**Equipment Site Description**

The facility focuses on lifeline testing, laboratory simulation of soil-structure interaction under large ground deformation, and database generation and model-based simulation of lifeline component response to large transient and permanent displacements induced by earthquakes. The essential service that the experimental equipment provides for NEES is the capability to simulate large earthquake-induced displacements and to evaluate the ramifications of such displacements with respect to the soil-structure interaction of underground facilities and the ductile performance of aboveground structural components.

The facility will be equipped with large-stroke actuators, capable of 0.91-m cyclic and 1.82-m one-way displacements. High and low strong walls will provide reaction members for underground and aboveground lifeline experiments. Soil storage bins and a portable conveyor system will allow for rapid movement and placement of soil for large-scale experiments on underground lifelines subject to large permanent ground displacements. In addition, special split-box centrifuge containers will be housed at RPI for use in their geotechnical centrifuge. Centrifuge testing can be performed at RPI to complement and refine the large-scale testing performed at Cornell.

It should be recognized that the experimental facility is not only critically important for earthquake engineering simulations, but is well suited for evaluating the effects of locally severe deformations arising from adjacent construction, subsidence, undermining excavations, and other extreme events, such as flooding and high winds. Moreover, the experimental equipment will provide simulation capabilities for the effects of landslides, submarine instabilities, and offshore construction effects on oil and gas gathering and transmission systems.

**Potential Research Projects**

Three potential experimental projects are discussed below.

1. **Soil Structure Interaction Under Permanent Ground Deformation**

Some of the most serious damage to underground lifelines during an earthquake is caused by permanent ground deformation (PGD) [e.g., O’Rourke, 1998]. Figure D.1-1 illustrates the concept, which provides the basis for laboratory simulation of the most severe PGD effects associated with surface faulting, liquefaction-induced lateral spread, and landslides.

Relative displacement is generated along a moveable interface between two test basins, or boxes, containing soil and the buried lifeline. Soil is placed and compacted according to field construction practice. The scale of the experimental boxes is chosen by computation modeling and previous test experience such that the soil-lifeline interaction is unaffected by the boundaries of the test facility. The experimental facility also will have the capability of imposing simultaneous vertical and horizontal displacement, as well as modest amounts of extension or compression normal to the rupture plane.

Soil storage bins will be fabricated that are recessed within the structural column system of the Winter Laboratory. The bins are located within the lifeline testing area, and a moveable conveyor system has been chosen for rapid transfer of soil from bin to test boxes.

Large displacements will be generated with large stroke actuators. Two actuators will each provide ± 0.91m of cyclic movement, and 1.82m of one-way displacement. An additional actuator (a exact match to an existing actuator) will provide ± 0.63m of cyclic and 1.26m of one-way movement. By linking actuators in series, it will be possible to generate several meters of movement. The test boxes will slide on Teflon strips, having a coefficient of friction of about 0.05. Cornell experience with this sliding system has been very good (Yoshisaki, et al., 2002), and provides a sound basis for sizing both the actuator stroke and load capacity.

As shown in Figure D.1-1, it will be possible to evaluate many different conditions with the experimental facility, including different types of pipelines, electric conduits, and telecommunication cables. Straight pipe sections and pipelines with elbows and tees can also be investigated. Steel, plastic, ductile iron, reinforced concrete piping, as well as a variety of specialized joints, coatings, and retrofitting techniques are viable candidates for testing. Soil-lifeline interaction for different soils, unit weights, and moisture contents, depths of burial, and pipeline diameters can be investigated.
One of the most interesting conditions to investigate involves the effects of trench geometry and backfill. As illustrated in Figure D.1-1 (d) pipelines and conduits are frequently placed in trenches backfilled with soil that is different than the native soil. Currently, there are no guidelines for evaluating soil-pipe reaction under these conditions. The experimental facility is ideally suited to clarify soil-pipe interaction for various trench geometries and properties of native soil and backfill.

Specialized trench geometries and advanced materials have been recommended for fault crossings to reduce soil pressures, as illustrated in Figure D.1-1 (d). Measures to reduce soil resistance to pipe and conduit movement include sloped trenches; high-density polyethylene (HDPE) sheets to promote sliding and lateral pipe movement, and the use of expanded polystyrene (EPS) or other crushable materials. The experimental facility is ideally suited to investigate these mitigation measures.

Coordinated experiments with the RPI centrifuge and large-scale Cornell facility will cover the range of geometric characteristics, material properties, construction practices, and loading rates encountered in the field. A centrifuge test can be performed more rapidly and at significantly less expense than a large-scale experiment. Hence, the centrifuge is used to define parameters for tests at full scale. It is important for deciding on the appropriate boundary conditions, trench configuration, backfill material, and protective
measures to be investigated. Likewise, centrifuge tests extend the range and relevance of full-scale experiments. After a full-scale test has provided detailed information on soil-structure interaction for specific cases, the influence of key parameters can be explored in several centrifuge tests that follow the full-scale experiment and clarify the role of different parameters.

2. Soil-Structure Interface Interactions

Soil-structure interface problems involve locations where abrupt transitions from structure to soil create localized stresses and deformations. As illustrated in Figure D.1-2, examples include bridge abutments where a number of different cables and conduits may transition from soil through the abutment and/or other structural elements.

The experimental facility will have the ability to simulate complex interactions at soil-structure interfaces. The experimental concept is shown in Figure D.1-2 (d). An actuator can apply lateral displacements to a structural vault or bridge abutment element at the same time another actuator applies displacements to a test box with backfill soil and a buried conduit that penetrates the structural element. A special sliding connection can be fabricated to allow relative movement between the test box and structural element. As discussed with respect to the previous text example, Teflon strips will allow for low-friction sliding of the experimental members. Although not shown in the figure, vertical movement between the soil and structural element can be imposed to simulate the effects of soil settlement adjacent to the structure.

The experimental facility will be able to simulate and evaluate the effects of many different variables, including soil properties, pipe trench characteristics, pipe material properties, pipe diameter, depth, and characteristics of the pipe/conduit penetration. The cyclic displacements imposed by the actuators will be derived from computational simulations of the full-scale structure and surrounding ground conditions.

As illustrated in Figure D.1-2 (c), another problem that can be addressed with the experimental facility involves the effects of near field transient displacements on base isolation elements. Large deformation across base isolation elements, as well as contemporaneous interaction with adjacent soil, can be simulated with the equipment. The effects of such deformations and interactions with adjacent soil are largely unknown. Experimentation to quantify these conditions can improve base isolation design.

3. Highly Ductile Structural Response

The predominant emphasis in earthquake-resistant design practice is on ductility. In reinforced concrete, ductility traditionally has been achieved with monolithic construction and proper reinforcement detailing, such as adequate concrete confinement. With steel structures, moment-resisting frames with adequate connection details are a common approach to ductile design. In highway structures, innovative restrainers and isolation devices also are becoming more common. The limits of ductility are being pushed steadily, and further improvements in ductility will continue into the future.

An example of a highly ductile system is that of precast segmental concrete bridge piers with unbonded vertical post-tensioning and localized use of highly ductile fiber-reinforced concrete. One-fifth scale experiments on partial columns with unbonded post-tensioning and localized use of the ductile composites have proven the feasibility of this system (Yoon et al., 2002). As shown in Figures D.1-3 (a) and D.1-3 (b), it was found that the highly ductile concrete located in hinge regions maintains its integrity beyond drifts of 20% while the unbonded post-tensioning does not yield and thus minimizes any residual displacement after reaching such high drifts. The load-carrying capacity of the system was also maintained at these large drifts. Residual drifts were on the order of 2-3%.
Experiments now are needed on full-height columns (roughly half-scale will be feasible with the facility) due to the use of unbonded post-tensioning. Because the post-tensioning is unbonded, there is no localized yielding of the post-tensioned steel. Strain induced in the bridge columns is spread along the entire length of the post-tensioning. Therefore full bridge piers using the full length of strand are necessary for accurate investigation of such systems. Figure D.1-3 (c) illustrates the experimental concept. Full bridge pier experiments will require stroke capacities of 0.65-1.0 mm. The Cornell NEES facility will include a modular 1.2-m-high low reaction wall and a modular 7.2-m-high reaction wall. The experiments will be carried out on the upper surface of the low reaction wall and lateral load would be applied from the high portion of the strong wall. Equivalent gravity load would be applied using high capacity (force) actuators that would react off of the strong floor or from a stiff frame supported at the top of the reaction walls. This support system would be designed to allow the actuators to move with the specimen as it undergoes large drift cycles.
Cyclic experiments on large-scale specimens are necessary to understand the impact of segment size and fabrication techniques on potential energy dissipation in these highly ductile materials. Such tests would be a part of the above-mentioned project, for instance single or half-column tests, and would be carried out also on the surface of the low reaction wall, reacting laterally from the high reaction wall.

Finally, smaller-scale material characterization is necessary in the development of new ductile materials. In this example case, new mix designs for ductile cement-based composites, which are needed to facilitate large-scale fabrication, will be characterized before selection for use in the larger-scale experiments. It is also essential that such material characterization be carried out in conjunction with the large-scale system characterization tests to facilitate model-based simulation. The material tests are necessary for constitutive model development. Such models will be used to predict experimental results, develop the appropriate test series and test set-ups, and provide tools for design once the system behavior is understood and the materials and preparation procedures are ready for implementation in practice.