Seismic Recording Station At Northeastern University
Boston, Massachusetts

M. K. Yegian [1], Fellow ASCE

ABSTRACT

In 1998, through the generous support of alumni and friends of Northeastern University's Department of Civil and Environmental Engineering, a Seismic Recording Station (NUSRS) was established. The mission of the station includes: 1- gathering and disseminating seismic ground motion data, 2- supporting the education and research programs in earthquake engineering at Northeastern University, 3- increasing K-12 students' interest in science and engineering, and 4- heightening public awareness of earthquake hazard. The station has four general components: a weak motion system that records long- and short-period motions worldwide, a strong motion array, portable triaxial accelerometers, and a multimedia center that displays earthquake records and serves as an outreach and public education facility. The purpose of this paper is to present an overview of the seismic recording station and provide details of the instrumentation with a primary focus on the strong motion components of the facility.

SEISMIC RECORDING STATION

Overview

Seismic hazard mitigation in the northeastern United States, and especially in New England, continues to receive increasing attention. The historic seismicity record of New England dates back to the mid 1700s and confirms the seismic vulnerability of the region. In 1755 an earthquake occurred off Cape Ann, 40 kilometers northeast of Boston that caused significant damage in the Boston area. The Modified Mercalli Intensity (MMI) of the event has been estimated to be about VIII in Boston. Since then the region has experienced many smaller earthquakes.

The Saguenay earthquake of 1988, in eastern Canada, provided a rare opportunity to record and analyze the characteristics of moderate earthquake ground motions in Eastern North America, (ENA). In the absence of identifiable active faults and known offsets, the seismo-tectonics of the region is not well understood. However, a number of general obser[1]vations have been made from the limited seismicity data and the few ground motion records available. It appears that ground motions in the ENA attenuate slower than in the Western North America, (WNA). Also, rock motions in ENA compared with typical rock motions in WNA show higher energy in the high frequency range (10-40 Hz), and lower energy in the lower frequency range (0.5-1 Hz).

[1] Distinguished Professor of Engineering, Northeastern University, Boston, MA. 02115

Because of the historic seismic activity, New England building codes now incorporate requirements for seismic design. Bridges and other critical facilities must meet seismic design guidelines set forth by governing federal and local agencies even though such seismic guidelines are typically based on national codes. New England is now faced with an urgent need to develop reliable seismic design guidelines. These guidelines should be based on a more current understanding of the seismo-tectonics of the region and of the influence of geologic and local site conditions on ground motions. To achieve this goal, it is imperative that we obtain quality ground motion records of future regional earthquakes.

In 1998, Northeastern University was given an opportunity by generous Civil and Environmental Engineering alumni to develop a unique facility that would support our educational and research activities in Earthquake Engineering. With their financial support a seismic recording station was conceived and established to specifically meet the following goals:

- To gather and disseminate valuable seismic ground motion data from smaller, less frequent, moderate earthquakes in the region.
- To improve our understanding of region specific ground motion attenuation and frequency characteristics of seismic motions.
- To understand the effects of deep clay deposits on ground motions and to determine the in-situ shear wave velocity of the Boston Blue Clay. This information will be useful in the preparation of microzonation maps.
- To investigate the soil-structure interaction effects on structures founded on deep deposits of clay.
- To support our educational and research programs in earthquake engineering.
- To heighten the earthquake awareness of both the regional professional and public communities.
- To educate and stir interest of K-12 students in the field of engineering.

To accomplish these overarching goals, four major components were identified for inclusion in the seismic recording station (as shown in Figure 1).

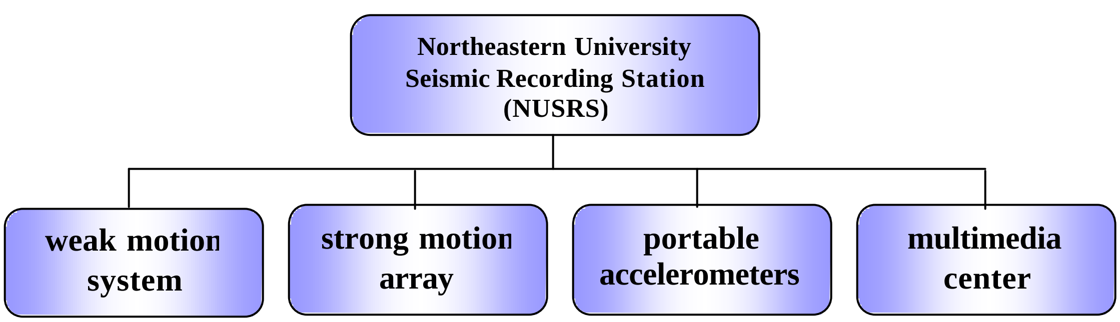


Figure 1. The four major components of the Northeastern University Seismic Recording Station (NUSRS).

The four components of the station are:

1. A weak motion system that records long- and short-period motions from worldwide events
2. A strong motion array with surface and borehole accelerometers
3. Portable triaxial accelerometers
4. A multimedia center that displays all records and supports outreach and public education activities

Details of each component are briefly presented with especial emphasis on the strong motion recording system.

NUSRS Components

1. Weak Motion System

The long- and short-period components of earthquake motions from around the world are recorded separately using two different systems (shown in Figure 2).

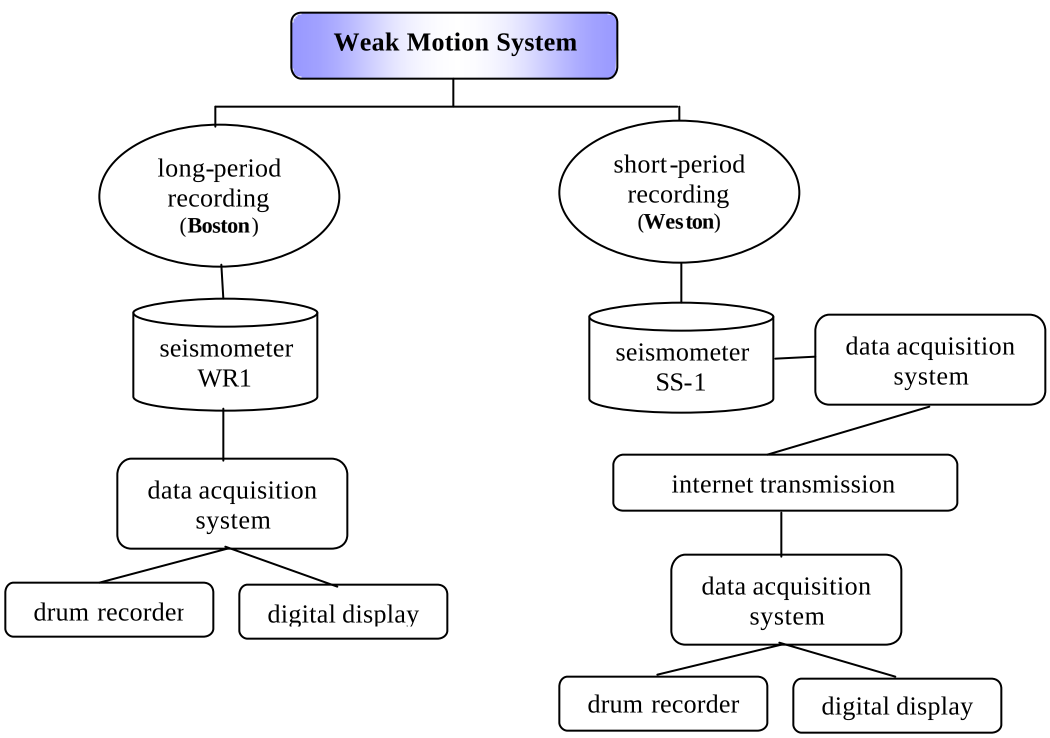


Figure 2. The long-period recording system (in Boston) and the short-period recording system (in Weston).

Long-Period Recording

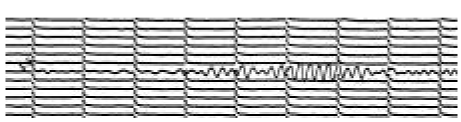
Long-period motions are monitored using a Kinematrics wideband Ranger, WR1 seismometer, placed in the basement of the Snell Engineering Center, located on Northeastern University's Boston campus. The high frequency motions emanating from nearby vehicular and transit operations are filtered allowing clear recording of long-period motions from worldwide earthquakes. The resulting data is first saved electronically, then digitally displayed on a monitor and recorded on a drum (both of which reside in the lobby of the Snell Engineering Center), and finally, the record is posted on the station's web site. The technical details of the seismometer are presented below in Figure 3.

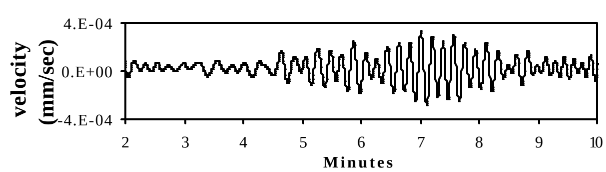
Sensitivity	160 V/m/s @ 0.05-20 Hz ± 2.5V / ± 0.01g @ 0-20 Hz
Natural frequency	20 Hz
Critical damping ratio	70%
Output	± 2.5 V
Dynamic range	125 dB @ 0.1-10 Hz
Power	± 12 Vdc, 14 mA
Weight	10.9 lb
Dimensions	5.5" diameter x 12" height
Housing	Cast aluminum

(a) (b)

Figure 3. The wideband ranger WR-1 seismometer (a), and the recording drum (b) used for monitoring long-period motions from worldwide earthquakes.

Figure 4 shows typical drum and digital records obtained by the long-period WR1 seismometer. The record shown below corresponds to data collected from an earthquake that occurred on September 18, 2004, referred to as the North Atlantic Ocean earthquake, (M = 5.7), and with its epicenter located about 2200 km south of Boston.





(a) drum record (b) digital record

Figure 4. The drum and digital records of the earthquake of September 18, 2004, (M = 5.7), recorded by the long-period WR-1 seismometer.

Short-Period Recording

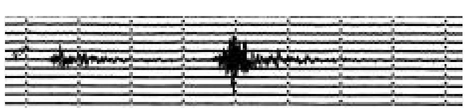
The short-period motions of an earthquake are recorded using Kinematrics SS-1 seismometer (Figure 5). Due to the level of high frequency ambient vibrations present on the Boston campus, the SS-1 seismometer is located in the basement of Henderson House, owned by Northeastern University, in the town of Weston, 25 km west of Boston. The seismometer is secured on bedrock and records high frequency motions from local small events as well as large worldwide events. The SS-1 seismometer is digitally monitored by a PC stationed next to the seismometer. The data collected is then transmitted, via Internet, to the Boston campus where it is digitally saved and displayed on a drum recorder located in the Snell Engineering Center.

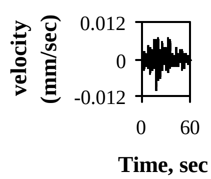
Natural frequency	1 Hz
Critical damping ratio	70%
Power	none
Weight	10.9 lb
Dimensions	5.5" diameter x 12" height
Housing	Cast aluminum

(a) (b)

Figure 5. The short-period seismometer Kinematrics SS-1 located in Weston (a), and the recording drum displaying the record at the Boston campus (b).

Figure 6 shows the record obtained by the short-period SS-1 seismometer from the September 18, 2004 earthquake (M = 5.7), referred to previously.





(a) drum record (b) digital record

Figure 6. The drum record (a) and the digital record, for a 1 minute period of the main pulse of the earthquake that occurred on September 18, 2004 (b). The records were obtained by the short-period SS-1 seismometer located in Weston, Massachusetts.

2. Strong Motion Array

General Description

The primary research goals for the strong motion array of NUSRS are: 1) to record and evaluate the characteristics of rock motions in New England, and 2) to determine the influence of a deep deposit of clay (in particular Boston Blue Clay) on the earthquake rock motions generated in New England.

The strong motion array consists of borehole accelerometers and a surface accelerometer installed adjacent to the Dana Engineering building at Northeastern University's Boston campus (Figure 7). The instruments are connected through underground cables, and through Dana and Snell Engineering buildings to a central recording system.

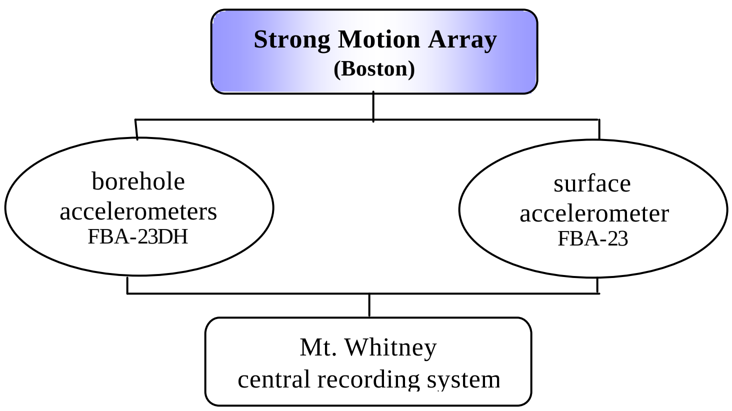


Figure 7. Components of the strong motion array on the Boston campus.

Figure 8 depicts the arrangement of the strong motion array and the soil profile. The soil profile at the location of the array is typical for Boston which has a deep deposit of clay commonly known as Boston Blue Clay.

The original plan called for the installation of three borehole accelerometers. The accelerometers were to be installed in the bedrock, and in the middle and top of the clay layer, as shown in Figure 8. Although three boreholes were drilled, cased, and wired to the central recording system, due to shortfall of funds only two borehole accelerometers were purchased and installed (the one in the bedrock and that at the top of the clay layer). The borehole with its tip in the middle of the clay layer (97 feet below the ground surface) is ready to receive the third accelerometer when funds are made available.

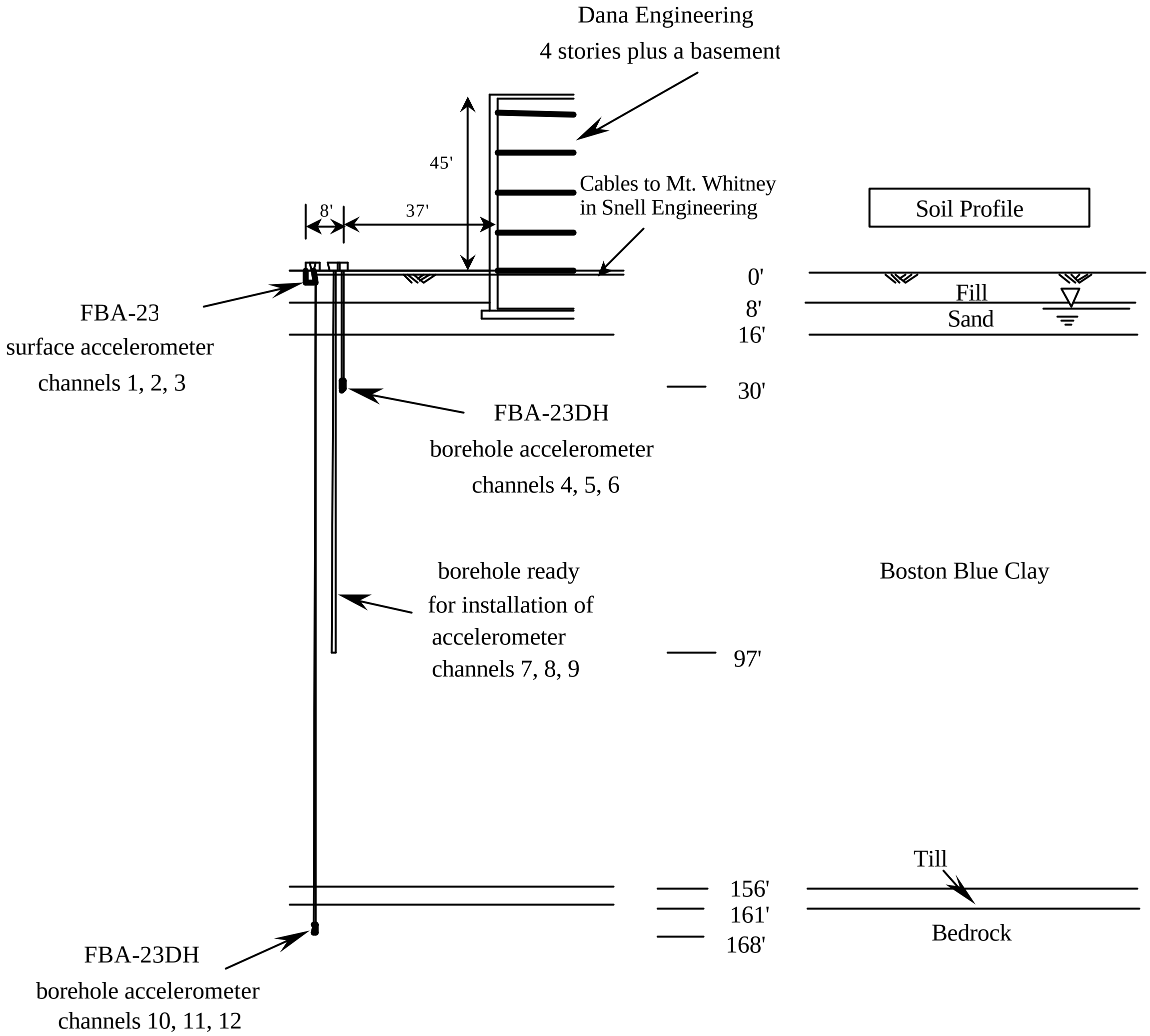


Figure 8. Details of the strong motion array and the soil profile.

The location of the array is 37 feet from the Dana Engineering building, which is a four-story structure with one basement floor. Dana Engineering building is directly connected to Snell Engineering Center, where NUSRS is housed.

Figure 9(a) is a photograph of the location of the strong motion array. The array is immediately behind the gazebo. Dana Engineering building is to the right of the gazebo. Figure 9(b) shows a closer look of the array location where the four terminal boxes are that house the casing tops of the borehole accelerometers and the surface accelerometer. The university maintains the landscaping of the array site. The granite plaque seen in Figure 9(b) identifies the location of NUSRS, and recognizes its sponsors.

(a) (b)

Figure 9. The strong motion array located just behind the gazebo on Northeastern University's Boston campus (a). The location of the four terminal boxes and the dedication granite plaque (b).

Soil Profile

Northeastern University's Boston campus was an ideal location for the installation of the strong motion array because it fulfilled the basic requirements of the intended goals. The campus is located atop a thick layer of Boston Blue Clay. The university was able to offer the logistical support required by this endeavor, and to provide a substantial amount of data on subsurface soil conditions throughout the campus. This data had been collected, over the years, from various building construction sites and reflects measurements gathered from test borings, test pits, and the installation of ground water wells. Based on the data obtained from these explorations, the subsurface soil profile of the strong motion array region is described in Figure 10.

Soil Layer Description	Layer Thickness	SPT, average blow count
Fill: *Matrix of sand with varying amounts of silt and gravel intermixed with ash cinders, brick, wood, steel and concrete concrete slabs and remains of previous buildings and foundations*	8 to 10 ft.	12 - 41
Sand: *Outwash sand consisting of compact gravelly sand with varying amounts of silt*	8 to 9 ft.	22 - 55
Boston Blue Clay: *Marine clay consisting of gray silty clay, stiff at the top and becoming softer with depth*	140 to 150 ft	10 - 18 (top 10 ft.) 6 - 10 (below 10 ft.)
Glacial Till:	5 to 10 ft.	> 100
Bedrock: *Shale*	165 to 175 ft. below ground surface	cored

Figure 10. Details of the soil profile at the strong motion array site.

Accelerometer Details

The two borehole accelerometers that were installed are Kinematrics FBA-23DH. Each unit consists of three force-balance accelerometers mounted orthogonally in a rigid internal frame (Figure 11). An electronic compass was mounted inside the accelerometer frame to provide information about the orientation of the accelerometer after deployment. The electrical connections were made with the use of a waterproof cable and a connector assembly.

Full scale range	± 0.5 g
Natural frequency	50 Hz
Critical damping ratio	70%
Output	± 2.5 V
Dynamic range	130 dB @ 0-50 Hz 140 dB @ 0-10 Hz
Power	± 12 Vdc, 2.5 mA per axis
Weight	13.25 lb
Dimensions	3" diameter x 18-3/4" height
Housing	Stainless steel

Figure 11. Kinematrics FBA-23DH downhole accelerometer and technical specifications.

The surface accelerometer is an FBA-23 unit that consists of three force-balanced accelerometers mounted orthogonally, in a 2.75" x 5.5" x 5.5" watertight aluminum cast housing (Figure 12).

Full scale range	± 0.5 g
Natural frequency	50 Hz
Critical damping ratio	70%
Output	± 2.5 V
Dynamic range	135 dB @ 0.01-50 Hz 145 dB @ 0.01-20 Hz
Power	± 12 Vdc, 2.5 mA per axis
Weight	5.2 lb
Dimensions	2.75"x5.5"x5.5"
Housing	Cast aluminum

Figure 12. A photograph of the Kinematrics FBA-23 surface accelerometer and its technical specifications.

The surface accelerometer and the top of each borehole accelerometer are enclosed in a watertight, stainless steel, protective boxes that are secured on top of concrete pedestals (shown in Figure 13).

(a) (b)

Figure 13. Four watertight stainless steel terminal boxes (a), one encases the surface accelerometer and three encase the three boreholes. An inside view of a stainless steel terminal box (b) .

Central Recording System

The accelerometers are wired through underground cables that extend through the Dana Engineering building to the directly connected Snell Engineering Center where a central recording system (Kinematrics, Mt. Whitney) monitors the array. Figure 14 shows the specifications of the Mt. Whitney system that monitors the strong motion array.

Data acquisition resolution	19 bits @ 200 sps
Dynamic range	110 dB @ 200 sps
Input range	± 2.5 V
Anti-aliasing filter	Brickwall FIR filter
Storage unit	20 MB Memory Card
Storage capacity	25 minutes from all 18 channels
Power Supply	12 Vdc. Two batteries Model LCL12V38P (Panasonic)
Battery capacity	Operates 50 hours
Weight	100 lb
Dimensions	20"x17"x24"
Housing	Type NEMA 12

Figure 14. The Mt. Whitney central recording system and the technical specifications.

Mt. Whitney is a multichannel central recording station that acquires and stores data from the downhole and surface accelerometers. It can record up to 18 channels of acceleration at 19-bit resolution. Mt Whitney is connected to a computer that records events and allows for the manipulation of data using the Quicktalk and Quicklook programs. It can also be reached via a modem to retrieve data remotely.

Further details and photographs of the strong motion array and its installation can be found on the NUSRS web site (http://www.dac.neu.edu/nueerl/). The installation of the accelerometers, the alignment of their compass orientations, and the connection of the system to Mt. Whitney were all completed by personnel from Kinematrics.

The strong motion array has been functioning efficiently. While the array continuously monitors vibrations, the recording of the data from the accelerometers is initiated when the bedrock accelerometer is triggered. An example of a record obtained by the strong motion array is shown in Figure 15. This event, which is referred to as the Gulf of Maine earthquake (M = 3.6), occurred on July 22, 2003, northeast of Boston about 95 km from the strong motion array site. Records of channels 1 through 3 correspond to the longitudinal, vertical, and transverse components of the motion at the ground surface. Records of channels 4 through 6 correspond to the longitudinal, vertical, and transverse components of the motion near the top of the clay layer. Records of channels 10 through 12 correspond to the longitudinal, vertical, and transverse components of the motion at bedrock, 168 feet below the ground surface.

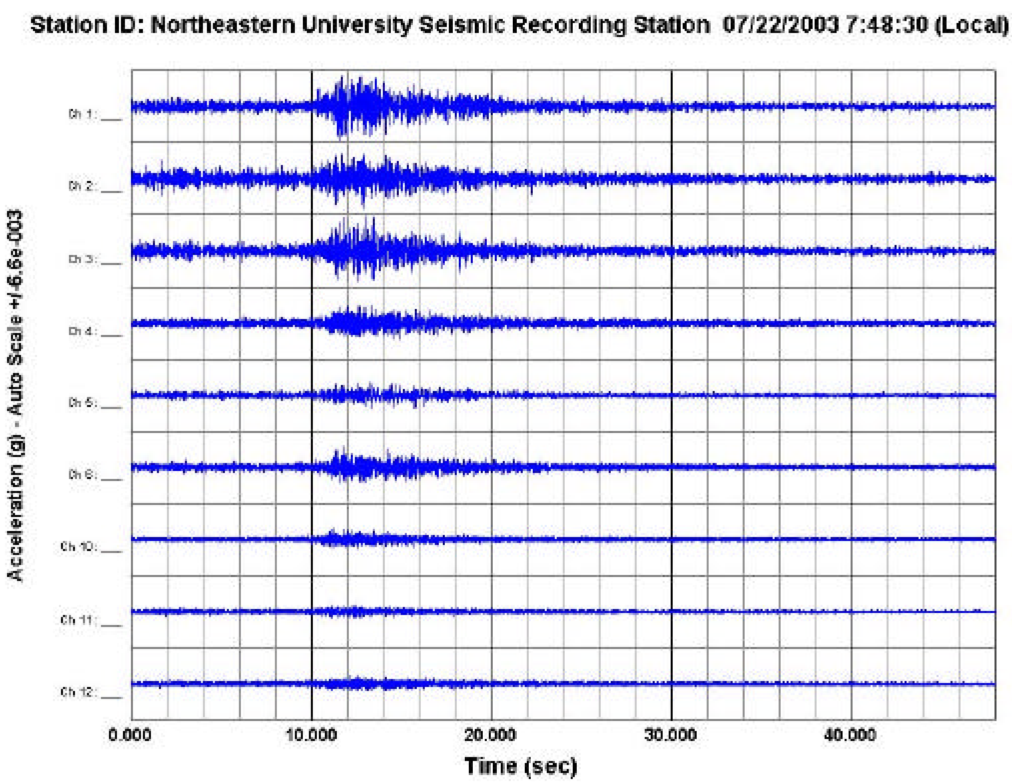


Figure 15. Nine channel-records obtained from the surface and two borehole accelerometers of the July 22, 2003, Gulf of Maine earthquake.

Analysis of the records showed that the peak horizontal acceleration at the bedrock level was about 0.0012g. The peak horizontal accelerations at the top of the clay layer and at the ground surface were about 0.0036g and 0.006g, respectively, indicating significant amplification of the microtremor rock motion. These records are currently being analyzed to assess their frequency characteristics and the influence of the clay on the ground motions.

3. Portable Accelerometers

The NUSRS includes two portable digital accelerometers (Kinematrics K-2) as described in Figure 16.

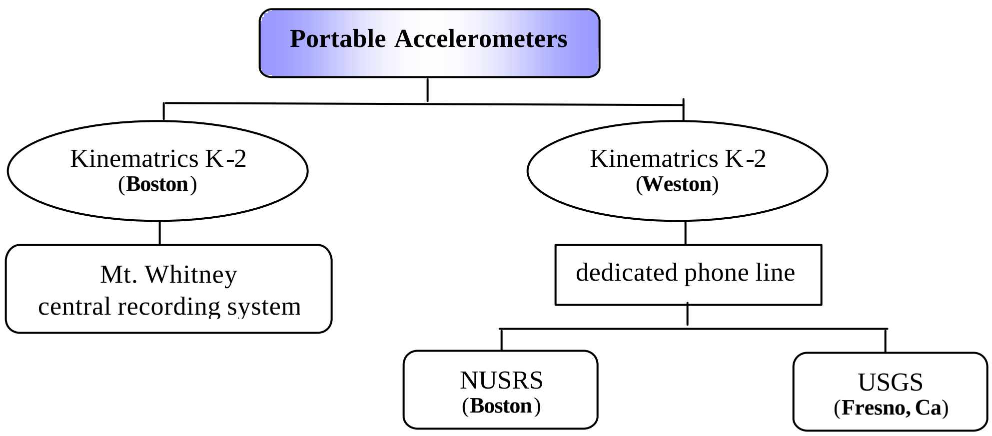


Figure 16. The locations of two Kinematrics K-2 triaxial portable accelerometers.

The first K-2 accelerometer is owned by Northeastern University and is located in the basement of the Snell Engineering Center at the Boston campus. The building is a five story, steel frame structure, on shallow foundations over the same soil profile as that shown for the strong motion array (Figure 8). This K-2 accelerometer is monitored to record earthquake motions in the basement of the building so that they may be compared with those recorded in the free field for the purpose of assessing soil-structure interaction effects in a building resting on a deep deposit of clay.

In 2002, as part of the National Strong Motion Program, the USGS, from Fresno, Ca installed a K-2 accelerometer in the basement of Henderson House located in Weston, Massachusetts. The purpose of this second K-2 accelerometer is to record accelerations at outcropping of rock near Boston. This K-2 accelerometer is connected to a dedicated telephone line that allows USGS and NUSRS direct access to the information when available.

A K-2 accelerometer contains a triaxial force-balance accelerometer within a protective casing. It can be connected to an AC power source or used in the field by way of its internal battery, which provides operations for 36 hours. The data is saved on an internal memory card that can be downloaded using Mt. Whitney. Figure 17 provides detailed specifications of the portable K-2 accelerometer.

Data acquisition type	Over-sampled delta sigma system with 24 bit DSP
Dynamic range	110 dB @ 200 sps
Input range	± 2.5 V
Anti-aliasing filter	Brickwall FIR filter
Storage unit	6 MB Scan Disk
Power Supply	12 Vdc.
Battery capacity	36 hours
Weight	24 lb
Dimensions	10.1"x15"x7
Housing	Lexan structural foam housing internally coated with EMI/RFI shielding material.

Figure 17. Technical specifications of the portable Kinematrics K-2 accelerometer.

4. Multimedia Center

The multimedia center was created so that the Seismic Recording Station could achieve its intended educational, public awareness, and outreach goals. The NUSRS multimedia center has been a major attraction on Northeastern University's campus.

Figure 18 shows the different components of the multimedia center.

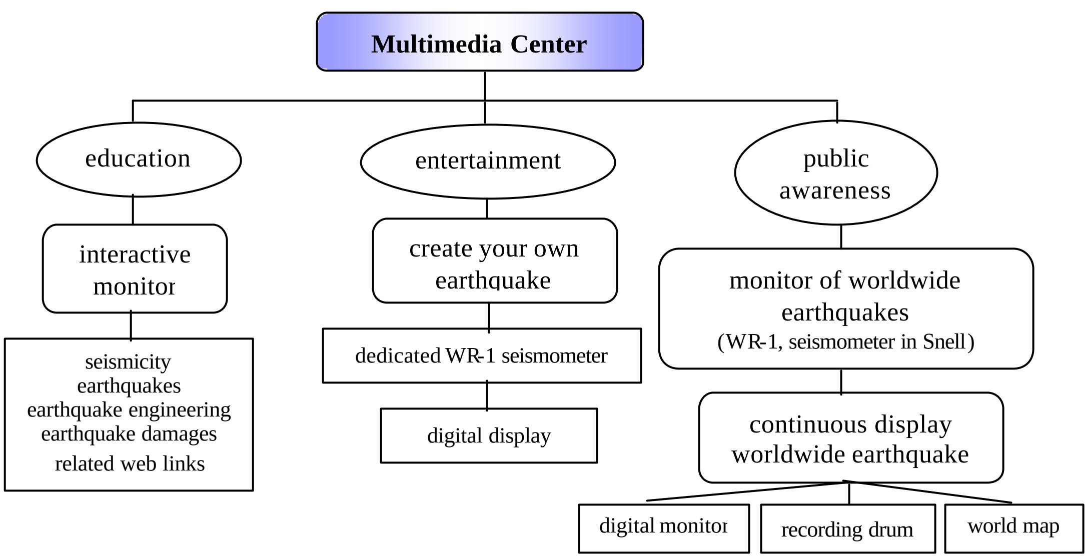


Figure 18. The various components of the multimedia center used for education, entertainment, and public awareness purposes.

The center displays weak motion records (digital and on a drum recorder) from worldwide events, demonstrates the P- and S-wave arrival times, and identifies the magnitude and the location of the event on a world map. The facility also invites people to create their "own earthquake" by taping their feet or jumping next to the display which has a duplicate Kinematrics WR-1 seismometer (Figure 19). Finally, a computer monitor provides educational information on seismicity, earthquakes, and earthquake damages, and can be used to link to other useful web sites.

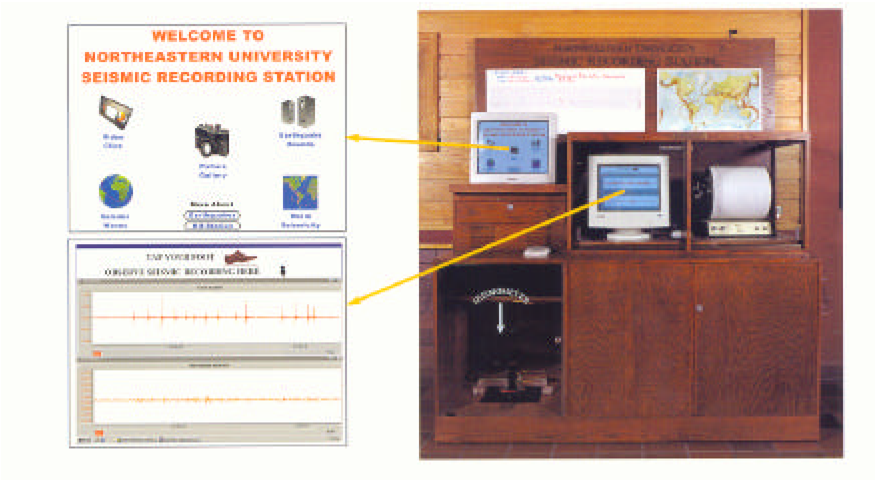


Figure 19. The multimedia center located in the lobby of Snell Engineering Center.

FUTURE OF NUSRS

The Seismic Recording Station at Northeastern University was conceived to support unique educational, research, and outreach activities. It has been a valuable resource to many, including undergraduate and graduate civil engineering students, the university at large, its alumni, and local middle school and high school students, teachers, and media. NUSRS is operated by Professor Mishac Yegian with the help of a graduate student who is supported by the Department of Civil Engineering. Through a recent generous donation by Mr. Peter J. Ogren, President of Hayes Engineering Inc., (the original donor who initiated the establishment of the seismic recording station), an endowment fund was established to cover the cost of essential supplies and maintenance needs of the station.

At the present time, strategic plans are being formulated to address the long-term needs for maintenance, operation, and replacement of the equipment of NUSRS. It is imperative that such a plan includes external financial support for a graduate student and for repair and replacement of major equipment, in particular, the strong motion accelerometers. To ensure sustainability of NUSRS, one option is to explore the possibility of expanding and integrating the strong motion components of NUSRS within the Advanced National Seismic System (ANSS). We at Northeastern University have the experience and the logistical support to assist in the development, establishment, maintenance, and operation of strong motion arrays in the greater metropolitan Boston. We look forward to participation in potential opportunities in national and regional programs aimed at enhancing capabilities for recording strong motions in the metropolitan cities of the northeastern United States.

SUMMARY

Through generous support from its alumni, Northeastern University has established a Seismic Recording Station (NUSRS), which has a unique mission to integrate educational, research, public awareness, and outreach activities. The station includes weak motion instruments as well as a strong motion array. We record and display seismic motions for scientific use as well as for public education through a multimedia center located in the Snell Engineering Center on the Boston campus. This paper describes the mission, the various components, and the instruments of NUSRS. Example records recently obtained by the station are also presented. We look forward to future opportunities to expand the station's strong motion array to include additional instruments on the Boston campus, as well as at other sites and in additional buildings in Metropolitan Boston. We also hope to integrate its activities in future national and regional seismic instrumentation programs.

ACKNOWLEDGMENTS

The Northeastern University Seismic Recording Station was established through a generous donation by Mr. Peter J. Ogren, President of Hayes Engineering, Inc. We would also like to acknowledge the generous contributions of Mr. George E. Panitsidis, and Mr. Andreas Bardis, of Athens, Greece, and the continuous support of the Civil Engineering Department for the operation of the station.

The establishment of the NUSRS, as well as its maintenance and operation could not have been possible without the invaluable support of the following Northeastern University Civil and Environmental Engineering laboratory personnel and graduate students: Ghahraman, V., Whelpley, D., Kaklamanis, A., Kadakal, U., Catan, M., Yakut, A., Corbett, C., Malkoc, E., Petrin, T., Hall, T., Ozgu, S., Ali, S., and Eseller. E.