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General Report —Session II: Model Testing in Cyclic Loading

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INTRODUCTION

The use of model testing for earthquake applications has a long history and recent developments, particularly in the widespread use of centrifuge modelling for dynamic applications are reflected in the papers accepted for Session II, Model Testing. In detail the papers considered in this General Report on model testing can be considered under three major headings:

a) propagation of elastic waves in model tests (all three papers on this subject addressed centrifuge models),

b) shake table model test studies (four papers), and

c) centrifuge model test studies (four papers).

A final paper of particular note in this session is by Iwashita et al. and relates to large scale laboratory and in-situ field tests of rockfill dams.

PROPAGATION OF ELASTIC WAVES

The nature of the boundary conditions and input motion is increasingly recognised as of paramount concern in the specification of model test studies and three papers addressed this subject in detail.

Luong (1995) describes a theoretical model for the dissipation of energy in frictional materials and shows that cyclic loading under high stress ratios (shear stress to normal effective stress) above the critical state or characteristic threshold leads to substantial increase in damping of wave energy through heat generated on frictional sliding contacts. This phenomenon is demonstrated by infrared thermography of vibratory triaxial tests on dry medium-dense sand and then explored further as a potential wave barrier in a series of centrifuge model test experiments using the CEA CESTA centrifuge near Bordeaux, France. The large coffin shaped model chamber (1.3 m maximum by 0.8 m) provides a field 130 m by 80 m at 100 g and using a drop ball arrangement Rayleigh waves are generated which propagate radially outwards from a point source, decaying with distance. This arrangement then allows for the investigation of a novel wave barrier concept (which is described only in outline in the paper) which significantly increases the attenuation of the seismic waves through frictional energy dissipation. This technique could have important applications both in model testing and in the field for reducing the surface wave energy reaching model boundaries or field structures.

Madabushi (1995) and Fiegel et al. (1995) both address the vertical propagation of shear waves into centrifuge models. Fiegel used a hinged plate container which at 100 g simulated a prototype soil deposit 38 m by 21 m by up to approximately 20 m deep. A field accelerogram recorded at Santa Cruz during the 1989 Loma Prieta earthquake was used as the basic input motion, and this was scaled in amplitude and time to generate alternative input motions for the model tests. The experiments, on both sand and clay deposits, showed clearly the strong influence of both the soil and the soil container on the dynamic response of the model and recommendations are made on the importance of carefully selecting input motions. Response spectra calculated from the theoretical input motion show substantial differences in comparison to the achieved motion at the base of the model. Future publications will also need to provide guidance for researchers on the validity of using surface motions as base inputs to model tests.

Madabushi has analysed the vertical propagation of elastic shear waves through a soil column to assess the influence of soil stiffness on the modification of the wave train, from which guidance for the interpretation of centrifuge model tests can be derived. He particularly notes the evidence of phase changes between base and surface caused by reducing stiffness of the soil model and illustrates this phenomenon by reference to centrifuge model test data.

SHAKE TABLE AND CYCLIC MODEL TESTS

Considerable investment has been made over several decades in the development of shake table facilities worldwide and this has led to a wide range of important research results. In this conference several papers address field problems using shake table or cyclic model tests and these illustrate both the advantages and disadvantages of this form of modelling.

Saran et al. (1995) describe cyclic plate load tests on reinforced and unreinforced sand beds which show an improvement in stiffness and linearity obtained by the use of a geogrid reinforcement. The plate size of 0.15 m square is small compared to the size of the tanks (0.9 and 1.5 m square) but extrapolation from this test to load-deflection relationships for larger footings is not clear as no attempt was made to scale the geogrid netlon.

Bolt and Dembicki (1995) also use laboratory model tests to study the uplift capacity of anchors in loose sand. These models were constructed at a scale of 1:10 and pulled upwards through a saturated sand test bed in a large circular tank around 2 m in diameter. (Tests were carried out at Delft and at Gdansk Technical Universities.) Upward or downward seepage through the sand beds was controlled to liquefy or consolidate the sand bed. Load tests were then conducted to identify the relationship between upward displacement and number of cycles. As expected, depending on the magnitude of the cyclic load, increasing numbers of cycles at high load can lead to "softening" and breakout or for smaller amplitude cycling to "hardening" and an increase in the ultimate breakout load.

Fishman et al. (1995) describe an analytical procedure and experimental data of the rotational failure of mass gravity retaining walls. Historically research has concentrated on sliding modes of failure, but loss of bearing capacity under the lateral acceleration field can become the critical mode of failure in certain cases, particularly for walls with a high static overturning moment. Threshold accelerations for bearing are computed (analagous to threshold accelerations for sliding) and these were compared with the results of shake table model tests on the SUNY Buffalo facility. The analytical calculation, based on earlier research provides a good basis for the prediction of dynamic bearing capacity. The model tests broadly confirm the approach but further detail should be presented on the treatment of the applied loads from the bridge deck and the mobilisation of shearing resistance in the sand (and on the interfaces) with strain. It would also be valuable to seek comparative scale model tests on a centrifuge facility, such as the RPI centrifuge, in future research studies.

There have been many studies over recent years on the development of excess pore pressures in level ground under base shaking, and Yanagisawa and Jafarzadeh (1995) present data from a shake table experiment on a sand body 1 m x 1 m x 0.45 m deep. The experiment was considered to represent a larger prototype by speeding up the input time histories by a factor of 10, combined with not changing soil particle size or pore fluid characteristics. Because of the nature of the experiment careful consideration of the scaling of the soil strength and of the boundary conditions (to ensure uniformity of shear strain across the chamber) is needed and in discussion the authors should describe how this was overcome, for example by changing the relative density of the soil with depth, and how the boundaries were treated.

CENTRIFUGE MODEL TESTS

Several papers are presented which use centrifuge model testing to study field problems. Two of these considered retaining walls.

Dewoolkar et al. discuss the development of dynamic earth pressure behind a cantilever wall retaining dry fill based on experiments carried out at 55 g on the University of Colorado centrifuge at Boulder. Pressure cells were used to measure lateral earth pressures on the wall and the authors note differences along the wall and with depth compared to the predicted values. There may be several reasons for this and the authors identify the difficulty of achieving plane strain conditions particularly with a length of wall to height ratio of only around 1. Experiments very similar to this were reported over ten years ago, Steedman (1984), and it was noted at that time that the mobilisation of shearing resistance with strain was a critical factor in the back-analysis of such experiments. From the data presented shear strains in the backfill appear to have been quite low and the authors might wish to present data of the mobilisation of strength with strain, for comparison with the achieved levels of shear strain in the model.

Ting and Whitman have continued a long history of research at MIT into the behaviour of tilting retaining walls by presenting data of walls retaining loose saturated sand susceptible to liquefaction. The experiments show clearly the characteristic features of liquefaction in the backfill with varying degrees of modification of the input motion as excess pore pressures develop. The significance of the "permeability" of the soil (as affected by the viscosity of the pore fluid) was highlighted and careful analysis of the time histories of wall propping force, wall inertia and excess pore pressures allowed the derivation of the effective soil thrust to be determined. The pattern of ratcheting outward displacement of the wall was modelled using a Newmark analysis; further clarification of how the threshold acceleration (particularly the shear strength in the backfill) was determined would be useful.

Law et al. present model test data of the response of buried pipelines in dry and damp soil in uniform soil beds and in beds with discontinuities in the foundation level beneath. The tests used a long pipe (4 feet) in a model chamber 4 feet x 1 foot x 9 inches deep shaken at 50 g using the Colorado centrifuge using the El Centro input motion. These data, mainly comprising axial strain along the pipe, will require careful analysis and interpretation to understand the influence of the different ground conditions, taking into account the uncertain initial loading conditions on the pipe. For example the authors may wish to explain why there is variation in the strain data along the pipe in test 1, which comprised a uniform sand bed with uniform base input.

Sato et al. used the centrifuge facility at Shimizu Corporation in Tokyo to study the behaviour of a pile foundation in saturated sand as excess pore pressures build up to a fully liquefied state. This class of research is very relevant to the design of structures in the field, as was demonstrated in the Hanshin earthquake disaster of January 17, 1995. The experimental procedure was thorough and is well documented in the paper. The findings illustrate clearly the effects of deterioration of the stiffness and strength of the upper soil layer on the behaviour of the pile group and pile cap, as bending moments are concentrated at the interface between liquefied and non-liquefied ground with the piles being driven by the soil strain field. The nature of the load transfer between pile and soil is highly distributed both along the pile and between piles in the group and the capacity of piled foundations to withstand rapid and substantial variations in soil strength is well illustrated in this work.

FIELD TESTS

A final paper which is particularly worthy of note, although not directly relevant to Session II is the work of Iwashita et al. (1995) on the dynamic analysis of rockfill dams. Field tests, large scale cyclic triaxial tests and geophysical work were combined to analyse two dams in Japan in a well written and interesting paper.

CONCLUSIONS

In conclusion, Session II has generated a number of valuable contributions. Much data has been presented. However in order for industry to gain the full benefit of this research authors need to pay particular attention to the mechanics of the problem being addressed, the details of boundary effects, input motions and the quality of instrumentation. The analysis and interpretation of model test data depends heavily on a thorough appreciation of the advantages and limitations of the physical techniques. The authors in this session are to be congratulated on the new developments which have taken place and the opportunities which these present for advancing the technology.

REFERENCES

Bolt A.F. and Dembicki E. (1995) The uplift capacity of anchors embedded in loose sand, Proc 3rd Int Conf Recent Adv Geotech Earthquake Eng & Soil Dynamics, St Louis, MO, April 2-9.

Dewoolkar M.M., Stadler A.T., Batiste S.N., Ko H.Y. and Pak R.Y.S. (1995) Dynamic centrifuge experiment on a cantilever retaining wall, Proc 3rd Int Conf Recent Adv Geotech Earthquake Eng & Soil Dynamics, St Louis, MO, April 2-9.

Fiegel G.L., Idriss I.M. and Kutter B.L. (1995) Earthquake input motions for physical model tests, Proc 3rd Int Conf Recent Adv Geotech Earthquake Eng & Soil Dynamics, St Louis, MO, April 2-9.

Fishman K.L., Richards J.R., Divito R.C. (1995) Critical acceleration levels for free standing bridge abutments, Proc 3rd Int Conf Recent Adv Geotech Earthquake Eng & Soil Dynamics, St Louis, MO, April 2-9.

Iwashita T., Yasuda N., Nakamura A. and Takeda O. (1995) Dynamic deformation characteristics of rockfill materials from laboratory test, in-situ test and earthquake motion analysis, Proc 3rd Int Conf Recent Adv Geotech Earthquake Eng & Soil Dynamics, St Louis, MO, April 2-9.

Law H.K., Ko H.Y., Tohda J., Li L., Hamada T. (1995) Preliminary investigation of a buried pipe excited by an earthquake, Proc 3rd Int Conf Rec Adv Geotech Equake Eng Soil Dynamics, St Louis, MO, April 2-9.

Luong M.P. (1995) Efficiency of an energy-absorbing barrier, Proc 3rd Int Conf Recent Adv Geotech Earthquake Eng & Soil Dynamics, St Louis, MO, April 2-9.

Madabushi S.P.G. (1995) Numerical modelling of shear wave propagation in centrifuge models, Proc 3rd Int Conf Recent Adv Geotech Earthquake Eng & Soil Dynamics, St Louis, MO, April 2-9.

Saran S., Lavania B.V.K., Sharma R.K. (1995) Cyclic plate load tests on reinforced sand, Proc 3rd Int Conf Recent Adv Geotech Earthquake Eng & Soil Dynamics, St Louis, MO, April 2-9.

Sato M., Shamoto Y., Zhang J-M (1995) Soil-pile-structure interaction during liquefaction on a centrifuge, Proc 3rd Int Conf Recent Adv Geotech Earthquake Eng & Soil Dynamics, St Louis, MO, April 2-9.

Steedman R.S. (1984) Modelling the behaviour of retaining walls in earthquakes, PhD Thesis, Cambridge University.

Ting N-H and Whitman R.V. (1995) Centrifuge modelling of a tilting wall with liquefiable backfill, Proc 3rd Int Conf Recent Adv Geotech Earthquake Eng & Soil Dynamics, St Louis, MO, April 2-9.

Yanagisawa E. and Jafarzadeh F. (1995) Behaviour of saturated sand models under principal stress rotation in shake table tests, Proc 3rd Int Conf Rec Adv Geotech Equake Eng Soil Dyn, St Louis, MO, April 2-9.