**Equipment Site Description**

In the past, few structural experiments have been performed at large-scale with load rates approaching those that occur in actual structures under earthquake loading. Although there is a long tradition of using structural tests to advance the state-of-the-art in seismic design and performance of structural systems in the US, experiments on large-scale (near real-scale) structural subassemblages, components and connections have become common only during the past two decades. This deficiency in existing experimental research capability is being overcome through the creation of the Lehigh NEES Equipment Site. The Lehigh NEES Equipment Site features a real-time multidirectional testing (RTMD) facility with the capabilities to perform integrated experimental and analytical research. The RTMD facility enables the effects of real time multidirectional ground motions on the structural response of buildings, bridges, and foundation systems to be investigated.

The centerpiece of the Lehigh NEES Equipment Site is the ATLSS Center’s multidirectional reaction wall and strong floor. A primary component of the loading system is the hydraulic power system. The hydraulic system, combined with dynamic actuators and a real-time digital servo-control system, enables real-time strong ground motion effects to be sustained for up to 30 seconds. Testing methods include the effective force method, real-time pseudo-dynamic testing method, and the real-time pseudo-dynamic hybrid testing method. The facility also supports multi-site pseudo dynamic hybrid testing.

**Equipment Capabilities**

The equipment for the RTMD facility is located and stored at the ATLSS Center at Lehigh University. A description of the facility and equipment is given below.

**Fixed installations:** The laboratory of the RTMD facility includes a strong floor that measures 31.1m x 15.2 m in plan, and multidirectional reaction wall up to 15.2 m in height. Anchor points are spaced on a 1.5-m grid along the floor and walls. Each anchor point can resist 1.33 MN tension force and 2.22 MN shear force. Additional steel framing is used in combination with the strong floor and reaction walls to create a wide variety of test configurations.

A 178-kN capacity overhead crane services the test area and an adjacent fabrication area. Additional smaller cranes with capacities of 45-kN and 27-kN also serve this area.

**NEES equipment performance specifications:** The equipment portfolio and resources of the Lehigh NEES equipment site include:

- Five channels of dynamic loading, with the system configured for up to 8 channels and control by using either displacement or force, consisting of two 2050 kN dynamic actuators ported for three 400 gpm servovalves, +/- 500 mm stroke, and three 1500 kN dynamic actuators ported for three 400 gpm servovalves, +/- 500 mm stroke.
- Ten three-stage 1500 liters/min high flow-rate servo-valves.
- Hydraulic distribution lines and service manifolds, with a low-pressure and high-pressure setting, to operate at 20.7 MPa with a maximum flow of 1500 liters/min.
- Surge tank and two banks of accumulators, when utilized in conjunction with existing 20.7 MPa 2270 liters/min hydraulic power system, will enable strong ground motion effects to be sustained for up to 30 seconds. Each bank consists of eight 190-liter accumulators, providing a total accumulated oil supply of 3040 liters.
- Hydraulic system modifications, to connect the accumulators to the pressure line of the existing system, with dedicated connections for the new, high-flow hydraulic service manifolds, and a new return line from...
these dedicated connections to the pump house area, along with a new hydraulic oil reservoir in the pump house area for the oil needed to fill the accumulators and to receive the return flow, as well as connections between this reservoir to the existing reservoirs, heat exchangers, and pumps.

- Digital 8-channel control system with real-time hybrid control packages, with each channel of the controller designed to follow an independent, random load, or displacement history.
- Digital video teleobservation system including a system of video cameras, video server, data server, restricted access web server, and a public access web server.
- Teleoperation equipment consisting of an application server that coordinates the data streams to/from the test process module, digital controller, and video server, synchronizes the time stamps between these with the time server, and allows a control client application to interact with these elements of the test scheme.
- High speed 256-channel data acquisition system, capable of acquiring data at 1000 Hz (1000 samples per second) per channel and expansion to 512 channels.
- Advanced sensors that include wireless MEMS-based accelerometers, piezoelectric transducers (strain and acceleration measurement), and fiber optic strain gages of Stimulated Brillouin Scattering principles.

**Communications:** The RTMD facility communication capabilities include the Internet, televideo conferencing, as well as traditional capabilities that include telephone and Fax machines.

**Data acquisition, processing, and storage:** The data acquisition includes a high speed 256-channel data acquisition system, capable of acquiring data at 1000 Hz (1000 samples per second) per channel and expansion to 512 channels. Data will be processed using LabView software. Storage includes a local data repository having a 1.3TB capacity, with a 2.5TB disc mirrored Fiberchannel RAID array. The storage has been configured as a redundant array attached to the local repository with an appropriate amount of tape based backup.

**Teleobservation and teleoperation:** Teleobservation capabilities include five Canon VCC4 cameras in conjunction the NEESpop, telepresence manager, and video/image encoding storage servers.

**Connection to high performance network:** The equipment site will be connected to the NEES network through the Mid-Atlantic GigaPop Internet 2 (MAGPI) connection, with 155 Mb/sec Ethernet capabilities that can be scaled to 1 Gb/sec Ethernet capabilities when necessary. Like the other NEES equipment sites, the expanded lab will allow for shared-use access and training, the exchange of data in real time over the Internet, and telepresence and educational opportunities.

**Examples Of Potential Research And Educational Uses**

The functional flexibility of the RTMD facility enables numerous possibilities for integrating analytical and experimental research. These include not only seismic testing but also testing to evaluate response to other types of loading conditions, including wind and bridge structures with moving traffic loads. Large-scale structural components, subassemblages, and superassemblages can be built and tested at the Lehigh NEES Equipment Site, as illustrated in Figure D.2-2. Some examples of research that can be performed at the Lehigh NEES Equipment Site include: (1) large-scale testing to evaluate the seismic performance and behavior of structural systems with either passive, semi-active, or active controlled devices for wind or seismic hazard mitigation; (2) multidirectional earthquake testing of large-scale structural components such as a reinforced concrete bridge cap beam - pier - foundation system; (3) concurrent seismic testing of several components of a structural system using the hybrid testing method to couple the components; (4) response of structural elements and connections to high strain rate of loading, including blast loading.
The multidirectional earthquake testing of a reinforced concrete bridge cap-beam-pier foundation system is illustrated in Figure D.2-3. The objective of this test is to investigate the effects of soil-structure interaction on bridge structures subjected to realistic (4-DOF) seismic demands, and to acquire data for verifying analytical predictions. Using the multidirectional reaction wall, the structural test component is tied down to the strong floor and the dynamic actuators arranged to load the specimen, as illustrated in Figure 3. The bridge cap beam and pier are set on top of its pile foundation (which is placed in a soil box). Since the portion of the superstructure between bridge bents is known to remain elastic, it and other remaining parts of the bridge not appearing in the test structure are analytically modeled and coupled to the test structure. The top of the bridge pier is subjected to bi-directional earthquake loading (resulting in transverse, longitudinal, torsional, and rotational motions to the top of the bent with simultaneous gravity loading from static actuators), where the displacements are based on the real-time pseudo-dynamic hybrid testing method. In addition to conventional instrumentation, the structural and soil behavior are measured using a grid of MEMS accelerometers and continuous distributed fiber-optic sensors that are embedded in the soil and reinforced concrete. The data from the fiber-optic sensors are mapped digitally to obtain real-time evolution of strains over 2D or 3D configurations.
The teleobservation equipment at the Lehigh NEES Equipment Site enables remote users to observe tests, or observe visual data and measured response data from completed tests that are stored on an archive server. Hence, the response of several structures tested using the RTMD facility can be observed, providing a powerful means of education though examining and comparing the response of different structural systems and components to earthquake loading.