Chapter 21
Earthquake Engineering Experimental Facility for Research and Public Outreach

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Abstract Over the past two decades, important advancements have been made in earthquake engineering practice aimed at reducing seismic risk to urban communities worldwide. Since earthquakes occur infrequently and often in unpredictable locations, the role of experimental research in these advancements has been invaluable. Experimental tests performed under controlled environment can provide high quality data that can advance fundamental knowledge of the behavior of geotechnical and structural elements, validate analytical models, and help explore development of innovative, cost-effective seismic mitigation technologies. It has become evident also that implementation of and investment in seismic risk reduction technologies to vulnerable urban communities requires heightened awareness at all levels of society of the earthquake risk. The authors have found that a shaking table facility while providing valuable research opportunities, is also ideally suited for educational and outreach activities tailored for regional communities and media to heighten their awareness of earthquake risk and demonstrate the important role engineers play in seismic mitigation. The shaking table utilized is uni-directional (1.5 m $\times$ 2 m) and has 254 mm peak to peak lateral displacement capacity. The shaking table has been crucial in many research projects in areas such as structural and soil isolation, dynamic interface properties of geosynthetics, seismic permanent deformations, and liquefaction mitigation. The facility is also utilized weekly, as well as at times of heightened public and media interest in earthquake damage, to present various

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educational modules and carry out shaking table model demonstrations. This paper and presentation will focus on highlights of research conducted using the shaking table and how the facility has been integrated into formal and community-wide educational and outreach programs.

21.1 Introduction

Research performed to date in earthquake engineering has had tremendous effect on understanding earthquake motion, its modification through subsurface soil profiles and its devastating damage to infrastructures and to loss of lives. There is still need for the development of new practical and low-cost mitigation techniques to reduce the loss of lives and prevent collapse. Figure 21.1 demonstrates a collapsed building during the 2011 Van Earthquake in Turkey. The role of earthquake engineering experimental infrastructure can be significant in developing new technologies, and testing novel risk reduction ideas and measures. The Earthquake Engineering Experimental Facility at Northeastern University, Boston, MA provides an integrated infrastructure and instrumentation for several research and educational projects performed on seismic improvement of ground and civil structures, and recently on the development of a new mitigation technique against liquefaction. The experimental facility includes a one-directional servo-controlled shaking table, a data acquisition card and software, accelerometers, linear variable displacement

Fig. 21.1 Building collapsed during the 2011 Van Earthquake in Turkey (Courtesy of National Turk)

transducers (LVDTs), miniature pore water pressure transducers and bender elements and bending disks. Recently, a new mitigation technique was evaluated by performing cyclic shear strain tests on partially saturated sand specimens using the experimental facility. The facility also has had a great impact on increasing public awareness by performing open house demonstrations where students can build structural models and test them under real earthquake motions. In this paper, the details of a current research project that has been conducted using the facility is presented, along with the significant role of the facility in improving public awareness about earthquake risk.

21.2 Earthquake Engineering Experimental Facility at Northeastern University

The earthquake engineering experimental facility at Northeastern University provides large-scale dynamic testing of soil samples under uniform cyclic or earthquake motions. It includes a shaking table (Fig. 21.2), a data acquisition card (NI-DAQ) and software (LabVIEW), a set of instruments including accelerometers (Crossbow, 1g, 2g, 5g, Fig. 21.3a), linear variable displacement transducers (LVDT, RDP DCTH400AG, Fig. 21.3b), miniature pore pressure transducers (GE Druck PDCR 81, Fig. 21.3c), and multiple bender element and bending disk measurement equipment for S and P wave measurements (Fig. 21.3c–e).

The shaking table is one-dimensional, medium size (1.5 m × 2 m), light weight (made of 25.4 mm thick aluminum plate), and servo hydraulic controlled system. The table motion can be controlled from a control unit as well as from a computer. The control unit provides harmonic excitation options such as sinusoidal, step motion, triangular at various frequencies and amplitudes utilizing a plug-in function generator. On the other hand, earthquake records can be simulated from a computer

Fig. 21.2 1-D Shaking table used for research, education and outreach activities at Northeastern University

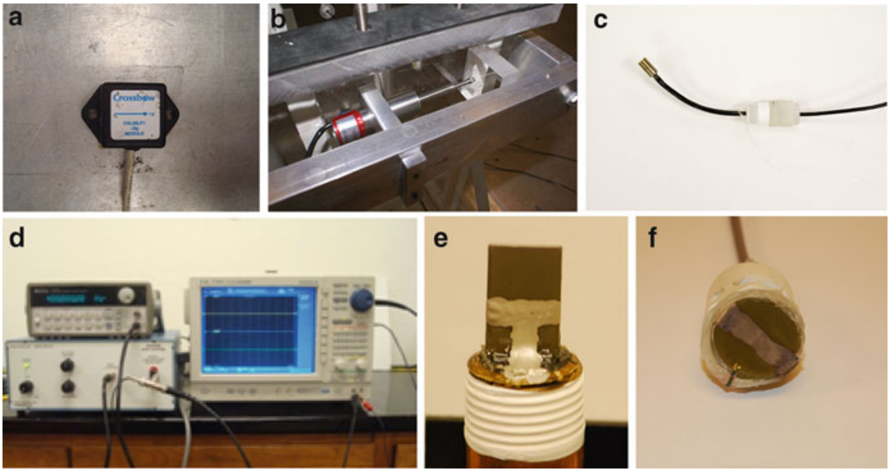

Fig. 21.3 Instruments used in Earthquake Engineering Experimental Facility at Northeastern University: (**a**) Crossbow Accelerometer; (**b**) LVDT (Linear Variable Displacement Transducer); (**c**) GE Druck PDCR81miniature pore pressure transducer; (**d**) HP Function generator, power amplifier and Yokogawa Oscilloscope; (**e**) Bender element; (**f**) Bending disk

utilizing a data acquisition card (NI-DAQ) and data processing software LabVIEW. The shaking table has a load capacity of 25 kN and can effectively perform at a frequency range of 0–50 Hz. It incorporates MTS Model 244.21 actuator with a 254 mm stroke capability (±127 mm lateral displacement) (Kadakal and Whelpley 1997).

Various research projects in areas of structural and soil isolation, dynamic interface properties of geosynthetics, seismic permanent deformations, and liquefaction mitigation have been conducted using this facility. A recent research project conducted on liquefaction mitigation will be presented in the following section.

21.3 Induced Partial Saturation (IPS) for Liquefaction Mitigation

Liquefaction is one of the most catastrophic earthquake-induced events that impacts infrastructure built on fully saturated loose sands. Using the earthquake engineering experimental facility at Northeastern University, the liquefaction strength of partially saturated sands has been investigated by performing cyclic simple shear tests on prepared specimens.

A special liquefaction box was designed and built in which fully and partially saturated sand specimens can be prepared and tested under uniform cyclic simple shear strains induced through a shaking table. The liquefaction box, named Cyclic Simple Shear Liquefaction Box (CSSLB), can accommodate an integrated set of instrumentation, minimize the sidewall boundary effects and induce uniform shear

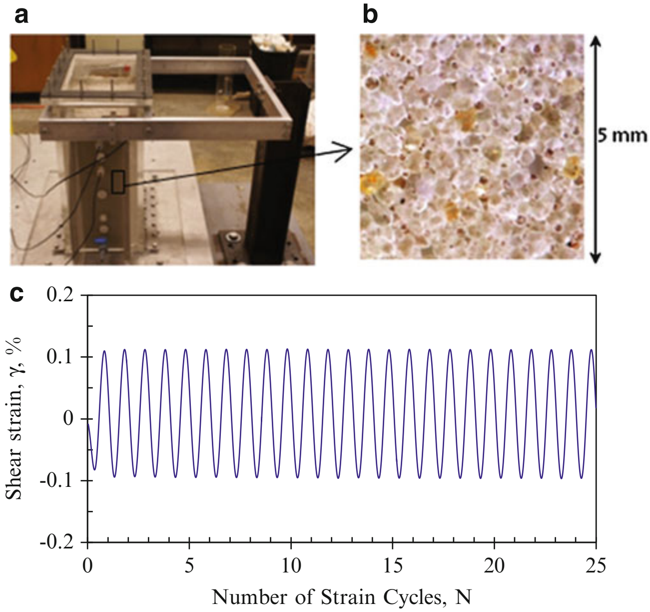

Fig. 21.4 (**a**) Partially saturated sand specimen tested in Cyclic Simple Shear Liquefaction Box (CSSLB); (**b**) A micro picture of air induced sand specimen (S = 80 %) (Gokyer 2009); (**c**) Simple shear strain record applied using the shaking table (for shear strain amplitude is 0.1 %)

strains on large sand specimens. Figure 21.4a demonstrates the side-view photograph of CSSLB which has inside plan dimensions of 190 mm × 305 mm (7.5" × 12") and a height of 490 mm. CSSLB consists of two fixed walls (fixed walls being in the direction of shaking) and two rotating walls which are hinged to the bottom plate, and also are connected to the two fixed walls and the bottom plate by a joint sealant called Sikaflex 15LM. The walls are made of plexiglass. The sealant makes the joints water tight yet flexible allowing movements along the joints by being compressed and elongated. An aluminum frame is attached to the top of the CSSLB at one end and to an outsider fixed beam next to the shaking table at the other end, through unthreaded bolts. Hence, when the shaking table is excited with cyclic displacements, controlled simple shear strains can be induced on the specimens through rotation around the bottom hinge as well as by means of compression and/or elongation of Sikaflex. The elastic compression and elongation capacity of Sikaflex in connections up to 5 mm leads to a maximum 1 % shear strain capacity on sand specimens. The details of the CSSLB design can be found at (Ortakci 2007).

Partially saturated sand specimens were prepared using a special chemical compound “sodium perborate”, a main ingredient of dental product “Efferdent” which produces oxygen gases when reacted with water. Specimens were prepared by wet pluviation technique which basically consists in raining the powdered Efferdent-dry sand (Ottawa sand) mix in the partially filled with water CSSLB (keeping 30 mm of free water on top). The intended partial saturation level could be

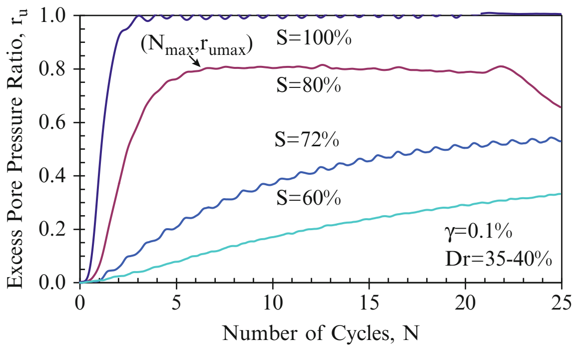

Fig. 21.5 Comparison of excess pore pressure ratio (r_u) generation in specimens at different degrees of saturation ($\gamma = 0.1$ % $\sigma'_v = 2.5$ kPa)

achieved in each specimen based on a correlation determined between the degrees of saturation induced in the specimen versus the Efferdent-sand mass ratios. The presence of oxygen gases and their distribution within the sand specimens were evaluated by taking micro pictures of the specimens with a professional camera as shown in Fig. 21.4b (Gokyer 2009).

A series of cyclic simple shear strain tests were performed on partially saturated sand specimens prepared at degrees of saturation ranging from S = 40 % to S = 90 %. The effects of the main parameters: "degree of saturation (S), relative density (D_r), shear strain (γ)", on the maximum excess pore water pressure generation were evaluated. Consequently, based on the test results, an empirical model was developed, which predicts maximum excess pore water pressure ratios in partially saturated sand specimens.

Figure 21.5 demonstrates the excess pore pressure ratio (r_u) generations in medium dense sand specimens with different degrees of saturation under the shear strain record shown in Fig. 21.4c. The results reveal that during cyclic loading, excess pore pressures also generate in partially saturated sands and can remain high as the degree of saturation increases. However, as the degree of saturation reduces, maximum excess pore pressure (r_{umax}) gets lower, while at the same time the number of cycles required to reach r_{umax} (N_{max}) gets higher.

A parametric study was performed on experimental results to estimate individual, as well as cooperate effects of S, D_r and γ on r_{umax}. Test results showed that r_{umax} depends significantly on the degree of saturation (S) and to a lesser extent on relative density (D_r) and amplitude of the cyclic shear strain (γ). Ultimately, a mathematical model was developed to predict maximum excess pore water pressure ratios (r_{umax}) in partially saturated sands. The r_{umax} model function (Eqs. 21.1, 21.2, 21.3, 21.4 and 21.5) was obtained by the product of a base function f_b and scaling factor functions F_D and F_γ. Details on the formulation of these functions and estimation of model parameters and their statistics are presented in (Eseller-Bayat 2009).

$$r_{u\max} = f(S, D_r, \gamma) \quad (21.1)$$

$$r_{u\max} = f_b(S, D_r = 20\,\%, \gamma = 0.1\,\%)F_D(S, D_r)F_\gamma(S, \gamma) \quad (21.2)$$

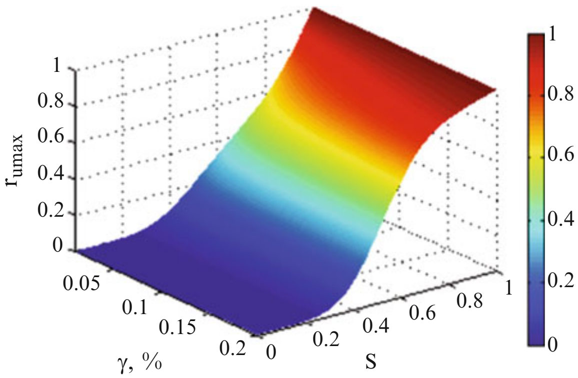

Fig. 21.6 Graphical presentation of the mathematical model presenting maximum excess pore pressure ratio (r_{umax}) generated in loose sands based on cyclic simple shear tests

where:

$$f_b = S^{0.5} e^{-\left[\frac{1-S}{0.54}\right]^4} \tag{21.3}$$

$$F_D = 1 - 8.75(D_r - 0.2)(1 - S)\exp\left[-\frac{1}{2}\left(\frac{1-S}{1-0.84\left(\frac{0.2}{D_r}\right)^{0.25}}\right)^2\right] \tag{21.4}$$

$$F_\gamma = 1 + 1.75\left(\log\frac{\gamma}{0.001}\right)(1 - S)\exp\left[-3.1(1 - S)^2\right] \tag{21.5}$$

Figure 21.6 demonstrates graphical representation of the r_{umax} model for loose sands (D_r = 25 %). The model depicts that the effect of shear strain on r_{umax} is more pronounced at degrees of saturation higher than 60 %. Below S = 60 %, regardless of the shear strain level applied, r_{umax} is smaller than about 0.4.

Finally, the shaking table tests on partially saturated sands allowed the authors to investigate the beneficial effect of partial saturation on liquefaction strength and led to the development of a new liquefaction mitigation technique.

21.4 Use of Earthquake Engineering Experimental Facility for Public Awareness and Education

The Northeastern University Earthquake Engineering Experimental Facility has had a great impact on attracting the interest of middle, high school and undergraduate students in civil and earthquake engineering. Open house activities are organized for middle and high school students to increase their interest in science, technology, engineering, and mathematics as well as to learn, hands-on, what engineering is about. In the open house activities, after seeing the basic principles

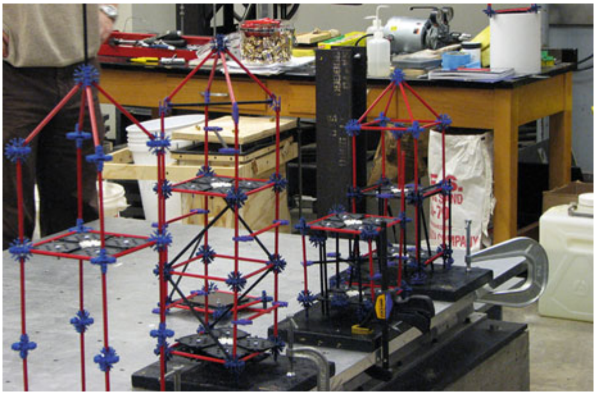

Fig. 21.7 Shaking table testing of toy building models designed by high school students under earthquake motion records

of how earthquakes can damage buildings, they are expected to design their own structure models, using plastic structural elements, which are in turn tested under real earthquake motions simulated on the shaking table (Fig. 21.7). These activities are very useful in improving the creativity and engineering skills of the students.

Graduate and undergraduate students are exposed to innovative experimental research aimed at mitigating earthquake-related damage to the built environment. Such exposure enhances their awareness of and interest in the field of earthquake engineering. Furthermore, class demonstrations help students understand essential concepts in earthquake engineering such as dynamic behavior of single and multi degree of freedom models, response spectra and earthquakes. Also, demonstrations performed in the Earthquake Engineering Experimental Facility at Northeastern University which are covered by the media raise public awareness about the risks of earthquakes to our society.

21.5 Conclusion

In this paper, the Earthquake Engineering Experimental Facility at Northeastern University was presented. The facility includes a uni-axial shaking table, a data acquisition card and software, accelerometers, LVDTs, miniature pore pressure transducers and bender element and bending disk measurement equipment. The facility has been used for various research projects including testing of partially saturated sands under earthquake motions. The liquefaction strength of partially saturated sands were confirmed through cyclic simple shear tests performed utilizing the shaking table facility. The results of the experimental study further led to the development of a new liquefaction mitigation technique: "Induced Partial Saturation" which is an ongoing project at Northeastern University. The facility also hosts outreach activities to attract the interest of middle, high school and also undergraduate students in earthquake engineering problems and risks.

In summary, earthquake engineering facilities have a significant role in seismic risk reduction because they

– provide high quality data that can advance fundamental knowledge of the behavior of geotechnical and structural elements,
– validate analytical models,
– help explore the development of innovative, cost-effective seismic mitigation technologies,
– encourage educational and outreach activities and increase awareness of earthquake risk
– demonstrate the important role engineers play in seismic mitigation.

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