NEW TOOLS FOR PREDICTING AND MITIGATING EARTHQUAKE IMPACTS BASED ON GROUND MOTION DATA

Charles A. Kircher, Ph.D., P.E.

Kircher & Associates
Mountain View, California

ABSTRACT

This paper describes the key features and components of the regional earthquake loss estimation methodology developed by the National Institute of Building Sciences (NIBS) with funding provided by the Federal Emergency Management Agency (FEMA). The FEMA/NIBS earthquake loss estimation methodology is intended primarily to assist emergency response planning and mitigation efforts of state, regional and local community governments. The FEMA/NIBS methodology incorporates state-of-the-art approaches for characterizing earthquake hazards, including ground shaking, liquefaction and land-sliding; estimating damage and losses to buildings and lifelines, estimating casualties, shelter needs and economic losses.

Of particular importance is the use of quantitative measures of ground shaking hazard (i.e., response spectra) in the estimation of building damage. Damage and loss are based on ground motion data, rather than on Modified Mercalli Intensity (MMI) commonly used by other earthquake loss estimation methods. While the FEMA/NIBS methodology was developed primarily for pre-earthquake planning purposes, the use of response spectra to predict damage makes the technology potentially valuable as a post-earthquake processor of near-real-time data from strong-motion networks such as the TriNet system. It is suggested that the FEMA/NIBS methodology be interfaced with strong-motion instrumentation networks to better assist post-earthquake response and recovery efforts. It is also suggested that predictions of earthquake damage and loss be used to assist locating strong-motion instruments in areas where buildings and other infrastructure are most at risk.

INTRODUCTION

With publication in 1972 of *A Study of Earthquake Losses in the San Francisco Bay Area* (Algermissen, et al., 1972), the federal government began to produce comprehensive estimates of the effects of major earthquakes on large urban regions. Direct economic losses, casualties, essential facilities' functionality, and some lifeline impacts were estimated. By the mid-1980's, similar studies had been produced for about dozen metropolitan areas in the United States, typically with more than one study for each area (FEMA, 1994). In general, these studies relied on predictions of Modified Mercalli Intensity (MMI) to estimate damage and loss.

The influential 1985 study, *Earthquake Damage Evaluation Data for California* (ATC, 1985), commonly referred to as ATC-13, used damage probability matrices based on expert opinion as its central framework. ATC-13 devised intensity-damage relationships for a large number of buildings and structure types, predicting a greater variety of losses than previous methods, and developed inventory relationships relating structure type and building occupancy. As in other methods, MMI remained the measure of ground shaking used to predict damage. However, in late 1980's the prestigious National Research Council's Panel on Earthquake Loss Estimation noted that,

> *more complex representations of ground shaking, for example, through a filtered "effective" peak motion, a single-degree-of-freedom linear response spectrum, a nonlinear spectrum, a time history of motion, and the duration of strong shaking, have the ability to be more accurate predictors of damage and loss.* (NRC, 1989).

The FEMA/NIBS methodology has addressed the Panel's comment by use of response spectra (rather than MMI) to characterize ground shaking and by use of building damage functions that include pushover analyses that parallel procedures used in engineering design and evaluation of actual buildings.

USERS OF EARTHQUAKE LOSS ESTIMATION

The FEMA/NIBS methodology "is intended primarily to provide local, state and regional officials with the tools necessary to plan and stimulate efforts to reduce risk from earthquakes and to prepare for emergency response and recovery from an earthquake" (NIBS, 1997). Different users will have different needs and the methodology has been programmed using GIS-based software (HAZUS) to be executed at different levels of analysis according to the user's ability to provide necessary data. At the lowest level, users rely on default databases supplied with HAZUS to make preliminary evaluations or crude comparisons among different study regions. More reliable results can be obtained when users have both the time and resources to develop additional data including such items as maps of site soil conditions or improved inventory data on building type, use and value.

Examples of pre-earthquake planning by local, state and regional government users includes development of earthquake hazard mitigation strategies (e.g., zoning or hazard abatement ordinances), development of preparedness (contingency) planning measures, and identification of response and recovery efforts. Federal government officials are now able to assess nationwide risk of loss from earthquakes. In the private sector, the methodology is available to building owners (e.g., large corporations) for identifying vulnerable structures and lifelines and to insurance and financial personnel for establishing appropriate premiums and loan criteria.

Example post-earthquake response and recovery applications include immediate economic impact assessments for state and federal resource allocation and immediate activation of emergency recovery efforts and long-term reconstruction plans. Immediate post-earthquake applications require that the study region to be developed prior to the event and that data be available describing the ground shaking that has just occurred. While ground shaking can be estimated based on event magnitude and location (of epicenter), the most accurate predictions of damage and loss would come from a detailed map of ground shaking based on instrumental measurements. In this sense, strong-motion networks, such as the TriNet system (Shakal et al., 1997) may be able to provide the rear-real-time strong-motion data necessary to make reliable post-earthquake estimates of damage and loss.

OVERVIEW OF THE FEMA/NIBS METHODOLOGY

The NIBS/FEMA earthquake loss estimation methodology is a complex collection of many components or modules (Whitman, et al., 1997). Modules are associated with either inventory, potential earth science hazards (PESH), damage (including both direct and induced damage) or loss (including both direct and or indirect economic impacts). Building-related modules (excluding inventory) of the FEMA/NIBS methodology and the flow of data between each is illustrated in Figure 1.

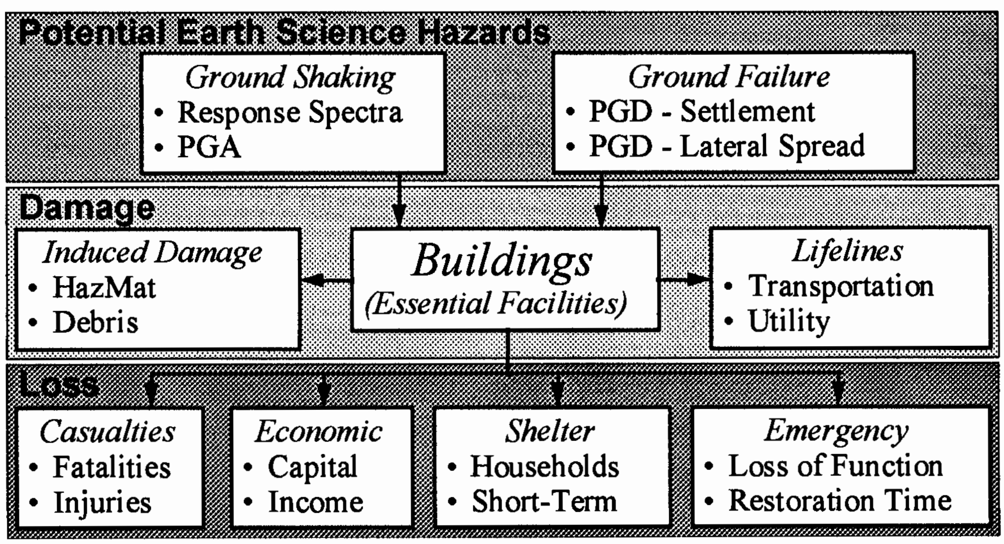


Figure 1. Building-related modules of the FEMA/NIBS methodology

Inputs to the estimation of building damage include ground failure, characterized by permanent ground deformation (PGD) due to settlement or lateral spreading, and ground shaking, typically characterized by response spectra, or, for those few buildings that are components of lifeline systems, by peak ground acceleration (PGA).

Estimates of building damage are used as inputs to other damage modules (e.g., debris generation), and as inputs to transportation and utility lifelines that have buildings as a part of the system (e.g., airport control tower). Most importantly, building damage is used as an input to a number of loss modules, including the estimation of casualties, direct economic losses, displaced households and short-term shelter needs, loss of emergency facility function and the time required to restore functionality.

The FEMA/NIBS building damage functions have two basic components: (1) capacity curves and (2) fragility curves. The capacity curves are based on engineering parameters (e.g., yield and ultimate levels of structural strength) that characterize the nonlinear (pushover) behavior of different model building types. For each building type, capacity parameters distinguish between different levels of seismic design and anticipated seismic performance. The fragility curves describe the probability of damage to a model building's (1) structural system, (2) nonstructural components sensitive to drift and (3) nonstructural components (and contents) sensitive to acceleration. For a given level of building response, fragility curves distribute damage between four physical damage states: Slight, Moderate, Extensive and Complete. A more thorough description of the FEMA/NIBS building damage functions is given below and in a recent *Earthquake Spectra* paper (Kircher, 1997a).

Earthquake loss due to building damage is based on the physical damage states that are the most appropriate and significant contributors to that particular type of loss. The number of buildings in the Complete damage state, which includes the kind of partial and complete collapse most likely to cause fatalities, heavily influences deaths. In contrast, direct economic loss (e.g., repair/replacement cost) is accumulated from significant loss contributions in all states of structural and nonstructural damage.

BUILDING DAMAGE FUNCTIONS

Buildings are classified both in terms of their use, or occupancy class, and in terms of their structural system, or model building type. Damage is predicted based on model building type, since the structural system is considered the key factor in assessing overall building performance, loss of function and casualties. Occupancy class is important in determining economic loss, since building value is primarily a function of building use (e.g., hospitals are more valuable than most commercial buildings, primarily because of their expensive nonstructural systems and contents, not because of their structural systems).

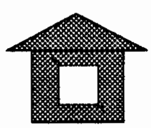
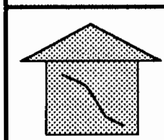
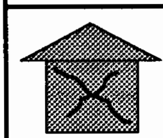
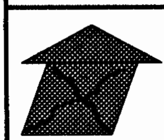
Twenty-eight occupancy classes distinguish among residential, commercial, industrial or other buildings, and 36 model-building types classify buildings within the overall categories of wood, steel, concrete, masonry or mobile homes. Building inventory data relate model building type and occupancy class on the basis of floor area, so that for a given geographical area the distribution of the total floor area of model building types is known for each occupancy class.

Model building types are derived from the classification system of the *NEHRP Handbook for the Seismic Evaluation of Existing Buildings* (FEMA, 1992), expanded to include mobile homes, and considering building height. Building damage functions distinguish among buildings that are designed to different seismic standards, or are otherwise expected to perform differently during an earthquake. These differences in expected building performance are determined on the basis of seismic zone location, design vintage and use (i.e., special seismic design of essential facilities).

Buildings are composed of both structural (load carrying) and nonstructural systems (e.g., architectural and mechanical components). While damage to the structural system is the most important measure of building damage affecting casualties and catastrophic loss of function (due to unsafe conditions), damage to nonstructural systems and contents tends to dominate economic loss. Typically, the structural system represents about 25% of the building's worth. Building damage functions separately predict damage to: (1) the structural system, (2) drift-sensitive nonstructural components, such as partition walls that are primarily affected by building displacement, and (3) acceleration-sensitive nonstructural components, such as suspended ceilings, that are primarily affected by building shaking. Building contents are also considered to be acceleration sensitive.

Building damage is defined separately for structural and nonstructural systems of a building. Damage is described by one of four discrete damage states: Slight, Moderate, Extensive or Complete. Of course, actual building damage varies as a continuous function of earthquake demand. Ranges of damage are used to describe building damage, since it is not practical to have a continuous scale, and damage states provide the user with an understanding of the building's physical condition. The four damage states of the FEMA/NIBS methodology are similar to the damage states defined in *Expected Seismic Performance of Buildings* (EERI, 1994), except that damage descriptions vary for each model building type based on the type of structural system and material. Table 1 provides structural damage states for light-frame wood building typical of the conventional construction used for single-family homes.

Table 2. Example damage states - light-frame wood buildings

Damage State		Description
	**Slight**	Small plaster cracks at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneers. Small cracks are assumed to be visible with a maximum width of less than 1/8 inch (cracks wider than 1/8 inch are referred to as "large" cracks).
	**Moderate**	Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.
	**Extensive**	Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations.
	**Complete**	Structure may have large permanent lateral displacement or be in imminent danger of collapse due to cripple wall failure or failure of the lateral load resisting system; some structures may slip and fall off the foundation; large foundation cracks. Five percent of the total area of buildings with Complete damage is expected to be collapsed.

BUILDING CAPACITY AND RESPONSE CALCULATION

A building capacity curve is a plot of a building's lateral load resistance as a function of a characteristic lateral displacement (i.e., a force-deflection plot). It is derived from a plot of static-equivalent base shear versus building displacement at the roof, known commonly as a pushover curve. In order to facilitate direct comparison with spectral demand, base shear is converted to spectral acceleration and the roof displacement is converted to spectral displacement using modal properties that represent pushover response. Pushover curves and related-capacity curves, are derived from concepts similar to those of the *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (FEMA, 1997), and in *Seismic Evaluation and Retrofit of Concrete Buildings* (SSC, 1996), commonly referred to as ATC-40.

Building capacity curves are constructed for each model building type and represent different levels of lateral force design and building performance. Each curve is defined by two control points: (1) the "yield" capacity, and (2) the "ultimate" capacity. The yield capacity represents the lateral strength of the building and accounts for design strength, redundancies in design, conservatism in code requirements and expected (rather than nominal) strength of materials. Design strengths of model building types are based on the requirements of current model seismic code provisions (e.g., 1994 *UBC* or *NEHRP Provisions*) or on an estimate of lateral strength for buildings not designed for earthquake loads. Certain buildings designed for wind, such as taller buildings located in zones of low or moderate seismicity, may have a lateral design strength considerably greater than those based on seismic code provisions.

The ultimate capacity represents the maximum strength of the building when the global structural system has reached a full mechanism. Typically, a building is assumed capable of deforming beyond its ultimate point without loss of stability, but its structural system provides no additional resistance to lateral earthquake force. Up to yield, the building capacity curve is assumed to be linear with stiffness based on an estimate of the expected period of the building. From yield to the ultimate point, the capacity curve transitions in slope from an essentially elastic state to a fully plastic state. The capacity curve is assumed to remain plastic past the ultimate point. Examples of building capacity curves are shown in Figure 2.

Building response is determined by the intersection of the demand spectrum and the building capacity curve. Intersections are illustrated in Figure 2 for three example demand spectra representing what can be considered as weak, medium and strong ground shaking, and two building capacity curves representing weaker and stronger construction, respectively. The terms "weak," "medium," and "strong" and "weaker" and "stronger" are used here for simplicity; in the actual methodology, only quantitative values of spectral response and building capacity are used. As shown in Figure 2, stronger and stiffer construction displaces less than weaker and more flexible construction for the same level of spectral demand, and less damage is expected to the structural system and nonstructural components sensitive to drift. In contrast, stronger construction will shake at higher acceleration levels, and more damage is expected to nonstructural components and contents sensitive to acceleration.

The demand spectrum is based on the 5%-damped response spectrum at the building's site (or centroid of a study area containing a group of buildings), reduced for effective damping when effective damping exceeds the 5% damping level of the input spectrum. Effective stiffness properties are based on secant stiffness, and effective damping is based on combined viscous and hysteretic measures of dissipated energy. Effective damping greater than 5% of critical is used to reduce spectral demand in a manner similar to the capacity-spectrum method of ATC-40.

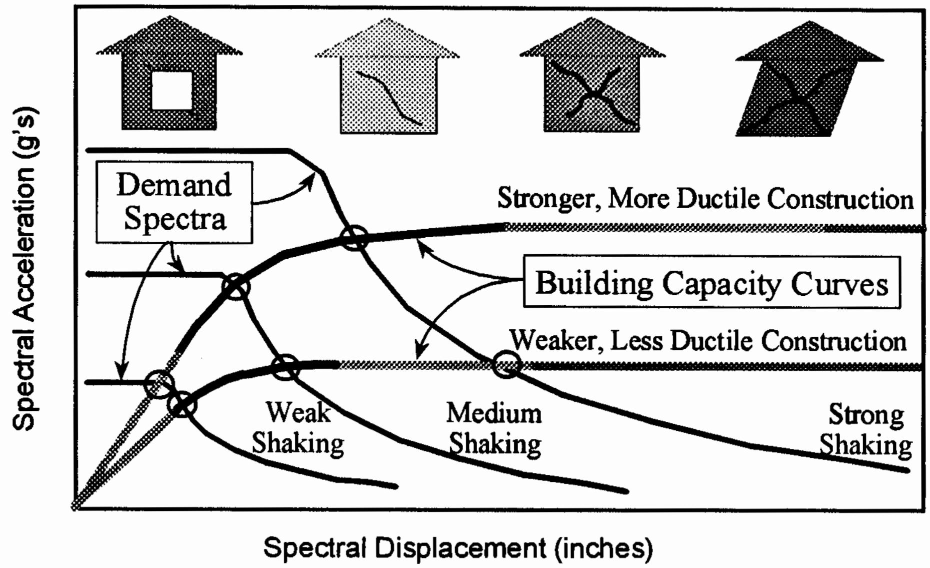


Figure 2. Example demand spectra and building capacity curves

The FEMA/NIBS methodology characterizes ground shaking using a standard response spectrum shape, as shown in Figure 3, for spectra representing rock, stiff soil and soft soil conditions, respectively. The standard shape consists of two primary parts: (1) a region of constant spectral acceleration at short periods and (2) a region of constant spectral velocity at long periods. Short-period spectral acceleration, S_S, is defined by 5%-damped spectral acceleration at a period of 0.3 seconds. The constant spectral velocity region has spectral acceleration proportional to 1/T and is anchored to the 1-second, 5%-damped spectral acceleration, S_1. A region of constant spectral displacement exists at very long periods, although this region does not usually affect calculation of building damage and is not shown in Figure 3.

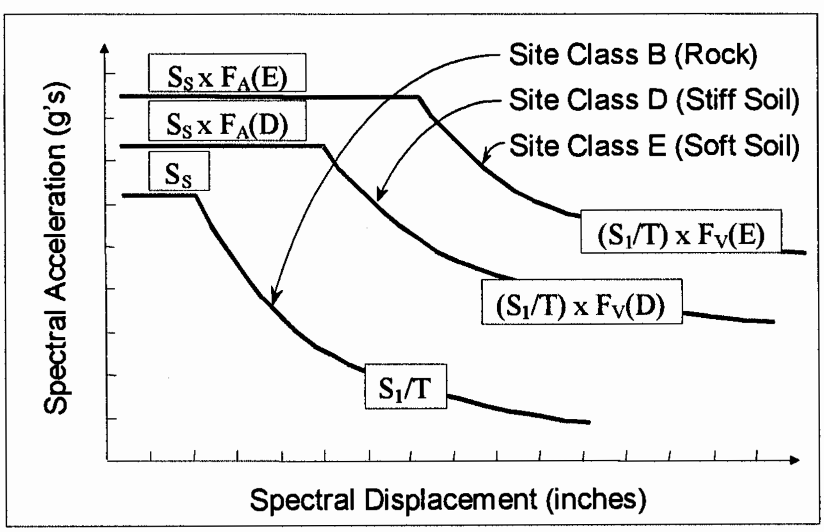


Figure 3. Example 5%-damped response spectra for three site classes

The FEMA/NIBS methodology predicts spectral response as a function of distance from scenario earthquake sources based on the same attenuation functions as those used by the United States Geological Survey to create national seismic hazard maps for *Project 97* (Frankel et al., 1996). These functions define ground shaking for rock (Site Class B) conditions based on earthquake magnitude and other source parameters (e.g., fault type).

Amplification of ground shaking to account for local site conditions is based on the soil factors of the *NEHRP Provisions*. The *NEHRP Provisions* define a standardized site geology classification scheme and specify soil amplification factors (i.e., F_A for the acceleration domain and F_V for the velocity domain). Figure 3 shows construction of demand spectra for stiff soil sites (Site Class D) and soft soil sites (Site Class E). These spectra illustrate the importance of soil type on spectral demand (and building response), particularly in the velocity domain.

BUILDING FRAGILITY AND LOSS CALCULATION

Building fragility curves are lognormal functions that describe the probability of reaching, or exceeding, structural and nonstructural damage states, given deterministic (median) estimates of spectral response, for example spectral displacement. These curves take into account the variability and uncertainty associated with capacity curve properties, damage states and ground shaking.

Figure 4 provides an example of fragility curves for the four damage states used in the FEMA/NIBS methodology and illustrates differences in damage-state probabilities for three levels of spectral response corresponding to weak, medium, and strong earthquake ground shaking, respectively. The terms "weak," "medium," and "strong" are used here for simplicity; in the actual methodology, only quantitative values of spectral response are used.

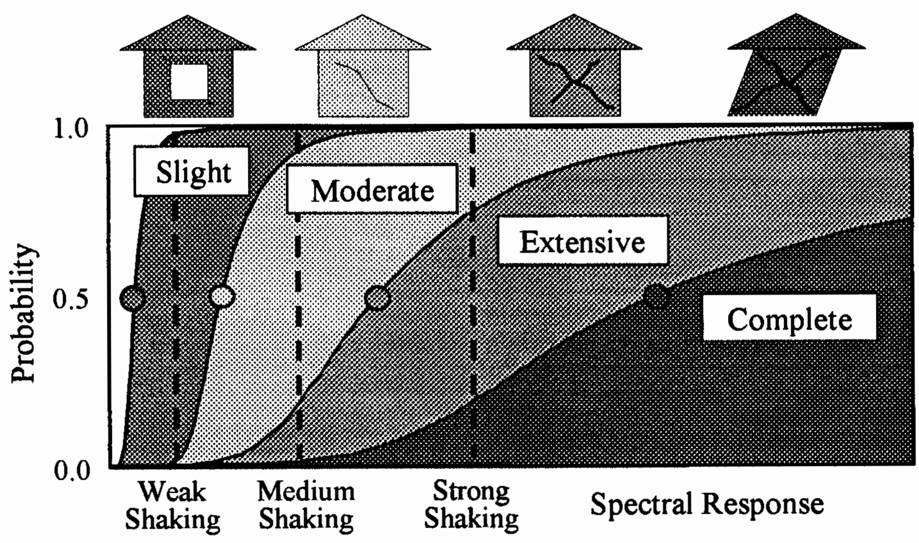


Figure 4. Example fragility curves for Slight, Moderate, Extensive and Complete damage

The fragility curves distribute damage among Slight, Moderate, Extensive and Complete damage states. For any given value of spectral response, discrete damage-state probabilities are calculated as the difference of the cumulative probabilities of reaching, or exceeding successive damage states. Discrete damage-state probabilities are used as inputs to the calculation of various types of building-related loss. Figure 5 provides an example of discrete damage state probabilities for the three levels of earthquake ground shaking.

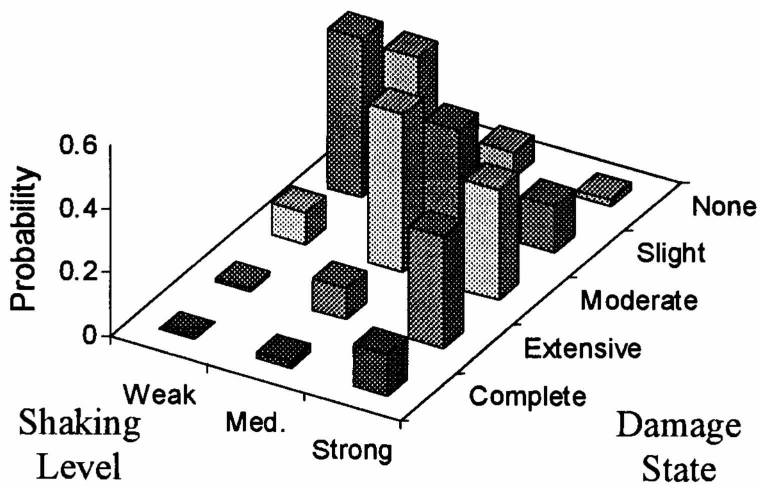


Figure 5. Example damage-state probabilities for weak, medium and strong shaking levels

Each fragility curve is defined by a median value of the demand parameter (e.g., spectral displacement) that corresponds to the threshold of that damage state and by the variability associated with that damage state. The total variability of each damage state is based on a complex combination of three primary sources of damage variability, namely the variability associated with the capacity curve, the variability associated with the demand spectrum and the variability associated with the discrete threshold of the damage state. While some fragility formulations have separated uncertainty from randomness, the FEMA/NIBS methodology does not and damage state variability represents composite “best-estimate” fragility. This approach is similar to that used to develop fragility curves for the FEMA-sponsored study of consequences of a large earthquake on six cities of the Mississippi Valley region (Kircher and McCann, 1983).

As mentioned previously, discrete probabilities of damage state are used as inputs to a variety of different building loss functions. In general, these functions return an estimate of the amount of loss for each building system (e.g., structural, nonstructural or contents) of each building type (e.g. light-frame wood) of each building occupancy (e.g., single-family residence). Estimated loss is based on the square footage of that particular combination of building type/occupancy in the area of interest (e.g., census tract or whole study region). Since the damage state probabilities are based on "best-estimate" fragility, loss estimates represent the center of the true distribution of actual loss that could occur.

UTILIZATION OF STRONG-MOTION DATA IN LOSS ESTIMATION

By basing hazard on quantitative measures of ground shaking (e.g., response spectra), the FEMA/NIBS methodology utilizes strong-motion data in loss estimation, rather than relying on MMI to describe hazard. Strong-motion data are used indirectly in the form of various Western United States (WUS) attenuation relationships that are based on response spectra of actual earthquake records. Strong-motion data may also be input directly in the form of spectral contour maps of recorded ground shaking.

The methodology provides three approaches for characterizing ground shaking: the deterministic scenario event, the scenario event based on probabilistic seismic hazard maps, and the scenario event based on user-supplied ground shaking maps. In the first case, the user selects scenario-earthquake magnitude and identifies the source (fault) of interest. The HAZUS software provides a database of historical earthquakes and their epicenters, as well as databases (maps) of WUS faults (including fault type, location and orientation). Fault rupture length is determined based on the scenario-earthquake magnitude. Alternatively, users can specify all fault criteria for an "arbitrary" scenario-earthquake event.

After determination of scenario-earthquake magnitude and fault criteria, attenuation functions are used to calculate response spectra at various locations throughout the study region of interest. Response spectra are calculated at specific locations of special buildings (e.g., essential facilities) and at the centroid of census tracts for evaluation of general building stock (i.e., general building stock is grouped by census tract). For reference, there are about 1,650 census tracts in Los Angeles County, which has a population of about 9 million and a total building count of about 2.2 million (of which about 2 million buildings are residences).

Ground shaking is a function of the distance from the plane of fault rupture (which is defined by fault criteria). The location and geometry of the fault rupture plane are important to accurate estimation of damage and loss, particularly for thrust or reverse-slip faults that have a pronounced dip angle. The region of strongest ground shaking may not be well represented by the location of the earthquake's epicenter. For example, Figure 6 contrasts the location of the region of strongest ground shaking and the location of the epicenter of the 1994 Northridge earthquake (and the location of the region of densest residence value). In the Northridge earthquake, fault rupture occurred along a plane that dips at angle of about 45^0. Fault rupture initiated at about 20 km below the epicenter and propagated up and to the north. The region of strongest ground shaking is located approximately over the plane of fault rupture.

In Figure 6, the region of strongest ground shaking is defined as ground shaking having a spectral acceleration of 0.75 g, or greater, at a period of 0.3 seconds. Spectral acceleration maps of the 1994 Northridge Earthquake were taken from the work of Somerville who developed smooth contour maps from ground shaking records for the SAC project (SAC Joint Venture, 1995). The spectral acceleration maps were also used to compare observed economic loss with that predicted by the FEMA/NIBS methodology (Kircher, 1997b). Predicted loss was found to compare favorably with observed loss when loss predictions were based on actual ground shaking data.

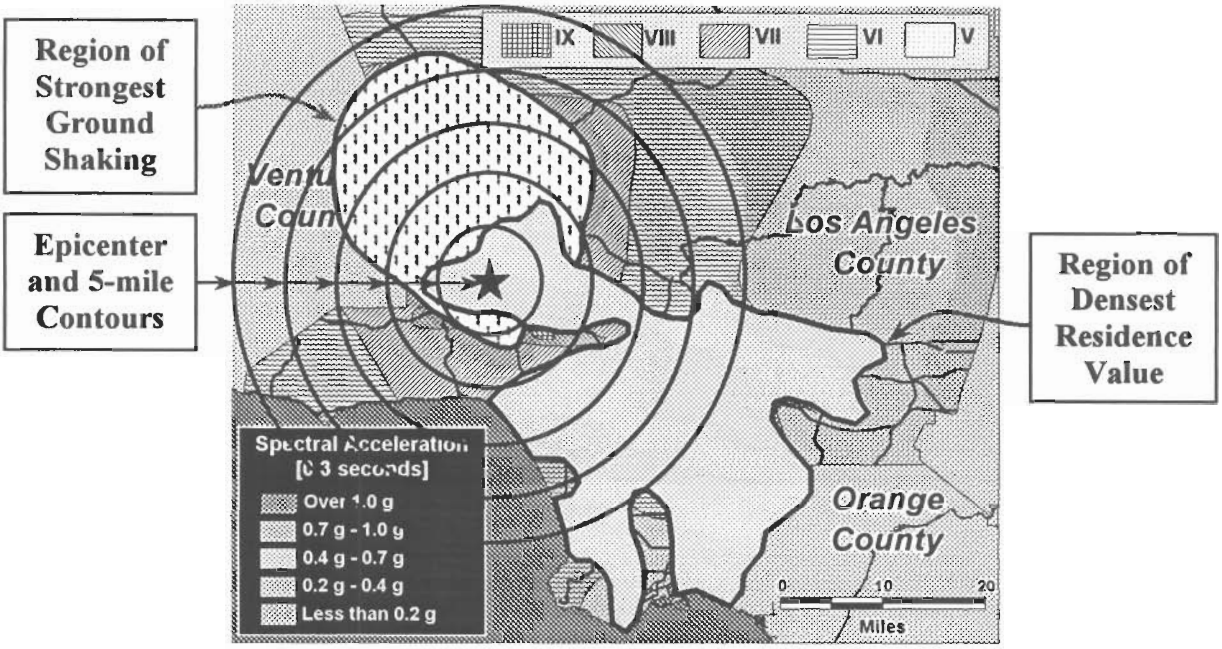


Figure 6. Map of Los Angeles County showing regions of densest residence value and strongest ground shaking of the 1994 Northridge Earthquake

In Figure 6, the region of densest residence value in Los Angeles County is defined approximately by those areas having a residential value density of more than 100 million dollars per square mile. While a portion of the region of strongest shaking overlaps with the region of densest residence value in the San Fernando Valley, most of the strong shaking occurred in the mountains and sparsely built areas to north and west of the valley. Only about 10% - 20% of Los Angeles County residences felt this level of strong ground shaking. A different location of the fault rupture plane would have created an entirely different region of strongest shaking, possibly closer to (or possibly farther from) the region of densest residence value, and the amount and spatial distribution of losses would likely have been quite different from those observed. Accurately relating the spatial distribution of strong ground shaking to the inventory of buildings (and other infrastructure) is a key factor in developing reliable estimates of earthquake loss.

The FEMA/NIBS methodology permits (and encourages) users to input detailed information on soil type. In lieu of such data, the methodology develops site or census-tract response spectra that include amplification factors for the default soil type (stiff soil). The use of true soil type (rather than default soil type) can significantly change the amount of damage and loss predicted for buildings, particularly for tall, flexible structures and/or for structures responding at or beyond yield. Likewise, post-earthquake damage and loss predictions based on instrumental records that explicitly include the effects of soil amplification would be expected to provide much better estimates of damage and loss.

To illustrate the importance of soil type on building response, and hence on damage and loss prediction, example response calculations are made for three soil profile types (rock, stiff soil and soft soil). Figure 7 illustrates the calculation of building response for strong ground shaking at a stiff soil site. The building has an initial period of 0.6 seconds, representing a typical mid-rise building. The building yields at a spectral acceleration of about 0.2 g and reached full yield at a spectral acceleration of about 0.4 g. These strength properties represent a building that was designed to seismic-code requirements, but of an older design vintage (e.g., a typical older California commercial building).

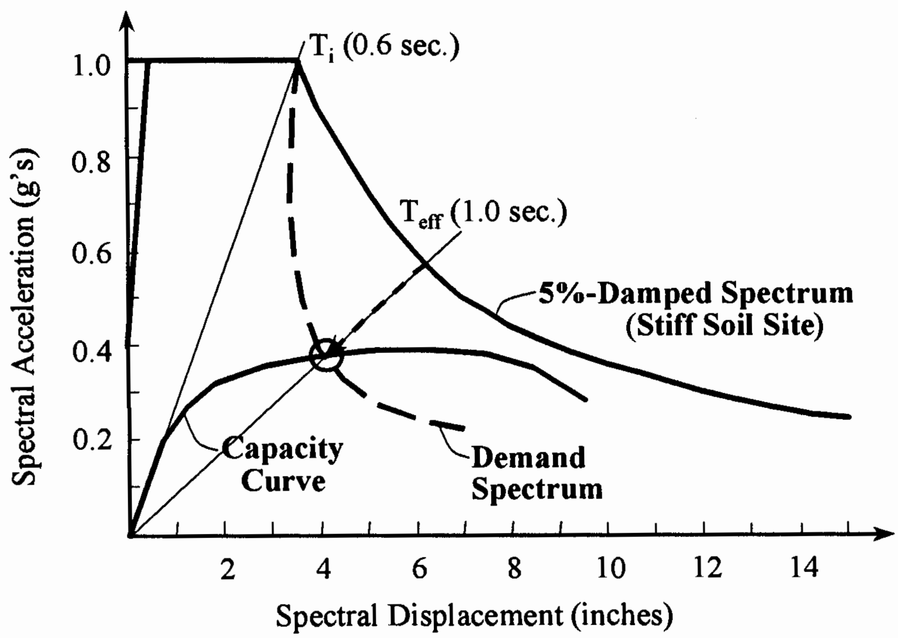


Figure 7. Example Response Calculation - Stiff Soil Site

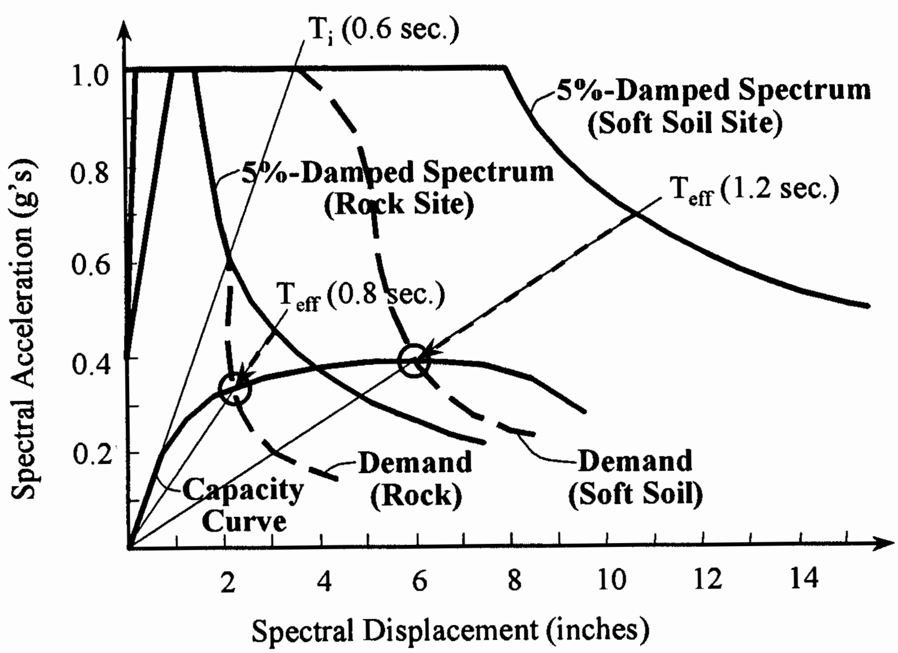


Figure 8. Example Response Calculation - Rock and Soft Soil Sites

Assuming the building to be a reinforced concrete, shear-wall structure, the FEMA/NIBS methodology specifies median spectral displacements (and corresponding inter-story drift values) for each structural damage state as given in Table 3. Median spectral displacements represent thresholds at which damage is expected to begin to occur for each damage state. For example, Moderate damage is not expected to begin to occur on average until spectral displacement reaches about 2.5 inches, or about 0.67 inch of inter-story drift.

Table 3. Example median spectral displacements and inter-story drifts corresponding to damage states of an older reinforced concrete mid-rise building

Building Damage State	Spectral Displacement (inches)	Inter-Story Drift (inches)
Slight	1.2	0.33
Moderate	2.5	0.67
Extensive	7.0	1.9
Complete	18.0	4.8

Figure 7 shows a 5%-damped response spectrum that represents ground shaking at a stiff soil site. A demand spectrum is constructed using procedures that parallel those of ATC-40. The building's capacity curve intersects the stiff soil demand spectrum at about 4 inches of spectral displacement. Based on Table 3, the building would most likely have Moderate structural damage (but could also have either Slight or Extensive damage due to the variability of the damage functions).

Figure 8 shows 5%-damped response spectra that represent rock and soft soil sites, respectively, and the demand spectra corresponding to these site conditions. The building's capacity curve intersects the rock demand spectrum at about 2 inches and intersects the soft soil spectrum at about 6 inches. For the rock site, the spectral displacement indicates that either Slight or Moderate structural damage is likely (i.e., 2 inches is near the threshold of Moderate damage), and the building has about the same probability of either Moderate or Extensive structural damage. For the soft soil site, the spectral displacement is close to the Extensive damage-state threshold and the building has about the same probability of either Moderate or Extensive structural damage.

In this example, structural damage varies approximately from Slight/Moderate for a rock site to Moderate for a stiff soil site to Moderate/Extensive for a soft soil site. In terms of loss, the direct economic loss ratios of the FEMA/NIBS methodology expect about 5 times more dollar loss with Extensive damage than with the Moderate damage. Thus, two similar reinforced concrete mid-rise buildings located the same distance from fault rupture, one on soft soil and the other on rock, are expected to have significantly different responses and losses. The building on soft soil is expected to displace laterally about 3 times farther during strong ground shaking and to cost about 5 times as much to repair the structural system than the building on rock.

CONCLUSION

This paper has summarized the key features and components of the regional earthquake loss estimation methodology developed by the National Institute of Building Sciences (NIBS) with funding provided by the Federal Emergency Management Agency (FEMA). The FEMA/NIBS earthquake loss estimation methodology is intended primarily to assist emergency response planning and mitigation efforts of state, regional and local community governments. The FEMA/NIBS methodology incorporates state-of-the-art approaches for characterizing earthquake hazards, including ground shaking, liquefaction and land-sliding; estimating damage and losses to buildings and lifelines, estimating casualties, shelter needs and economic losses.

The paper has emphasized the importance of using quantitative measures of ground shaking hazard (i.e., response spectra) in the estimation of building damage. Damage and loss are based directly on ground motion data, rather than on Modified Mercalli Intensity (MMI) commonly used by other earthquake loss estimation methods. While the FEMA/NIBS methodology was developed primarily for pre-earthquake planning purposes, the use of response spectra to predict damage makes the technology potentially valuable as a post-earthquake processor of near-real-time data from strong-motion networks such as the TriNet system. It is suggested that the FEMA/NIBS methodology be interfaced with strong-motion instrumentation networks to better assist post-earthquake response and recovery efforts.

It is further suggested that predictions of earthquake damage and loss be used to assist locating strong-motion instruments in areas where buildings and other infrastructure are most at risk. Recognizing that public safety needs require instrumentation networks that can be used to effectively reduce earthquake risk (not just improve earth science), strong-motion instrumentation should be located where there is the greatest likelihood of experiencing damaging ground shaking. This objective is best summarized by two criteria: (1) high probability of strong shaking, (2) large quantity of infrastructure at risk. While seismic hazard maps alone could address the first criterion, the second criterion requires determining the relative risk to the infrastructure of different seismic regions. Some visionary applications have already been made and suggest that loss estimation can be a valuable tool in developing strong-motion instrumentation networks (Borcherdt, 1997).

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