Estimating Earthquake Losses for the Greater New York City Area

by Andrea S. Dargush (Coordinating Author), Michael Augustyniak, George Deodatis, Klaus H. Jacob, Laura McGinty, George Mylonakis, Guy J.P. Nordenson, Daniel O’Brien, Scott Stanford, Bruce Swiren, Michael W. Tantala and Sam Wear

Research Objectives

The goal of the project is to use the federally sponsored loss estimation software, HAZUS (Hazards–U.S.), to project the magnitude of potential losses that might be experienced by the metropolitan New York City area as a consequence of a damaging earthquake. After modification of the default HAZUS datasets for soil and building characteristics, a more credible estimation of losses will emerge and be useful to metropolitan emergency personnel, as well as to other public and private stakeholders. It is hoped that the results will contribute to improved disaster mitigation and emergency response plans throughout the area.

The metropolitan New York-New Jersey region is vulnerable to several potential natural disasters. Ice storms, snow, and other severe weather events such as hurricanes, associated storm surges, and flooding, foot-and-mouth, and the West Nile virus are among those of current concern and prominent public attention. After adding such man-made disruptions as terrorism and hazardous materials releases, and the hazards posed by decaying infrastructure and aging buildings, earthquakes seem a dim prospect. But however unrecognized or unacknowledged the threat from earthquakes may be in New York City, seismic events have occurred and, until recently, no codes have existed to mandate earthquake strengthening of structures. Statistics indicate that potential losses to a large urban area such as New York would be considerable. According to Scawthorn and Harris (1989), the economic impact of a damaging earthquake (e.g., M6.0) in New York would be in the billions of dollars due to direct structural and architectural damage, and does not reflect additional impacts on building contents, business continuity, fire suppression and human safety. An earthquake in the greater New York area would thus be considered a low-probability, yet high consequence event. Credible estimates of future loss can be effective tools to encourage area stakeholders to mitigate against the possible future damaging consequences of earthquakes.

HAZUS U.S. (HAZUS) is a standardized, nationally-applicable loss estimation tool, developed by the Federal Emergency Management Agency (FEMA) in cooperation with the National Institute of Building Sciences. The HAZUS software utilizes geographic information systems, such as
ArcView and MapInfo, to produce detailed maps and analytical reports that describe a community's potential losses. The current version applies a uniform engineering-based loss estimation approach to quantify damages, economic losses and casualties resulting from earthquakes. Future adaptations are intended to carry out similar analyses for hazards such as flooding and high wind.

Similar loss modeling studies have been conducted in the New York area in past years to examine the impact of flooding and hurricanes, and have been used to guide emergency plans. Recognizing the potential collective benefits of a regional study, mitigation specialists at FEMA Region II, the New York State Emergency Management Agency (NYSEMO), the New Jersey State Police Office of Emergency Management (NJOEM) and the New Jersey Geological Survey joined together to develop a similar loss estimate for earthquakes. With NYSEMO and NJOEM, a FEMA-supported project was initiated in 1998 to apply HAZUS to the greater New York City area. A regional consortium has been formed - the New York City-area Consortium for Earthquake-loss Mitigation (NYCEM). MCEER was selected to provide general coordination of the activities and to conduct outreach activities to promote the outcomes of the project. The purpose of the consortium is to help develop the necessary databases to effectively utilize the loss estimation program HAZUS to identify potential economic loss to the greater New York City area as a consequence of a damaging earthquake. In the latter stages of Year 2, increased attention was given to inclusion of information on critical facilities, to assess post-event functionality. The consortium consists of public agency officials, business owners, emergency managers, engineers and architects, utility owners and other area stakeholders. Researchers at Lamont-Doherty Earth Observatory, Princeton University, and the City College of New York work together to develop soils and building stock inventories which can be used to refine the default data contained within HAZUS. The data will be used in future executions of HAZUS and will assist researchers in refining their ultimate loss estimations for New York.

These studies are being complemented by information generated by similar studies for Westchester County, New York and for a number of counties in New Jersey. A generalized HAZUS analysis will provide a regional picture of potential earthquake damage and loss.

These assessments will ultimately be used to encourage and promote earthquake mitigation action at the local, regional and statewide levels.

**Technical Summary**

After preliminary explorations of available data and its transferrability...
to a HAZUS format, the NYCEM team prioritized its efforts, focusing on the development of a database of geologic and building information for Manhattan below 59th Street. As the project progressed, additional stores of data became available that allowed expansion of the study to the entire borough. In the current Year 3 of the project, results of the Manhattan study will be merged with those of parallel studies being carried out in New Jersey and Westchester County, New York, for extrapolation to a larger region covering about 31 counties in New York and New Jersey. The respective activities of the team members and the parallel studies are described in the following section. Priorities, methodologies and progress of the NYCEM team have benefited from periodic technical advisement from a panel of experts in earthquake engineering and loss modeling.

Lamont Doherty Earth Observatory (LDEO)

Based on extensive prior research, the LDEO team, led by Klaus Jacob, realized from the outset that the default soils data within HAZUS did not accurately reflect the subsurface conditions of the Manhattan area. Near surface geologic differences can introduce local variations in shaking that can influence both the amplitude and spectral composition of ground motions, thus impacting structures and lifelines.

It would be a challenge to the team to upgrade the data to produce the needed NEHRP geotechnical site classes at an individual Manhattan census tract level (Jacob, 1999). Pre-existing geologic studies were geographically limited and not specific enough to derive important information on depth to bedrock. Other subsurface data collected in the form of borehole logs, were collected by private developers or other entities, holding the data as proprietary.

Using information provided by the New York City Department of Design and Construction, data from 150 geotechnical borings for lower Manhattan were studied in the first year of the project. Using casing information and results from the standard penetration tests (SPT) conducted, it was possible to derive shear wave velocity profiles as a function of depth at each location, then translated into the appropriate NEHRP site class. Some 200 other older borings were available, but only offered information on depth to bedrock.

To classify the overlying soils, a shear wave velocity vs. depth function was derived from a subset of the initial 150 borings and applied to generate point values at the 200+ sites. The resultant classifications were primarily NEHRP soil types D and C. Surprisingly, no class A (very hard rock) sites emerged, although numerous B (firm rock) sites were identified. Several individual borings indicated class E conditions. However, the conditions were not sufficiently continuous throughout the census tract to merit assignment of E to the tract.

This may be a pervasive problem associated with the census tract approach to geological classification. These differences in soil type from the default assignments resulted in apparent reductions of the total loss estimations for buildings
The NYCEM project is primarily linked to MCEER outreach efforts to increase awareness and acknowledgment of earthquake risk and the value of loss estimation methodologies as mitigation tools.

Data collected from the project may benefit ongoing projects focusing on earthquake risk to critical facilities in areas of low-to-moderate hazard but with high collateral damage.

Future phases of the project will likely benefit from MCEER lifeline research which has led to improvements in HAZUS treatment of buried pipeline systems.

by factors of 0.7, 0.72 and 0.8 for scenario events of \( M_w 5.0, 6.0, \) and 7.0, respectively. Additional refinement of the shear wave velocity functions made possible with added calibration borings may be reflected in future loss estimates.

In Year 2, additional refinement of the lower Manhattan study area was made possible by the inclusion of additional data provided by the Metropolitan Transportation Authority/New York City Transit Authority. The study area was also expanded to include the entire borough of Manhattan. In spite of the additional information, data density was greatest for midtown and lower Manhattan and sparse for areas north of 137th St.

Modifications were made to the methodology developed in Year 1 to reflect consideration of the NEHRP 10-foot rule, which assigns site category E to any soil profile that contains a continuous ten-foot thick layer of very soft soils (Jacob, 2000). Additional study also led to the increase in the calculated shear wave velocity for bedrock at the bedrock/soil interface, better reflecting the prevailing rock formations in the area. Site classes for all DDC borings in Year 1 were recalculated under these assumptions.

A primary product in Year 2 is a census-tract based soil map for the entire borough, which can be used in validating results, generated by HAZUS. Figure 1 describes the distribution of soil/rock types across the island, with higher elevations in uptown Manhattan on stiff rock/soil (Class B), intermediate type C in Midtown, and soft soil (Class D) in lower Manhattan, along the identified fault zones in Upper Manhattan and in low-lying, coastal areas. An anticipated product of this effort will be the development of a contoured soils map for Manhattan. This will allow more accurate extrapolation of census-tract specific geotechnical characteristics.

An important Year 2 activity was the coordination of approach to classification of soils among the New York City, New Jersey and Westchester County study areas. With input from members of the NEHRP Seismic Provisions Geotechnical Subcommittee and the Building Seismic Safety Council, a uniform methodology was derived to assure that assumptions used to assign NEHRP soil class types are, to the extent possible in agreement with the objectives of the NEHRP guidelines. There was
general consensus that the information needed to accurately assign NEHRP classes is often unavailable and that in view of other inherent uncertainties within the HAZUS algorithm, it should not unduly impact results.

The HAZUS algorithm is designed to execute loss estimations using both deterministic and probabilistic earthquake inputs. Using historical local seismic events, the LDEO team also provided the epicentral locations for scenario earthquake events to be used in the deterministic HAZUS executions.

Princeton University

New York City has one of the highest concentrations of high rise buildings per square foot than any other city. Unreinforced masonry structures housing businesses, architectural treasures, masonry fire stations, theaters and art galleries, apartment buildings, and more, stand shoulder to shoulder with these skyscrapers.

Many New York structures hold historical status and many more were constructed without the guidance of a seismic building code. Before 1996, earthquakes were not a design consideration although as construction progressed in the 20th century, wind load factors were being incorporated, thus addressing (albeit coincidentally) some of the horizontal displacements that might be experienced during an earthquake.

Even today, seismic statutes apply to new construction only. Consensus opinion is that retrofitting thousands of New York buildings to meet seismic standards is impractical and economically unrealistic. It is therefore even more important to accurately identify areas of highest potential vulnerability to earthquake ground shaking so that mitigation, emergency response and recovery approaches can be strengthened.

In HAZUS, the default building inventory is categorized by occupancy (commercial, residential, industrial, governmental, educational, religious, agricultural), model building type (e.g., steel, reinforced concrete, wood, masonry), structural configuration and height. HAZUS also makes other assumptions about typical percentage distribution of buildings within a census tract by age, quality (inferior, built to code, superior) seismic design level (low, moderate and high) and height. The NYCEM team at Princeton University (Guy J. P. Nordenson, George Deodatis, Michael Tantala and Amanda Kumpff) recognized the obvious disparities between the typical suburban building inventory presented in HAZUS and the actual structural characteristics of New York. Such disparities would ultimately affect the accuracy of damage and loss scenarios to be generated by the program.

One of the objectives of the studies being carried out at Princeton is to develop a credible building inventory for the New York City area, which will be more representative of its wide mix of structures. Various damage and loss scenarios would then be carried out, using both the improved building data and the soils data provided by the LDEO team.

In Year 1 of the study, the team used Sanborn fire insurance map data (building height, size, location, occupancy and type) and visual inspection to modify building inventories for two representative

### Web Sites

- **New York City-area Consortium for Earthquake Mitigation:**
  - [http://www.nycem.org](http://www.nycem.org)

- **Federal Emergency Management Agency HAZUS:**
  - [http://www.fema.gov/hazus](http://www.fema.gov/hazus)

- **Westchester County GIS:**
  - [http://giswww.co.westchester.ny.us](http://giswww.co.westchester.ny.us)
census tracts – Wall Street (primarily commercial) and Kips Bay (primarily residential) (Nordenson et al., 2000). Broader regional studies examined New York below 59th Street, and the 31 county, New York-New Jersey area. HAZUS runs were then carried out to assess the sensitivity of the methodology to changes in building inventory data. Dramatic differences in loss estimates emerged, particularly when using smaller magnitude earthquakes. Total loss estimates in the modified runs differed significantly from those of the default (in some cases more than a factor of ten). Based on the runs, it appears that the most sensitive building information for refined loss estimations might be square footage and height, and not structural type, as previ-
ously assumed. This will require further validation.

With assistance from Dr. Jack Eichenbaum, New York City Assessor, the Princeton team acquired valuable building data from the New York City Department of Finance. The Mass Appraisal System (MAS) data consists of over 2 million property entries for the entire city, including such information as parcel square footage, address, height, use, building footprint dimensions, construction year, quality, and architectural style (Tantala et al., 2001).

The year 2 studies used this information to further refine the building inventory, although geocoding of entries was needed to match information to the appropriate census tract. In addition the richness of the MAS data required simplification to fit into the HAZUS categorization scheme.

In contrast, the MAS construction type data required addition of more specific information. Field surveys were carried out with the City College team and were used to validate some of the existing data as well as some of the associated assumptions being made. Additional data sources from local engineers, Dun and Bradstreet business databases, aerial photography, existing structural drawings and other sources helped to further validate the new database.

After thorough modification, the resultant MAS database included records for more than 37,000 buildings, or over 2.2 billion square feet of area. Figure 2 shows the relative distribution of the number of buildings in each of four category types for twelve Manhattan neighborhood districts, illustrating that unreinforced masonry is the predominant building type. This is not, however, reflected in the amount of square footage occupied by unreinforced masonry, which is perhaps a more important variable.

In the end, the Princeton team was able to establish the building inventory for the entire island of Manhattan, with HAZUS-required information at the individual building level. This is a unique accomplishment for HAZUS applications. With the assistance of Princeton student Evan Schwimmer, the database has been further enhanced with the addition of critical facilities data (hospitals, schools, and police and fire stations). Several preliminary probabilistic and deterministic HAZUS runs have been carried out using the critical facilities data to generate projected functionalities of schools, hospitals, and police and fire stations, to assess their relative capabilities to provide shelter, provide emergency care and control conflagration. Casualties, population displacement and short- and long-term economic changes have also been projected. These are described in detail in the Year 2 report, which may be found at the NYCEM website.

These subsequent HAZUS (1999 and SR-16 versions) runs used the improved building inventory and further verified the need for improved data sources for buildings and soils to derive credible damage, loss and casualty estimates.

**Westchester County, New York**

Under sponsorship of the New York State Emergency Management Organization, a collaborative study was carried out in Westchester County, New York. The study evalu-
ated the applicability of the HAZUS default datasets, and made appropriate modifications to the extent possible.

Considerable effort was dedicated to data collection and to the updating of the HAZUS datasets, in particular additions of information on essential facilities (McGinty and Wear, 2001). Important new coverages were included for such facilities as day care centers and senior housing. Additional efforts were focused on the inclusion of information on essential facilities such as hospitals, schools, police and fire stations, and emergency medical services.

This led to the identification of shortfalls in county data availability and development of a strategy for future data creation. In the absence of borehole data, scientists at the New York State Geological Survey assisted by conducting seismic shear wave velocity tests on surficial soils within the county. Tests were conducted in locations of different NRC defined soil types so that a larger scale surficial soils map could be developed. Data was then extrapolated to a census tract level for necessary seismic soil classifications.

The Westchester study culminated in a HAZUS execution based on three earthquake scenarios. The goal of the study is to provide loss estimation data to the sponsor to enable development of a statewide mitigation approach for potential future earthquakes.

New Jersey

Under the oversight of Michael Augustyniak at the New Jersey Office of Emergency Management, studies were carried out by the New Jersey Geological Survey to define areas of seismic hazard. Building inventory data was collected for selected areas to upgrade HAZUS inventory data.

Geologic data were acquired and analyzed in order to compile maps of seismic soil class and liquefaction susceptibility for Hudson County, New Jersey (Stanford, 1999). The soil class and liquefaction susceptibility data were entered into the HAZUS model for each census tract in the county.

The HAZUS model was run with the upgraded geologic data and with the default geologic data for earthquake magnitudes of 5, 5.5, 6, 6.5, and 7. The upgraded building inventory data has not yet been included in the runs but is presently being processed by the Princeton team.

The upgraded geologic information produced significant changes in both the spatial distribution of damage and the total damage estimates. This increased building damage was particularly notable in the Hudson waterfront and Hackensack Meadowlands areas of the county, where soils are softer and more liquefiable than HAZUS default soil.

Building damage was less on the Palisades Ridge and on uplands in Kearny and Secaucus, where soils are stronger than the default. Because most building construction in the county is concentrated on these ridges, the total estimated building damage is somewhat less with the upgraded geologic data than with the default data at all magnitudes. Additional mapping and scenario executions have also been carried out in Bergen County, with Essex County underway.

In addition to the HAZUS data upgrades and scenarios executions,
shear-wave velocities were measured on the three softest soil types at nine locations. These were conducted to validate the soil class assignments used in the scenario executions, which use test-drilling data as a proxy for shear-wave velocities. The measured velocities confirmed the assignments. An additional 13 shear wave velocity measurements completed in Bergen County on four soil types indicate once again that the SPT data accurately proxy for shear wave velocities, except in gravel rich areas. These have faster velocities than SPT values suggest. Soil classes were adjusted accordingly in these areas.

**City College of New York**

To support the ongoing activities and to add some additional validation checks, MCEER provided support to George Mylonakis, CUNY, and his team of undergraduate engineering students to conduct field surveys of building inventory data. Their objectives were to assess the accuracy of both the default HAZUS building inventory data and to verify and benchmark the MAS data for two of three representative census tracts.

After initial training in HAZUS, the team carried out walking surveys of the Rockefeller Plaza census tract and a portion of the Kips Bay census tract. Buildings over a 10-block area were photographed, with data collected on frame type, exterior wall type, basement grade, construction quality, exterior condition, existing damage, HAZUS building code, and occupancy. These categories correspond to the required data fields within HAZUS (Mylonakis, et al., 1999). A total of more than 600 buildings were surveyed by the CUNY and Princeton teams.

Survey data was input into an ACCESS database and compared against the default data. The differences between the default and actual data were quite evident for the number of buildings and for the percentage of residential buildings. There is also a significant difference between the actual data and default data for the number of commercial buildings. The HAZUS dataset depicts a greater variety of building types within a census tract than actually exists. These led to further differences in loss estimations carried out for these areas.

To further validate the data sensitivity, the CUNY team generated HAZUS loss estimates for Kips Bay, Rockefeller Center and Wall Street census tracts (Mylonakis, 2000). The Wall Street tract data were collected by the Princeton team. Using a fixed location (1884 Rockaway Beach) scenario earthquake at varying magnitudes, the default and modified datasets were used to generate costs of structural damage. The 1999 version of the HAZUS software was used. The Princeton group conducted similar analyses using HAZUS version ‘97. Good agreement existed between the results generated by different versions of HAZUS.

**Outreach**

Several years after the passage of seatbelt legislation, drivers and passengers still disregard the need for simple protective actions. Convincing the public, the government and the private stakeholders in the northeastern United States of the

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need to prepare for an earthquake is a challenge not easily met. It has been an important objective of this project to convey that a low-probability event is a potential reality, carrying with it consequences for which the metropolitan area may be ill prepared.

The NYCEM project has taken advantage of numerous media opportunities to disseminate this information and to explain the importance of accurate inventories and loss characterizations to the development of mitigation strategies. The work has been featured in several articles in the New York Times and other area newspapers, has been the subject of a news focus piece on WNBC-News and has recently been prominently broadcast in the Discovery Channel program, “Earthquakes in New York?” The awareness campaign was further augmented by a minor tremor that struck midtown Manhattan, January 17, 2001 (see Figure 3). This attention, combined with the leadership of Bruce Swiren of FEMA Region II and Dan O’Brien of New York State Emergency Management, has helped to open dialogues with City and metropolitan area emergency managers about the importance of earthquake hazard mitigation.

In addition, conventional outreach activities have been carried out, targeted toward regional stakeholders who can both assist in refining the model through data provision, and can benefit from the enhanced loss estimation model. Workshops and briefings have increased their interest in the project and have led to sharing of information and data necessary to refine the default HAZUS data. Metropolitan transportation engineers are interested in being part of possible future studies that would include transportation lifelines in the model.

Project results are made widely available. A NYCEM website has been established by MCEER, which serves as a repository for technical reports, data and maps generated by the team. NYCEM results are reported regularly through the MCEER Bulletin and on the web, and several additional information briefings will be featured throughout the final year of the program. At the completion of the program, all data will be publicly accessible through a central repository.

Conclusions and Future Research

The study has revealed variances in HAZUS default data that would, left uncorrected, compromise its ability to accurately project potential losses due to a damaging earthquake. Loss quantifications generated by HAZUS have been found to be sensitive to variations

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*Figure 3. Epicenter of January 17, 2001 Manhattan Earthquake (courtesy of Dan O’Brien)*
in building inventory data, earthquake magnitude and local soil conditions.

In some cases, the damage and loss values generated were notably higher using default data than with the upgraded building and soils information. The data collection and modification activities have substantially enhanced the program’s ability to become a credible forecast instrument of economic impact.

These activities have also significantly improved the general knowledge base about New York area geology and have led to the development of a more comprehensive building inventory that can be used by others. In fact, it is notably the first database where the building inventory has been described in a building-by-building manner, which is not only unique, but quite valuable to future regional studies. The ability of the NYCEM team to build this information base is notable, since available data for such a complex and large urban area was difficult to identify and obtain. Surmounting this initial obstacle has been an important achievement of the project. Reconciling this information to the census-tract based approach of HAZUS has also been an intensive and challenging effort.

In an area of such vast and vital economic activity, it is paramount that any estimation of potential economic impact be based in well-founded data and analysis. While both the methodology, its inherent uncertainties, and its associated datasets have come under question, HAZUS is being utilized in other large urban areas with higher levels of seismic hazard as a tool to assist area planners, responders, and other stakeholders.

The studies conducted have established a foundation for more complete loss estimation studies for the greater New York metropolitan area. Additional data collection and study of regional lifeline systems, including water, gas and highway systems, will significantly enhance the risk characterizations that HAZUS can provide for the New York City area.

Further involvement by emergency responders, planners, builders, and health and human services officials will help improve the effectiveness of these studies. Accurate and complete fingerprints of risk, enabled by more widespread participation by other stakeholders, will ideally lead to the development of an acceptable damage and loss indicator that can be embraced by responders, builders and the public.

This goal has been encouraged as this study has progressed into its third year, as several presentations of results to municipal agencies has led to greater coordination, in particular with the New York City Office of Emergency Management and with officials in Westchester County.

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