Proceedings, Third UJNR Workshop on Soil-Structure Interaction, March 29-30, 2004, Menlo Park, California, USA.

Forced Vibration Tests of the Foundation Block and Surrounding Soil at the NEES/UCSD Large High-Performance Shake Table

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ABSTRACT

A Large High-Performance Outdoor Shake Table (LHPOST) is being built at the Camp Elliot Field Station of the University of California, San Diego (UCSD) as part of the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). The LHP Outdoor Shake Table will provide the capability to conduct real time tests of full or large–scale structural systems including large-scale soil-foundation-structure interaction models. The table will be able to simulate near-source earthquake ground motions with large acceleration, velocity and displacement pulses. The NEES shake table in combination with a large laminar shear box and two refillable soil pits funded by the California Department of Transportation (Caltrans) will constitute a unique seismic testing facility at Camp Elliot.

The moving platen of the NEES Shake Table is 7.62 *m* wide, 12.19 *m* long, and has a weight of 130 Ton (1.275 *MN*). In the initial phase of the facility, the motion of the table will be uni-directional with a maximum stroke of 0.75 *m*, a peak horizontal velocity of 1.8 *m/sec*, a (bare table) peak horizontal acceleration of 4.8 *g*, a horizontal force capacity of 6.8 *MN*, an overturning moment capacity of 50 *MN-m*, and a vertical payload capacity of 20 *MN*. The testing frequency range of the table will be 0-20 *Hz*. The facility has been designed to be upgradeable to 6-DOF. In the initial, phase the system will have two servo-controlled dynamic actuators with large servo-valves, a large power supply system (35 *MPa*, 9,500 liters) with 1,440 *liters/min* direct pumping

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capacity, an advanced real-time multi-variable controller, an innovative vertical load/ overturning moment bearing system including six pressure balance bearings and two hold down struts, and a steel platen.

The reaction block/foundation for the shake table is 19.61 *m* wide, 33.12 *m* long, and extends to a depth of 5.79 *m*. A smaller central area of the foundation housing the hold down struts extends to a depth of 7.92 *m*. To reduce the mass of concrete, the corners of the block have been truncated and the structure has been designed as a hollow tube along the perimeter. A 6 *m* long tunnel with a 2.44 *m* x 2.44 *m* section connects the reaction block to the adjacent pump building, which is a 2-storey structure with a partial basement. The pump building has plan dimensions of 15.5 *m* x 22.5 *m* and is founded at a depth of 3.5 *m*. The soil pit to the east of the shake table has dimensions of 14.6 *m* x 15.2 *m* and a maximum depth of about 3 *m*.

The construction of the LHP Shake Table at Camp Elliot and the availability of shakers, ground motion sensors and data acquisition equipment as part of the NEES/UCLA Field Testing Facility created a unique opportunity to conduct extensive forced vibration tests of the large excavations for the reaction block, soil pit and pump building. These tests have included measurements of the dynamic response at dense arrays of locations on the excavations for the foundations, and on the soil surface up to distances of 230 *m* from the excavations. These tests were repeated after the reaction block and the base of the pump building had been built.

The initial set of 28 forced vibration tests of the soils within the excavation for the foundation of the NEES/UCSD Shake Table and its vicinity were conducted in April of 2003. Two NEES/UCLA shakers with a maximum force capacity of 50 Tons each were placed at opposite ends of the 45 *m* x 24 *m* x 5.8 *m* excavation for the reaction block of the shake table. A third, smaller UCSD shaker with a force capacity of 2.5 Tons was placed on the 18 *m* x 12 *m* x

3.5 *m* excavation for the adjacent pump building. Ninety-two acceleration channels and twenty- seven velocity channels were used to record the three-dimensional motion at four stations in each of the three foundation blocks for the shakers, at 27 stations in the main excavation, 7 points in the excavation for the pump building, and at 34 stations on four legs extending up to a distance of 230 *m* from the excavations. The tests with the main shakers were conducted at three force levels and at frequencies ranging from 0-10 *Hz*, 0-18 *Hz*, and 0-23 *Hz* for large, medium, and small forces, respectively. Ambient vibrations of the site were also recorded. The frequency range selected for the tests reflected the frequency range of operation of the table (0-20 *Hz*), the frequency limitations of the shakers (25 *Hz*), and the maximum force capacity of the shakers and corresponding foundations.

A second set of tests was conducted in October 2003 after the reaction mass for the shake table and the foundation for the adjacent auxiliary building had been completed. The tests included the use of the two NEES/UCLA MK-15 shakers mounted on the reaction mass at locations close to the reaction points of the actuators. The three-dimensional dynamic response at 19 locations on the reaction block; at 12 points on the foundation of the adjacent auxiliary building; and at 32 locations on the ground surrounding the shake table up to distances of over 230 *m* were recorded for longitudinal, transverse, and torsional excitation of the block.

The first objective of the experimental study was to take advantage of a limited time window to obtain dynamic ground motion data, and by inference geotechnical data that will prove invaluable in the development of a future virtual model of the complete NEES LHP Shake Table Facility. The virtual model, which will need to be exercised in preparation for any major test on the shake table or soil pit, will need to include a soil island surrounding the shake table and soil pit, and models for the reinforced concrete foundation block, the steel platen, actuators and control system, and of the test specimens. The first objective of the current research was to obtain the basic data required to develop and validate the soil island and foundation block models.

The second objective of the study was to develop a body of dynamic high-quality response data on the foundation and surrounding soil that can be used for years to come to test and validate soil-structure interaction analysis methods and computer codes. In particular, the data set will permit to test the solution to the two canonical soil-structure interaction problems: the radiation (internal source) and scattering (external source) problems. The study offers information on the coupling through the soil between adjacent foundations, a topic of considerable interest when modeling the seismic response of structures in a dense urban environment.

The third objective was to validate the unconventional design of the NEES LHP foundation block in terms of its overall dynamic response, and to study experimentally the deformability of the foundation and surrounding soils. The conventional design of foundation reaction blocks for equipment subjected to impact loads relies on the use of massive foundations to react the impact loads essentially by inertia. In the conventional approach, the dynamic response of the foundation is reduced by designing the foundation to achieve a low characteristic frequency. In the case of the NEES foundation, the approach has been to take advantage of the natural conditions at the site in terms of high soil stiffness to design a lighter (4,300 Tons) and considerably less costly foundation which will result in a high characteristic frequency and a large effective damping ratio.

Finally, the forced vibration experiments served as a severe shakedown of the eccentric mass shakers, sensors and of the complete digitizing, recording and transmission system available through the NEES/UCLA Field Testing Facility.

The oral report presented at the workshop includes a summary of the most salient features of the recorded data and a discussion of the issues that arose during the course of the experiments. The main findings include: (i) preliminary analyses of the data obtained confirm the basic premises of the design of the facility in terms of the dynamic response of the reaction block; (ii) the data recorded during the initial tests in which the shakers were mounted on 3.7 *m* x 3.7 *m* x 1 *m* concrete blocks embedded in the soil indicate significant but very localized soil nonlinearities in the vicinity of the active block, while the response of the passive blocks was linear and scaled with the level of force; (iii) the results of the second phase tests show a very strong attenuation of the forced ground motion with distance from the reaction block; (iv) the data also showed a marked low frequency drift of the EpiSensor accelerometers; and (v) the excitation of unintended supra-harmonics by the shakers.