NEES@UCSD EXPERIMENTAL SITE

LARGE HIGH PERFORMANCE OUTDOOR SHAKE TABLE – LHPOST

GUIDE for
PROSPECTIVE USERS of the SHAKE TABLE
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1. SITE INTRODUCTION
The LHPOST is a 7.6m wide by 12.2m long shake table which permits simulation of severe earthquake ground motions. In its current configuration the shake table has a single axis of motion with a stroke of ±0.75m, a peak horizontal velocity of 1.8 m/s, a horizontal force capacity of 6.8MN, an overturning moment capacity of 50MN-m for a 400 ton specimen, and a vertical payload capacity of 20MN. The testing frequency range is 0-33 Hz. The LHPOST has been designed with performance characteristics that permit the accurate reproduction of strong near-source earthquake ground motions for the seismic testing at full-scale or very large-scale of structural and soil-foundation-structure interaction (SFSI) systems such as full-scale buildings, single and multiple column bridge bents in a laminar soil box, utility/lifeline structures such as electrical sub-stations, nuclear containment casks, and seismic isolation systems. The proximity of a soil pit to the LHPOST allows for hybrid shake table-soil pit experiments to be conducted. The LHPOST became operational in October 2004 and is managed as a national shared-use NEES equipment site, with tele-observation and limited tele-operation capabilities. The LHPOST was designed to be readily upgradable to a 6-DOF shake table, and in fact, it will be upgraded to 4-DOF starting in October 2009. Although this table is not the largest of its kind in terms of size in the world, the velocity, frequency range, and stroke capabilities make it the largest table outside Japan. The facility adds a significant new dimension and capabilities to existing United States testing facilities.

1.a Background and Experimental Site Objectives
Prior to the development of the NEES@UCSD shake table, researchers in earthquake engineering in the United States lacked the capability to conduct real-time shake table tests of structures and soil-foundation-structure interaction (SFSI) systems at full or close-to-full scales. Experimental capabilities to simulate near-source earthquake ground motions involving large velocity and displacement pulses were also missing. The existing shake table systems in the United States were limited by payload capacity (base shear and/or overturning moment), pumping capacity, stroke, and overhead room to construct and test tall structural systems. The development of the NEES@UCSD Large High Performance Outdoor Shake Table (LHPOST) provides the earthquake engineering community with a facility that allows the accurate reproduction of severe near-source earthquake ground motions for the seismic testing of very large structural and SFSI systems. The NEES@UCSD LHPOST is part of the Englekirk Structural Engineering Research Center located at Camp Elliott, a site located 15km away from the main UCSD campus (see Figure 1). In addition to the NEES@UCSD shake table, the Englekirk Center houses a Soil-Foundation-Structure Interaction (SFSI) facility, funded by the California Department of Transportation (Caltrans), which includes a large laminar soil shear box and a refillable soil pit. The Englekirk Center also houses an Explosive Loading Laboratory (ELL), funded by the Technical Support Working Group (TSWG). The combined facility is a one-of-a-kind worldwide resource for real-time testing of large structural and geotechnical systems subjected to earthquake or blast loadings.
The primary aim of the NEES@UCSD site is to allow the performance of transformative "landmark" experiments because of their scale, completeness, realistic seismic input, extensive instrumentation and careful data archiving. The main scientific research objective of these one-of-a-kind large-scale, system type experiments is in the validation and calibration of analytical simulation tools to capture SFSI and/or system response, which cannot be readily achieved from testing at smaller scale, or under quasi-static or pseudo-dynamic test conditions. Tests on this facility are ideal to establish benchmark performance for class A predictions, verification of actual designs (at full-scale) for construction, proof-of-concept data for clients such as Caltrans, FEMA, or DOE, as well as a concept development platform for researchers and industry, both nationally and worldwide. The experiments also provide an excellent tool for outreach at all levels including K-12, college, news media, policy makers, infrastructure owners, insurance, etc.

The facilities at the NEES@UCSD site are being used to investigate structural and geotechnical performance issues related to the area of Critical Infrastructure Protection (CIP). Potential research areas include: (a) the effects of passive and semi-active energy dissipating systems on building response, (b) large-scale testing of dynamic soil-foundation-structure interaction, (c) seismic response of nuclear waste dry storage casks, including soil-structure interaction and the interaction between casks, (d) loss estimation of buildings, including the interaction between their components, (e) seismic response of full-scale wood-frame construction including school buildings (f) response of building diaphragms, where the presence of a distributed mass constrains the testing to be performed solely under dynamic conditions, (g) assessment of liquefaction mitigation mechanisms, (g) seismic response of tall wind turbines, high-voltage towers and industrial chimneys, and (h) the study of the complex interaction between interconnected components of electrical substations, such as high-voltage transformer-bushing systems.
1.b Major Components of the NEES@UCSD Shake Table

Figure 2 provides a schematic rendering showing some of the key components of the LHPOST facility. These components include: (1) a moving steel platen (7.6m wide by 12.2m long) with an estimated mass of 144 Ton, (2) a reinforced concrete reaction block, (3) two servo-controlled dynamic actuators with a combined horizontal force capacity of 6.8MN, (4) a platen sliding system consisting of six hydrostatic pressure-balanced bearings, (5) an overturning moment restraint system consisting of two nitrogen-filled hold-down struts, (6) a yaw restraint system consisting of two pairs of slaved hydrostatic pressure-balanced bearings, and (7) cover plates to protect the actuators. The adjacent pump building houses a control room and the hydraulic power supply system consisting of a 10,000 liter surge tank, an accumulator bank with a total capacity of 10,000 liters, and two hydraulic power units with a maximum blow-down flow rate of 38,000 liters/min to recharge the accumulators and to provide pilot pressure to the servo-valves and pressure to the pressure-balanced bearings. The reaction block and the pump house are connected by an underground tunnel which provides a conduit for the hydraulic lines and also provides access to the major components of the shake table within the pit. The shake table is controlled by a real-time multi-variable MTS-469D controller which relies for feedback on the recorded acceleration of the platen and on the recorded relative displacement of the platen with respect to the reaction block (assumed to be unmovable).

![Figure 2: Schematic Rendering of LHPOST Showing Key Components](image)

The design of the LHPOST was a joint effort between the faculty and staff in the Department of Structural Engineering at UCSD and a group from MTS Systems in Minneapolis. The design included the innovative use of pressurized hold-down struts to overcome the large overturning moments resulting from tests of tall structures. A second innovation was the use of an unconventional design for the reaction block which took advantage of the natural conditions at the site in terms of high soil stiffness to build a lighter and considerably less costly foundation which resulted in a high characteristic frequency and a large effective radiation damping ratio as opposed to the conventional design which relies on the use of massive foundations to achieve a low characteristic frequency. The reinforced concrete foundation block 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. The mass of the reaction block is about 4,380 Ton. A 6.10 m long tunnel with a 2.44m 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. A 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 5.8 m.
1.c Design Considerations and Main LHPOST Specifications

The design criteria and main specifications of the shake table system were dictated by consideration of a number of potential research applications involving large or full-scale shake table experiments and a variety of earthquake ground motions. The resulting performance parameters including specifications for actuator stroke, velocity and force capacities, and frequency bandwidth of the earthquake simulator are summarized in Table 1. In deciding on these parameters, far-source (or “ordinary”) and near-source earthquake ground motions to be reproduced by the shake table were considered. Near-source records are characterized by a large velocity pulse in the fault-normal component, and a large ground displacement step in the fault-parallel component. For “ordinary” ground motions, a maximum horizontal peak ground and peak table acceleration of 1g, corresponding to an upper bound to the vast majority of recorded ground motion records, is required. Consideration of a suite of desired large or full-scale specimens for shake table experiments, together with the mass of the platen (initially assumed as 230 Ton) and accounting for elastic and inelastic dynamic amplification effects (for the base shear), the assumed effective height of the specimen (10 m), as well as dynamic similitude requirements, led to a maximum force of 6.8 MN to be imparted by the shake table actuators and a maximum overturning moment of 50 MN-m to be accommodated by the platen and its support mechanism.

Since for many sites, the seismic hazard of the built environment is controlled by near-source ground motions at long return periods (e.g., 2% probability of exceedance in 50 years), it was essential that the LHPOST be able to accurately reproduce near-fault ground motion effects. The reproduction capability of near-source ground motions by the shake table is controlled by the peak table velocity parameter. A peak table velocity of 1.8 m/s was selected by considering a set of representative near-source records which are used extensively in numerical earthquake engineering research. When the laminar shear box is mounted on the table, additional amplification takes place within the soil box and the peak velocity on the soil surface can exceed 1.8 m/sec.

<table>
<thead>
<tr>
<th>Table 1: NEES LHPOST Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
</tr>
<tr>
<td>Peak acceleration bare table / 400 ton payload</td>
</tr>
<tr>
<td>Peak velocity</td>
</tr>
<tr>
<td>Stroke</td>
</tr>
<tr>
<td>Maximum gravity (vertical) payload</td>
</tr>
<tr>
<td>Force capacity of actuators</td>
</tr>
<tr>
<td>Maximum overturning moment (bare table, 400 ton specimen)</td>
</tr>
<tr>
<td>Frequency bandwidth</td>
</tr>
</tbody>
</table>

The peak displacement or stroke specification of ±0.75 m for the shake table represents a compromise between the expected peak ground displacement for “ordinary” ground motions having a peak ground acceleration of 1g, and the expected degradation of shake table performance with increasing actuator stroke. The selection of the frequency bandwidth was guided by the observation that the significant frequency content of actual earthquake horizontal ground acceleration records lies in the range between 0 and 15 Hz. The requirement of a wider frequency bandwidth of 0-33 Hz allows for accurate reproduction of actual ground acceleration records with a time compression of up to 33% for test specimens scaled down to 56% (assuming “same material and same acceleration” similitude). The need to repeat several tests without waiting for the accumulators to be recharged resulted in the requirement of a hydraulic system that can deliver 7.5 m of swept table displacement (2500 liters at 21MPa).
1.d Infrastructure at Camp Elliott

The Englekirk Structural Engineering Center occupies a 2-acre site on the Northwest corner of the UCSD Camp Elliott situated on Miramar/Pomerado Rd. near Interstate 15. The site has restricted access, is a gated facility and has ample room for the simultaneous construction and instrumentation of multiple test specimens before placement on the shake table. Hotel and dining services for visiting researchers are available within 1 mile of the site. Networking capabilities are available via the 45Mbps High Performance Wireless Research and Education Network (HPWREN). In addition, a fiber-based service provides 1.25 Gbps seamless connectivity between the UCSD local area network including the San Diego Supercomputer Center (SDSC) and the Camp Elliott site. All utilities at Camp Elliott have been designed for future upgrades. Electrical power service is at a level of 1000kVA.
2. TABLE CHARACTERISTICS

2.1 Specifications of Mechanical and Hydraulic Components

The specifications for the various components of the LHPOST in its uniaxial configuration are summarized in Table 2. These components include the platen, horizontal actuators, hold-down struts, vertical bearings, and the hydraulic power supply.

<table>
<thead>
<tr>
<th>Description</th>
<th>Metric Units</th>
<th>English Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Table Foot Print</strong></td>
<td>7.6 m x 12.2 m</td>
<td>25 ft x 40 ft</td>
</tr>
<tr>
<td><strong>Table Weight</strong></td>
<td>1.41 MN</td>
<td>159 ton</td>
</tr>
<tr>
<td><strong>Specimen Payload</strong></td>
<td>20 MN</td>
<td>2248 ton</td>
</tr>
<tr>
<td><strong>Specimen CG</strong></td>
<td>10 m</td>
<td>32.8 ft</td>
</tr>
<tr>
<td><strong>Maximum Overturning Moment</strong></td>
<td>50 MN-m</td>
<td>18440 ton-ft</td>
</tr>
<tr>
<td><strong>Actuators</strong></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td><strong>Stroke</strong></td>
<td>± 0.75 m</td>
<td>± 29.53 in</td>
</tr>
<tr>
<td><strong>Peak Velocity</strong></td>
<td>1.8 m/s</td>
<td>5.9 ft/s</td>
</tr>
<tr>
<td><strong>Acceleration</strong></td>
<td>4.2 g / 1.2 g</td>
<td>4.2 g / 1.2 g</td>
</tr>
<tr>
<td><strong>Force Capacity</strong></td>
<td>2.7 MN / 4.2 MN</td>
<td>301.7 ton / 471.3 ton</td>
</tr>
<tr>
<td><strong>Tension/Compression</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rod Diameter</strong></td>
<td>0.3048 m</td>
<td>12 in</td>
</tr>
<tr>
<td><strong>Piston Diameter</strong></td>
<td>0.508 m</td>
<td>20 in</td>
</tr>
<tr>
<td><strong>Total Effective Piston Area</strong></td>
<td>0.332 m²</td>
<td>515.3 in²</td>
</tr>
<tr>
<td><strong>Tension Area</strong></td>
<td>0.1297 m²</td>
<td>201.1 in²</td>
</tr>
<tr>
<td><strong>Compression Area</strong></td>
<td>0.2027 m²</td>
<td>314.2 in²</td>
</tr>
<tr>
<td><strong>Hold-Down</strong></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td><strong>Struts</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nitrogen Pressure</strong></td>
<td>20.7 Mpa</td>
<td>3000 psi</td>
</tr>
<tr>
<td><strong>Stroke</strong></td>
<td>2 m</td>
<td>78.7 in</td>
</tr>
<tr>
<td><strong>Hold-down Force Capacity</strong></td>
<td>3.1 MN</td>
<td>348 ton</td>
</tr>
<tr>
<td><strong>Effective Area</strong></td>
<td>0.152 m²</td>
<td>235 in²</td>
</tr>
<tr>
<td><strong>Vertical</strong></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td><strong>Bearings</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Effective Bearing Area</strong></td>
<td>0.455 m²</td>
<td>706 in²</td>
</tr>
<tr>
<td><strong>Vertical Force Capacity</strong></td>
<td>9.4 MN</td>
<td>1060 ton</td>
</tr>
<tr>
<td><strong>Stroke</strong></td>
<td>± 0.013 m</td>
<td>0.5 in</td>
</tr>
<tr>
<td><strong>Hydraulic Supply</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Accumulator Swept Volume</strong></td>
<td>7.5 m</td>
<td>295.3 in</td>
</tr>
<tr>
<td><strong>Accumulator Bank Pressure</strong></td>
<td>35 MPa</td>
<td>5000 psi</td>
</tr>
<tr>
<td><strong>System Pressure</strong></td>
<td>20.7 MPa</td>
<td>3000 psi</td>
</tr>
<tr>
<td><strong>Blowdown Flow Rate</strong></td>
<td>38000 lpm</td>
<td>10000 gpm</td>
</tr>
<tr>
<td><strong>HPU Flow Rate @ 5000 psi</strong></td>
<td>431 lpm</td>
<td>114 gpm</td>
</tr>
<tr>
<td><strong>HPU Flow Rate @ 3000 psi</strong></td>
<td>718 lpm</td>
<td>190 gpm</td>
</tr>
<tr>
<td><strong>Surge Tank Capacity</strong></td>
<td>10000 liters</td>
<td>2642 gal</td>
</tr>
</tbody>
</table>
Table Performance Curves

UCSD Seismic System
7.6 meter × 12.2 meter Table
Sinusoidal Performance Estimate
MTS Systems Corp. Feb-04

Acceleration (g's) vs. Velocity (m/sec) vs. Frequency (Hertz)

- Base Table
- With 400 MTR Rigid Specimen
- With 2000 MTR Rigid Specimen
3. WHERE TO START

3.1 Check Table availability. Go to http://nees.ucsd.edu/ and learn more about our general testing capabilities.

3.2 Under Projects select “Site Schedule” or follow this link: http://nees.ucsd.edu/projects/schedule.shtml.

3.3 Check the table availability for the test window that you are interested. If the table is available during your preferred time window then:

3.4 Check the Required Input Motions against the Table performance curves presented on page 9 of this document.

3.5 Check the footprint of the specimen against the platen dimensions.

3.6 Check the overturning moment.

3.7 Check the instrumentation available on site against your requirements. Go to: http://nees.ucsd.edu/facilities/equipment.shtml.

3.8 If additional masses are needed please check the masses which are available on site. Go to: http://nees.ucsd.edu/facilities/added-mass-blocks.shtml

3.9 If restraining towers that are needed for safety purposes please go to: http://nees.ucsd.edu/facilities/restraining-towers.shtml

3.10 If above initial verifications are true then is time to contact us. To find information related to how and who to contact go to the following link: http://nees.ucsd.edu/about/contact.shtml

3.11 If you would like to reach other points of contact go to: http://nees.ucsd.edu/about/personnel.shtml

3.12 From this point on we can discuss the details of your project regarding technical aspects, information regarding local contractors, information regarding lodging for your personnel/students and safety training required for all personnel.

**NOTE:**

*If you need additional information and/or clarifications please feel free to contact us any time. Contact information can be found at:* http://nees.ucsd.edu/about/contact.shtml
4. **FINAL CONSIDERATIONS**

Depending on the type of test there are different requirements imposed by University of California rules. The recommended path for performing a test at Englekirk Structural Engineering Center (ESEC) testing facility is to contact us and get on the right track.

The LHPOST shake table is part of NEES network and all NEES research projects have priority.