the void ratio at the end of primary consolidation depends on the duration of primary consolidation. This question became apparent after Terzaghi introduced the theory of consolidation, and was explicitly raised by Leonards (1972) and by Ladd et al. (1977). To address the question, Mesri presented data obtained with 500 mm and 125 mm long specimens and showed that the void ratio at the end of primary consolidation is independent of strain rate. Additional laboratory and field data also show that the inferred preconsolidation stress is also independent of the strain rate. Therefore, predicted settlements closely match observed settlements (e.g., Mesri and Choi 1985, Mesri et al. 1995). Thus, while deformation parameters vary with strain rate, the longer the specimen the lower the strain rate but the longer the time to the end of primary consolidation (i.e., void ratio changes with respect to time and with respect to effective stress are interrelated). The combined effect is that the void ratio at the end of primary is unique.

Hansbo (Sweden) questioned the utility of presenting e-vs-σ plots in semi-log plots. DeGroot noted that even a linear e-vs-σ relationship appears as a misleading curved line in semi-log space. Mesri agreed with the validity of linear-linear plots, particularly for high quality specimens and highlighted the importance of tradition in this regard.

Lo Presti addressed strain rate effects in connection to the creep settlement of sands (e.g., the C_2 parameter by Schmertmann 1970). In particular, he showed extensive data that confirms that the C_α coefficient is inversely proportional to the bearing capacity factor of safety, i.e., the higher the applied load, the higher the value of C_α.

Jardine (UK) ratified that creep increases as factor of safety decreases and it is affected by the intermediate stress anisotropy. Hence, oedometer and axisymmetric triaxial data may differ.

Lo Presti also addressed strain rate effects on soil stiffness and damping. Data were presented for a stiffness correction parameter that takes into consideration both strain level and strain rate (Akai et al. 1975). Data for damping ratio show that D also varies with frequency, i.e., strain rate: at low frequencies ($f < 0.1$ Hz), the damping increases due to the viscosity of the soil skeleton while at higher frequencies ($f > 1$ Hz), damping increases due to fluid viscosity.

4 STATIC LIQUEFACTION

Lipinski reviewed criteria and conditions necessary for static liquefaction. He highlighted the importance of fast sampling of transducers during the execution of laboratory experiments to properly capture short duration events. Furthermore, he placed emphasis on the position of the instability line in stress path space, which for the soils and conditions he studied appears at $q/p' = 1$ which corresponds to a stress ratio $\sigma'_v/\sigma'_h = 2.5$.

Leroueil highlighted the non-uniqueness of the instability line (except for very loose soils). Furthermore, he indicated that while liquefaction is often related to the state parameter in the literature, it is more relevant to relate it to the change in void ratio from the void ratio starting at the instability line.

Verdugo (Chile) noted the difficulties related to sands with very flat steady state lines making the utilization of the steady state line very sensitive to measurement errors in the determination of the in situ void ratio.

5 CONCLUSIONS

The discussion session highlighted important scientific and practical aspects of soil behavior with respect to sample disturbance, strain rate effects, and static liquefaction. Research has shown the detrimental effects of sample disturbance on clay behavior and it is strongly recommended that sample disturbance be quantified during site investigations. Variations in strain rate affect soil behavior with important practical implications on key design parameters such as shear strength, yield stress, and soil stiffness. Accurate measurement of static liquefaction requires high quality laboratory equipment using fast sampling rates. Test results suggest the possible existence of a unique instability line that could be used to define the necessary conditions for static liquefaction to occur.

REFERENCES

Akai, K., Adachi, T., and Ando, N. 1975. Existence of a Unique Stress-Strain-Time Relation of Clays. *Soils and Foundations*. 15(1): 1-16.

Andresen, A. and Kolstad, P. 1979. The NGI 54-mm Sampler for Undisturbed Sampling of Clays and Representative Sampling of Coarser Materials. *Proc. of the Int. Conf. on Soil Sampling*, Singapore, 1-9.

Bjerrum, L. 1973. Problems of Soil Mechanics and Construction on Soft Clays: SOA Report. *Proc., 8th Int. Conf. on Soil Mechanics and Foundation Engineering*, Moscow, (3):111-159.

Burland, J.B. 1990. On the Compressibility and Shear Strength of Natural Clays. *Géotechnique* 40(3): 329-378.

Cao, L.F., Chang, M.F., Teh, C.I., Na, Y.M. (2001). Back Calculation of Consolidation Parameters from Field Measurements at a Reclamation Site. *Canadian Geotechnical Journal*. 38(4):755-769.

Clayton, C.R.I., Siddique, A., and Hopper, R.J. 1998. Effects of Sampler Design on Tube Sampling Disturbance – Numerical and Analytical Investigations. *Géotechnique* 48(6): 847-867.

Ladd, C.C. and R. Foott. 1974. New Design Procedure for Stability of Soft Clays. *J. of the Geotechnical Engrg. Div.* 100(GT7): 763-786.

Ladd, C.C., R. Foott, K. Ishihara, F. Schlosser, and H.G. Poulos. 1977. Stress-Deformation and Strength Characteristics: SOA Report. *Proc., 9th Int. Conf. on Soil Mech. and Found. Engrg*, Tokyo, 2: 421-494.

Leonards, G.A. 1972. Discussion, Shallow foundations. *Proc. Spec. Conf. on Performance of Earth-Supported Structures*, ASCE, Lafayette, IN, (3): 169-173.

Lunne, T., Berre, T. and Strandvik, S. 1997. Sample Disturbance Effects in Soft Low Plasticity Norwegian Clay. *Proc. of Conf. on Recent Develop. in Soil and Pavement Mechanics*, Rio de Janeiro, 81-102.

Mesri, G. and Choi, Y.K. 1985. The Uniqueness of the end-of-primary (EOP) void ratio-effective stress relationship. *Proc. 11th Int. Conf. Soil Mech. Found. Engrg.*, San Francisco, 2, 587-590.

Mesri, G., Feng, T.W., and Shahien, M. 1995. Compressibility parameters during primary. Invited Special Lecture. *Int. Symp. Compression and Consolidaiton of Clayey Soils*, Hiroshima, Japan, Lectures and Reports Volume, 201-217.

Schmertmann, J.H. 1970. Static Cone to Compute Static Settlement over Sand. *J. of the Soil Mechanics and Found. Div.*, 96(SM3):1011-1043.

Terzaghi, K., Peck, R.B. and Mesri, G. 1996. *Soil Mechanics in Engineering Practice – 3rd Edition*. John Wiley and Sons, NY.