12 Mar 1991, 2:30 pm - 3:30 pm

Session 2: Closing Remarks

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SESSION II CLOSING REMARKS

by: C.K. Shen

The first half of the Session IIA papers dealing with the general theme of "model testing in cyclic loading" cover a variety of topics under rather different situations. Dr. Mladen Vucetic, our General Reporter, presented a thorough and concise review of all the papers with excellent commentary. indeed these papers constitute an extensive scope of testing. One of the most important considerations of any testing program is to obtain accurate and meaningful measurements that can be interpreted to aid in engineering practice. Thus any experimental research in earthquake engineering should consider: 1) The applied loading closely simulate the loading paths generated by seismic events, 2) When field or experimental records are interpreted with the aid of numerical predictions, attention should be paid to the mathematical and physical models describing the dynamic soil response; i.e. conditions that may take place during an earthquake. Good engineering can only be achieved by studying carefully the experimental or field behavior with a sound theoretical interpretation; they compliment each other.

Earthquake motion are random in nature; a trajectory of acceleration of a point in the horizontal plane is shown in Figure 1. Note that it is rotational in nature. The effect of random and multidirectional (including rotational) loading path on the response of soil to liquefaction and volume change has been studied under different laboratory testing conditions and in shaking table tests. (1,2,3,5,6,7,9,12,13,14). For instance: Shen et al (7) reported that the generation of pore water pressure in undrained triaxial compression and extension is affected by the location and sequence of stress peaks within an irregular loading pattern. Yamada and Ishihara (12) showed that using the true triaxial device the resistance of sand to liquefaction decreases as the loading path changes its configuration from unidirectional to elliptical, crisscrossing and circular as shown in Figure 2. This irregular loading conditions reported by Ishihara and Nagase (1). Comparing with unidirectional, uniform loading a 15% reduction in liquefaction resistance can be expected under multidirectional loadings. Unfortunately, to date there is no published results showing the rotational simple shear response under K_o conditions. Such results could be very important because it captures the essential loading conditions in the field.

Realizing the path dependency of pore water pressure generation in granular soils, particularly under rotational shear loading, Wang, et al (11) formulated a comprehensive model to describe the behavior of granular soils under a wide range of loading conditions. One of the distinctive features of the model is it capability in predicting the behavior of sand under rotational shear. While different from the term used by the experimentalists, the rotational shear here has been defined more strictly as a class of loading under which the second isotropic invariant of the deviatoric stress tensor remains constant. The model was constructed with the general framework of bounding surface hypoplasticity (10). The hypoplasticity characterizes incremental nonlinearity of the stress-strain rate relations based on the postulation that the stress-strain rate relationship depends not only on the current stress state but also on the stress rate itself. In accordance with this concept, the model developers introduced the dependence of the plastic strain rate direction on the stress rate direction. This dependence is the key to the model in the description of the rotational shear response. Figure 3 shows the predictive capability of the hypoplasticity bounding surface model for granular soil.

The above soil model has recently been incorporated into a finite element procedure to analyze the response of stratified level grounds under multidirectional earthquake loading conditions. The procedure performs nonlinear effective-stress-based analysis under true three directional earthquake loading conditions and has been used for the Lotung site response study. A comparison of the measured predicted pore water pressure response during the 1986 Lotung earthquake was presented by Shen, et al (8) in this Conference. Typical ground motion predictions and comparisons are shown in Figure 4. It can be seen that the predictions match well with the field records.

Summing up, I believe strongly that laboratory and field measurements are essential to our understanding for the behavior of soil and the soil-structure interaction during earthquake. The papers presented in Session IIA has provided valuable information toward experiments and be studied and interpreted with the aid of analytical tools incorporation carefully scrutinized soil behavior models. We will then be able to extend our knowledge base for design and analysis pertinent to geotechnical earthquake engineering.

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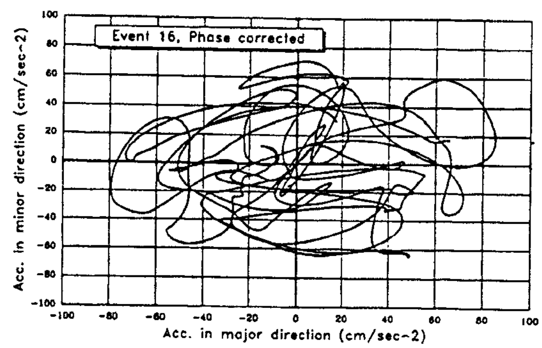


Figure 1

Phase corrected trajectory of event 16

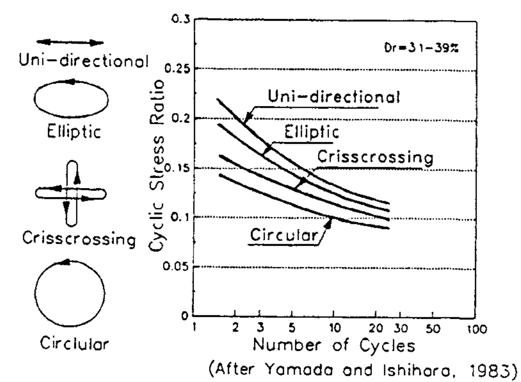


Figure 2. Liquefaction Resistance

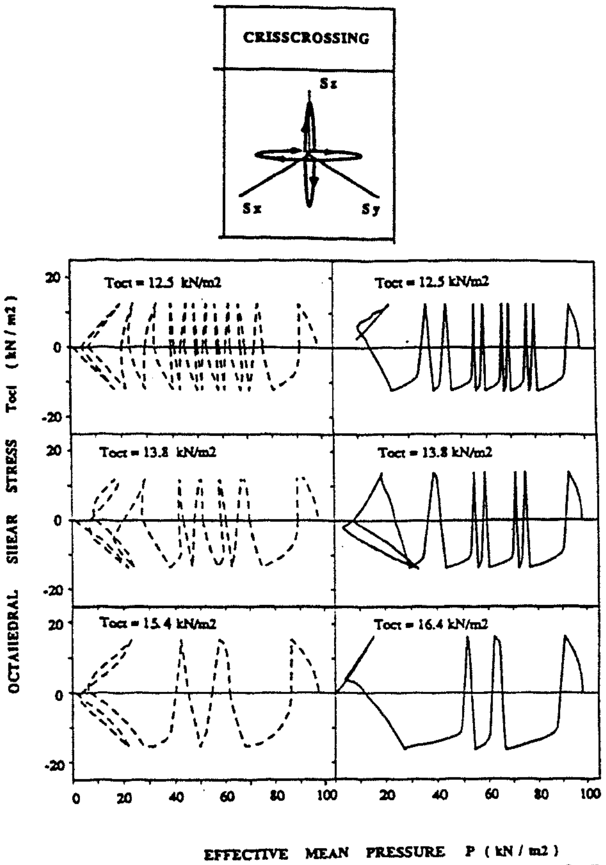
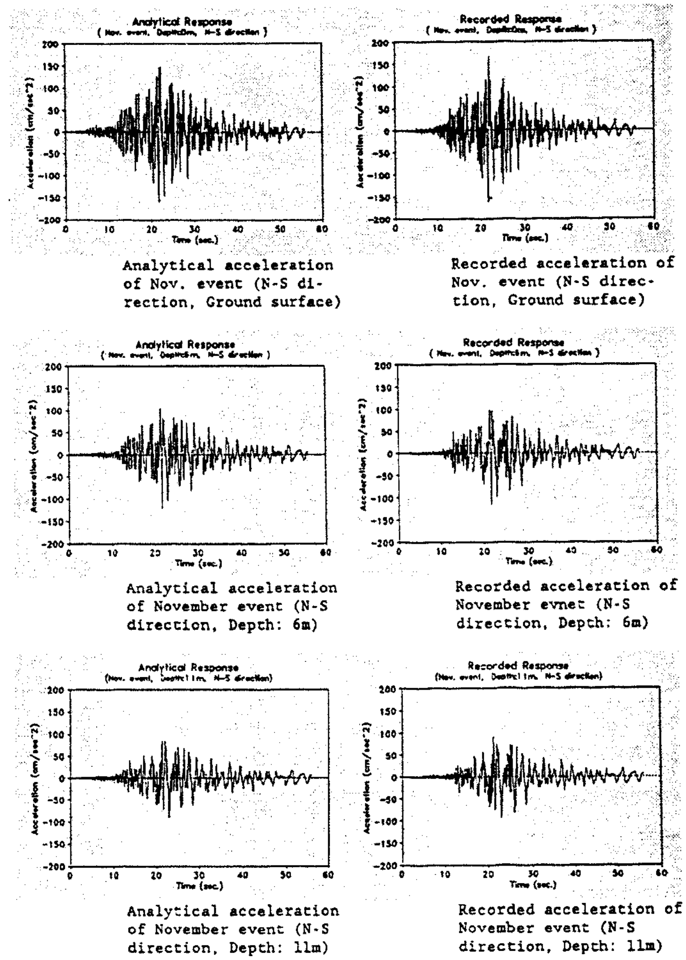


Figure 3. Effective Stress of Undrained Cyclic Path ZC-ZE ($T_{oct} = \tau_{oct} \cos\theta$)

____Model Calibration

--- Test Results from Yamada and Ishihara (1983)



Analytical acceleration of Nov. event (N-S direction, Ground surface)

Recorded acceleration of Nov. event (N-S direction, Ground surface)

Analytical acceleration of November event (N-S direction, Depth: 6m)

Recorded acceleration of November evnet (N-S direction, Depth: 6m)

Analytical acceleration of November event (N-S direction, Depth: 11m)

Recorded acceleration of November event (N-S direction, Depth: 11m)

Figure 4. Measured and Predicted Earthquake Acceleration Records -- from Li (1990)