Researches Related to Seismic Hazard Mitigation in Taiwan

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ABSTRACT

In view of the rapid development of economics and technology, perilous meteorological and geological conditions often cause natural disasters and result in severe loss of lives and properties in Taiwan. To promote multi-hazard mitigation strategies in an integrated approach, the National Science Council established a National Science and Technology Program for Disaster Mitigation in January 1998. This program emphasizes on the implementation of research results in the National Disaster Management System. This paper describes the earthquake loss estimation methodology that is currently developed in Taiwan. Topics of potential earth science hazards (PESH) and building vulnerability analysis are described in detail.

Key words *: seismic hazard analysis, seismic damage analysis, earthquake scenario*

1. Introduction

The recent economic prosperity of Taiwan has brought about the rapid development and expansion of residential, commercial, industrial, transportation, and other facilities. Because Taiwan is located in the circum-pacific earthquake belt, both people and properties are suffered from the inevitable occurrence of strong earthquakes. Therefore, the seismic hazard mitigation has become an importance issue. Over the years, the Taiwan government has spent a significant amount of funding and manpower on the researches of natural hazard mitigation, which includes the seismic hazard mitigation as one of its main objectives. While considerable progress has been made in earthquake engineering research, the overall effort has been far from satisfactory due to lack of an integrated multi-hazard mitigation strategy.

In 1990, to bring together scholars and engineers, who are specialists in the field of earthquake engineering, to cooperate and work together on both basic and applied research, the National Center for Research on Earthquake Engineering (NCREE) was founded. The NCREE has set up an earthquake simulation laboratory and a field experiment station for the testing of large-scale structural models under simulated and natural seismic conditions, respectively. The earthquake simulation laboratory has a shaking table, an L-shape reaction wall, a strong floor, and other testing equipment for both static and dynamic testing. The experiment station is located in I-lan, which is known to be highly seismically active. There are many integrated research projects, such as structural active/passive control, rehabilitation of bridge piers, seismic performance and design of composite structures, and so on, that are conducted by the NCREE.

In 1998, to have an integrated approach in natural hazard mitigation, the National Science Council in Taiwan approves the National Science and Technology Program

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for Disaster Mitigation. The objectives of the program are to combine the efforts of various government and private agencies, to promote the upstream and down stream research works, to integrate the research results and transfer them into practice, and to develop methodologies for natural hazard potential analysis, risk assessment and disaster scenario simulation. The conceptual framework for the program is shown in Fig. 1 and has six elements.

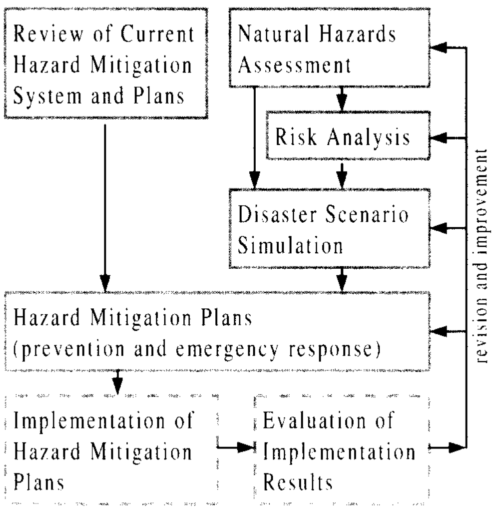

Fig. 1 Framework and major topics of the research and development for natural hazard mitigation

1) To assemble database for both the natural and the social/economic environment needed for the development and implementation of hazard mitigation methodologies;
2) To develop methodologies for hazard potential analysis, and to apply them to evaluation of the hazard potential in Taiwan area;
3) To select one or two pilot study regions for developing risk assessment methodologies and for simulating disaster scenarios;
4) To develop a disaster scenario display system in order to incorporate the risk assessment and scenario simulation results, so that the government agencies and the private organizations can response rapidly and correctly to reduce loss of lives and their properties;
5) To develop and test the hazard mitigation plans for the pilot study regions;
6) To review current codes and evaluate the hazard mitigation plans, and based on the evaluation results, to guide future improvement of the whole disaster mitigation work.

Based on the framework of earthquake loss estimation methodology in HAZUS,[12] the National Science Council is developing a similar methodology according to the engineering practices and the social/economic characteristics in Taiwan. The methodology can be used by a variety of users and with various degrees of sophistication. It may be implemented using either a GIS-based software Haz-Taiwan or by application of theory in the methodology. The Haz-Taiwan is an integrated geographical information system in estimation of seismic hazard potential and the induced damages and losses in a scenario earthquake. Although the Haz-Taiwan now only estimates losses due to earthquake, it will include other natural hazard loss estimation in the future. In the following sections, the term Haz-Taiwan will be used to indicate both the earthquake loss estimation methodology and the associated GIS-based software.

The framework of Haz-Taiwan, as shown in Fig. 2, mainly consists of five parts, that is, potential earth science hazards, direct physical damage, induced physical damage, direct social/economic losses and indirect economic losses. Also shown in the Figure, modules in each part are interdependent with output of some modules acting as input to others. However, the degree of sophistication and associated cost will vary greatly by different users and applications. The modular nature of the methodology permits a logical evolution of the methodology as research progresses and the state of the art advances.

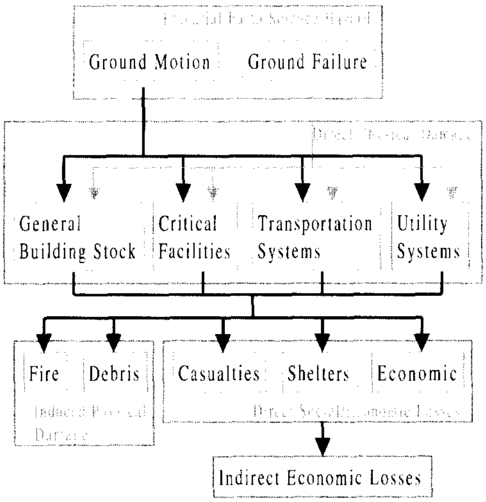

Fig. 2 Flowchart of earthquake loss estimation methodology

2. Potential earth science hazards

As shown in the Haz-Taiwan framework, the module of potential earth science hazards includes ground motion and ground failure (i.e., liquefaction, landslide and surface fault rupture), but excludes tsunami caused by earthquakes. Methods for developing estimates of ground motion and ground failure are discussed in the following subsections.

2.1 Ground motion

In general, peak ground acceleration (PGA), peak ground velocity (PGV) and spectral response characterize ground motion intensity in a given earthquake. To simplify analysis procedure in building damage predication, the spectral response based on a standard shape will be used in the estimation of earthquake demand spectra at a given site. Ground motion intensity at a site can be determined using either deterministic or probabilistic seismic hazard analysis.

In deterministic analysis, seismic demands are calculated for user-specified scenario earthquakes. Given earthquake magnitude, location and depth (including fault type and rupture mechanism in some cases), attenuation relationships are used to calculate ground shaking intensity in rock sites, which is then amplified by factors based on local site conditions. There are three options in selection of a scenario earthquake, that is,

1) specify an event based on a database of seismically active faults,
2) specify an event based on a database of historical epicenters, or
3) specify an arbitrary event.

However, to be more realistic, the scenario earthquake should be selected based on probabilistic analysis as described in section 5.

In probabilistic approach, the ground shaking intensity is characterized by contour maps of PGA, PGV and spectral values at some specific periods. These contour maps are constructed by performing seismic hazard analysis at many sites. The seismic hazard analysis calculates the exceedance probability of various shaking intensities at any given site. The total probability theorem is used to estimate the seismic hazard potential as

$$P[A > A_0] = \sum_{i=1}^{n} \int P[A > A_0 \mid E_{i,m}] f_M(m) dm ,$$

where n is the number of seismic zones, $P[A > A_0 \mid E_{i,m}]$ is the conditional probability of PGA being greater than A_0 given an earthquake of magnitude M occurring in seismic zone i, $f_M(m)$ is the probability density function of magnitude M. The contour map shows the ground shaking intensities for a given return period, *i.e.*, with the same exceedance probability, at different sites. For example, the return periods of 100, 250, 500 and 1000 years are used in Haz-Taiwan.

Fig. 3 lists the model parameters that are considered in seismic hazard analysis,(8) where ground motion attenuation relationship plays an important role. Much effort in the analysis is devoted to the determination of model parameters and physical relationships of ground motion characteristics. Except the attenuation relationship for PGA, a common regression model of the response spectral value $S(f)$ at frequency f is expressed as(5)

$$S(f) = b_1(f) e^{b_2(f)M} \left[R + b_4(f) e^{b_5(f)M} \right]^{b_3(f)} ,$$

where b_1 through b_2 are frequency dependent coefficients, and R is the closest distance to seismogenic rupture of the fault.

If the spectral value at each frequency has the same annual exceedance probability, the spectrum is called a "uniform hazard response spectrum." This kind of spectrum is considered superior to those developed by anchoring a fixed spectral shape to a probabilistic estimate of peak ground acceleration. However, it is not a simple task to calculate response spectrum in general shapes. An alternative is to specify the attenuation relationship of spectral response at some specific periods and to construct the response spectrum using a standard shape.

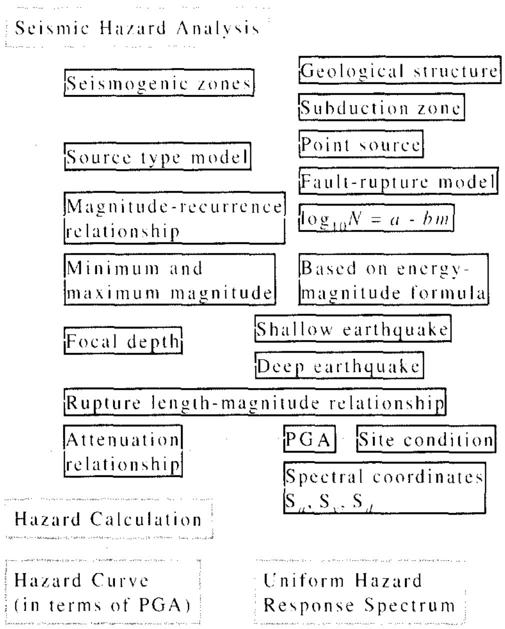

Fig. 3 Required hazard parameters for seismic hazard analysis

The standard shape of response spectrum consists of four parts, *i.e.*, peak ground acceleration, a region of constant spectral acceleration at periods from zero to T_{AV}, a region of constant spectral velocity at periods from T_{AV} to T_{VD} and a region of constant spectral displacement for periods of T_{VD} and beyond. As shown in Fig. 4, spectral acceleration is plotted as a function of spectral displacement rather than as a function of period. This is the format of response spectra used for evaluation of building vulnerability. The region of constant spectral acceleration is defined by spectral acceleration at a period of 0.3 second, $(S_A)_{T=0.3}$. The region of constant spectral velocity has spectral acceleration proportional to $1/T$ and is anchored to the spectral acceleration at a period of 1.0 second, $(S_A)_{T=1.0}$. The intersection of the regions of constant spectral acceleration and constant spectral velocity defines the period T_{AV}, *i.e.*, $T_{AV}=(S_A)_{T=1.0}/(S_A)_{T=0.3}$. The period T_{VD} is based on the reciprocal of the corner frequency and is expressed in terms of the earthquake's moment magnitude as[1]

$$T_{VD}=10^{\frac{M-5}{2}}.$$

Fig. 3 Required hazard parameters for seismic hazard analysis.

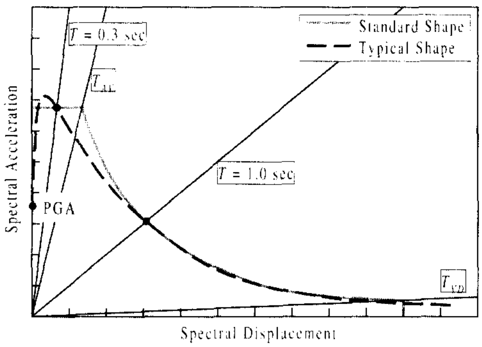

Fig. 4 Standard response spectrum curve

The attenuation relationships have been used to approximate the ground shaking intensities in rock sites as functions of earthquake magnitude, epicenter distance, and so on. For site conditions other than rock sites, the approximation needs modification to account for local site conditions based on the site factors such as those of the NEHRP provisions. Similar in the NEHRP provisions, Haz-Taiwan defines a standardized site geology classification scheme and specifies site amplification factors for the constant spectral acceleration domain F_A and for the constant spectral velocity domain F_V. Both F_A and F_V depend not only on the site conditions but also on the ground shaking intensities.

2.2. Ground failure

Three types of ground failure, *i.e.*, liquefaction, landslide, and surface fault rupture, are considered in Haz-Taiwan. Each type of ground failure is quantified by the expected permanent ground deformation and the probability of occurrence.

Liquefaction is a soil behavior phenomenon in which a saturated soil looses a substantial amount of shear strength due to high excess pore-water pressure generated by and accumulated during strong earthquake ground shaking. For a given earthquake E, the probability of liquefaction at a site can be expressed as:

$P_E[L]=P[L \mid E]P[E]$,

where $P_E[L]$ is the unconditional probability of liquefaction, $P[L \mid E]$ the conditional probability of liquefaction given occurrence of earthquake E, and $P[E]$ the probability that an earthquake occurs. From seismic hazard analysis, the annual probability of occurrence for different ground shaking intensity (*i.e.*, PGA A_0) at a site can be calculated. Several test methods have been used to simulate earthquake stress conditions on soil elements. Results from such tests may be used to evaluate cumulative damage in soil analogous to S-N curves in fatigue analysis. According to the Miner's linear cumulative damage law, $D=\sum(n_i/N-i)$, where n_i is the number of applications of shear stress level τ_i and N_i is the number of application that cause failure. For the purpose of incorporating conditional probability of liquefaction into an estimate of liquefaction hazard at a site, $P[L \mid E]$ can be replaced by $P[D > D_0 \mid A_0]$. Then, the total probability of liquefaction is obtained by integrating overall passive ground intensities,[7]

$$P[D > D_0] = \int P[D > D_0 \mid A_0] P[A_0] dA_0$$

Another approach to calculate the probability of liquefaction at a given site in an earthquake of magnitude M is described below. Divide the soil deposits into several susceptibility categories and find the relationship between the probability of liquefaction for each category and the peak ground acceleration A_0. The probability of liquefaction is also influenced by ground shaking duration (reflected by earthquake magnitude) and ground water depth. Thus, the probability of liquefaction for each category is determined by the relationship,[12]

$$P[L_{SC}] = \frac{P[L_{SC} \mid \mathrm{PGA} = A_o]}{K_M K_W} p_{ml},$$

where K_M and K_w are the correlation factors for earthquake moment magnitude and ground water depth, respectively, and p_{ml} the proportion of map unit susceptible to liquefaction. Once liquefaction occurs in a map unit, the expected amount of lateral spreading is a function of the ratio, A_0 / A_t, where A_t is the threshold acceleration necessary to induce liquefaction. However, the expected amount of settlement depends only on the susceptibility category, but not on A_0.

Earthquake-induced landslide of a hillside slope occurs when the static plus inertia forces within the slide mass temporarily exceed the shear strength. The value of the peak ground acceleration, which is required to cause landslide, within the slide mass is denoted by critical acceleration a_c. Landslide susceptibility categories are defined as a function of a_c. The process of landslide can be view as a sequence of start-and-stop cycles. So, the expected permanent ground displacement is obtained by $n a_{is} E[d \mid a_{is}/a_c]$, where n is the expected number of cycles expressed as a function of earthquake duration or magnitude, a_{is} the average peak acceleration within the slide mass, and $E[d \mid a_{is}/a_c]$ the expected amount of displacement in one cycle expressed as a function of a_{is}/a_c.

The correlation between surface fault displacement and earthquake moment magnitude developed by Wells and Coppersmith[13] is used to determine the permanent ground displacement induced by the surface fault rupture. It is based on the empirical data set for all type of faulting (strike slip, reverse and normal). For a given earthquake moment magnitude M, the median maximum displacement is given by

$$\log \hat{D} = -5.26 + 0.79M.$$

3. Direct physical damage-general building stock

Estimation of building damage and the associated probability in each damage state is one of the important issues in Haz-Taiwan. The estimation results are used to estimate the amount of debris, casualties, shelters, monetary losses, business interruption, social and economic impacts, and so on, due to building damage. Besides the earthquake demand spectra, two sets of functions, *i.e.*, capacity and fragility curves are used to estimate the building damage resulting from the ground shaking. The functions estimate the probability of discrete states of structural and nonstructural building damage separately. The capacity curves estimate peak building response for a given level of spectral demand. These curves are analogous to pushover curves of individual buildings. The fragility curves predict the probability of reaching or exceeding specific damage states for a given level of peak building response. The probability of being in a particular state of damage is calculated as the difference between fragility curves.

3.1 Building classification

To facilitate estimation of structural/non-structural damages and the associated economic losses, buildings are classified both in terms of their structural system, or model building type, and in terms of their use, or occupancy class, respectively. Classification of model building types are based on the material (wood, steel, reinforced concrete, masonry, *etc.*), lateral force resistance system (moment resisting frame, frame with bracing systems, frame with shear walls, *etc.*), and building height. To accommodate different seismic design level and code, each model building type is divided into four groups, that is, high-code, moderate code, low code and pre-code. The general occupancy classes are grouped into residential, commercial, industrial, agricultural, nonprofit/membership organizations, government, and education. The specific occupancy classes are then defined on the basis of standard classification scheme of vocation in Taiwan. There are 37 model building types and 31 specific occupancy classes in Haz-Taiwan.

Building inventory data are collected for each basic geographic unit, that is chunli in Haz-Taiwan or census tract in HAZUS. The total floor area of each specific occupancy class is calculated. The distribution of model building types in each specific occupancy class is also determined by a mapping scheme.

3.2 Building capacity curves

A building capacity curve is a plot of a building's lateral load resistance as a function of characteristic lateral displacement. It is derived from a plot of static-equivalent base shear versus building displacement at the roof, which is known as a pushover curve of individual building. In order to facilitate direct comparison with earthquake spectral demand, the base shear is converted to spectral acceleration and the roof displacement is converted to spectral displacement using modal properties that represent pushover response. Building capacity curves are constructed for each model building type and seismic design level to represent different levels of lateral strength and displacement ductility.

As shown in Fig. 5, two control points, *i.e.*, yield capacity and ultimate capacity define a capacity curve. The yield capacity represents the lateral strength of the building before the structural system has nonlinear response, taking into accounts the redundancy in design strength and the conservatism in code requirement and expected strength of materials. The ultimate capacity represents the maximum strength of the building when the global structural system reaches a full mechanism. A building is typically assumed to deform beyond the ultimate point without loss of stability, but the structural system provides no additional resistance to lateral load.

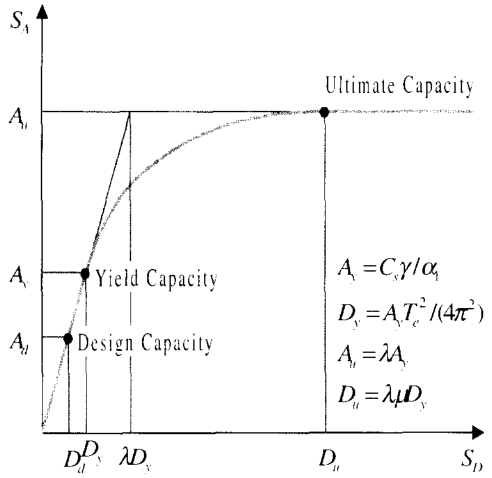

Fig. 5 Definitions of yield and ultimate capacities of a building capacity curve

The yield strength, yield displacement, ultimate strength and ultimate displacement are obtained by the following expressions,

$A_y = c_s r/\alpha_1$,

$D_y = A_y T_c^2/(2\pi)^2$,

$A_u = \lambda A_y$,

$D_U = \lambda\mu D_y$,

where C_s is the coefficient of design strength, r the over-strength factor relating true yield strength to design strength, α_1 the fraction of building weight effective in the pushover mode, T_c the true period of fundamental mode of building, λ the over-strength factor relating ultimate strength to yield strength, and μ the displacement ductility. According to the seismic design code of buildings in Taiwan,

$$C_s = ZIC/(1.4\alpha_y F_u) \tag{1}$$

where Z is the coefficient of horizontal acceleration, I the importance factor, C the coefficient of normalized response spectrum considering the site effects. α_y is equivalent to r and has typical value between 1.1 and 1.5. The coefficient of 1.4 in equation (1) corresponds to λ. It is noted that the value of λ ranges from 2 to 3 in HAZUS. According to current seismic design code of buildings in Taiwan, the displacement ductility μ is 1.6~4.8, while μ is to 4.0~8.0 in HAZUS.

3.3 Building demand spectra

Fig. 6 illustrates the process of constructing an inelastic demand spectrum from the 5% damped elastic response spectrum. The inelastic demand spectrum is obtained by dividing the elastic response spectrum with amplitude-dependent damping reduction factor, that is, R_A at periods of constant spectral acceleration and R_V at periods of constant spectral velocity. The spectrum reduction factors, R_A and R_V, are functions of the effective damping β_{eff} of the building and are expressed as,[11]

$R_A = 2.12/(3.21 - 0.68\ln(\beta_{eff}))$,

$R_V = 1.65/(2.31 - 0.41\ln(\beta_{eff}))$.

The amount of spectrum reduction typically increases for buildings that have reached yield and dissipate hysteretic energy during cyclic response.

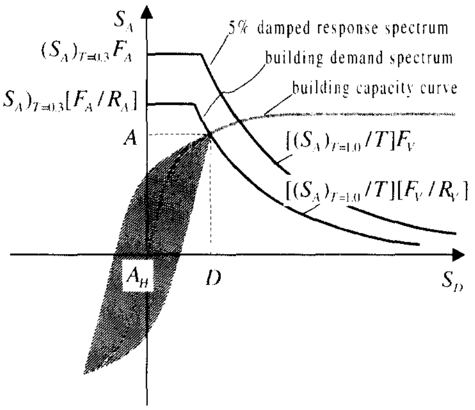

Fig. 6 Construction of building demand spectrum

Effective damping, β_{eff}, is defined as the total energy dissipated by the building during peak earthquake response and is the sum of an elastic damping term, β_E, and a hysteretic damping term, β_H. The elastic damping term is assumed to be amplitude independent and is evaluated for materials at or just below their yield points. The hysteretic damping term is dependent on the amplitude of post-yield response and is expressed as

$$\beta_H = K\left(\frac{A_H}{2\pi DA}\right),$$

where D and A represent the peak displacement and acceleration responses, respectively, A_H the area enclosed by the hysteresis loop as indicated in Fig. 6, K a degradation factor that defines the effective amount of hysteretic damping as a function of earthquake duration.

3.4 Building fragility curves

Building response is determined by the intersection of the demand spectrum and the building capacity curve. Fig. 7 shows the intersections of three demand spectra representing weak, medium and strong ground shaking levels, and two building capacity curves representing a weaker and a stronger construction, respectively. As shown in the Figure, the stronger and stiffer construction displaces less than the weaker and more flexible construction for the same level of spectral demand. Less damage is expected to the structural system and drift-sensitive nonstructural components. However, since the stronger construction will shake at higher acceleration levels, more damage is expected to acceleration-sensitive nonstructural components and building contents.

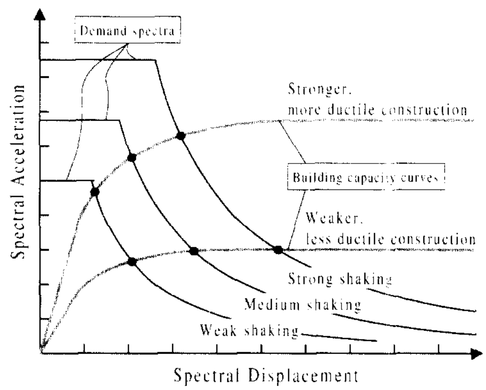

Fig. 7 Intersection of demand spectra and building capacity curves

To better estimate different types of losses, building damage functions separately predict damage to the structural system, drift-sensitive nonstructural components and acceleration-sensitive nonstructural components. Damage states are also defined separately for structural system and nonstructural components of a building. Although actual building damage varies as a continuous function of earthquake demand, four discrete damage states, *i.e.*, slight, moderate, extensive and complete damage states are used to describe the building damage and to provide the user with an understanding of the building's physical condition.

Fragility curves are log-normal functions that describes the probability of reaching or exceeding various damage states, given deterministic estimates of PESH parameters. Each fragility curve is defined by a median value of the demand parameter that corresponds to the threshold of that damage state, and by a logarithmic standard deviation associated with that damage state. For example, spectral displacement is the demand parameter used for damage estimation of structural system and drift-sensitive nonstructural components, as shown in Fig. 8. Median values of structural component fragility are based on inter-story drift ratios that describe the threshold of damage states. In general, these estimates of drift ratio are different for each model building type and seismic design level. Structural and nonstructural fragility curves are evaluated for spectral displacement and spectral acceleration defined by the intersection of the capacity and the

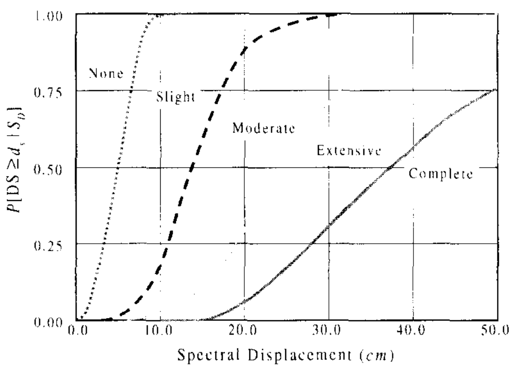

Fig. 8 Example of fragility curves for different damage states

demand curves of the building. Cumulative probabilities are subtracted between adjacent fragility curves to obtain discrete probabilities of being in each of five damage states. This process is shown schematically in Fig. 9.

From research point of view, the fragility curves of a specific model building type can be obtained by seismic reliability analysis.

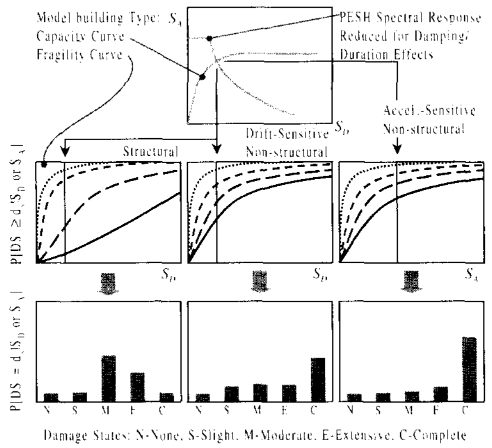

Fig. 9 Building damage estimation process

For example, to use a probabilistic method to evaluate the seismic reliability of buildings the following procedures may be used.

1) Select model of earthquake motion with hazard consistent PGA distribution,
2) analyze structural response in the inelastic range,
3) conduct risk analysis to obtain the exceedance probability of various limiting states such as pre-specified story drift ratios.

Hazard-consistent artificial accelerograms may be used as the input excitation to the building and nonlinear earthquake responses are calculated. The exccedance probability can be expressed as[6]

$$F_e(d) = 1 - P(D > d) = 1 - \exp\left[-\sum_{i=1}^{N} Q_i(D > d \mid E_i)\nu_i\right],$$

where $Q_i(\cdot)$=1- $P_i(\cdot)$, N is the number of seismic sources and v_i is the earthquake occurrence rate at source E_i. The output of fragility curves is an estimate of the cumulative probability of being exceeding each damage state for the given level of ground shaking.

4. Seismic demand based on damage control model

It has been recognized that the level of structural damage due to earthquakes depend not only on the displacement ductility but also on the cumulative damage resulting from numerous inelastic cycles. The cumulative damage potential of structural system is related to the input energy and/or hysteretic energy. Therefore, the energy equation of a dynamic system must be derived for the development of reliable seismic design parameters.

In design practices, there are many structural response quantities that can be considered as the damage parameters. To have a proper damage criteria for a structure, not only the displacement ductility μ_d but also the hysteresis ductility μ_e should be taken into consideration. The definition of μ_d and μ_e are defined as

$$\mu_d = \frac{\nu_{\max}}{\nu_y},$$

$$\mu_e = \frac{E_h}{f_y \nu_y} + 1,$$

where f_y, ν_y are the yielding strength and the yielding displacement of the system, respectively, $\nu_{\max}$ is the maximum displacement under ground motion excitation, and E_h is the total dissipated hysteretic energy. One of the widely used damage models is the Park and Ang's model, which was defined as

$$D_{PA} = \frac{\nu_{\max}}{\nu_{u,mon}} + \beta \frac{E_h}{\nu_{\max} f_y},$$

or

$$D_{PA} = \frac{\mu_d + \beta(\mu_e - 1)}{\mu_{d,mon}}, \tag{2}$$

where $\nu_{u,mon}$, $\mu_{d,mon}$ is the ultimate displacement and the displacement ductility due to monotonic loading, respectively, β is a coefficient depending on the material and structural type of the system and is assumed to be independent of the loading history. The better post-yielding behavior of structure the smaller β-value will be. The case of $D_{PA} \geq 1.0$ indicates that the structure is in extensive or complete damage states, and the case of $D_{PA} < 1/\mu_{d,mon}$ indicates that the structure responses within the linear range and there is no damage.

Based on equation (2), the Park and Ang's damage index is a function of yield strength f_y and other parameters and can be expressed as

$$D_{PA} = D_{PA}(f_y, \mu_{d,mon}, T, \beta, \ldots).$$

The relationship between any two of the parameters shown in equation (2) can be determined if the other parameters are prescribed. As an example, for specific values of $\mu_{d,mon}$, T, β, and so on, the strength demand is obtained by inverting equation (2) and is expressed as

$$f_y = f_y(D_{PA}, \mu_{d,mon}, T, \beta, \ldots). \tag{3}$$

Other demands can be obtained by a similar procedure.

As mentioned before, given the displacement ductility of structure, $\mu_{d,mon}$, the design objective is to provide sufficient capacity so that the ductility demand do not exceed the capacity of structure by an adequate margin of safety during the earthquake. Furthermore, the damage level of structures is controlled by the value of D_{PA}. For a prescribed target ductility, $\mu_{d,mon}$, the design seismic design parameters are defined as

$$C_y = \frac{f_y(D_{PA}, \ldots)}{\mathrm{PGA} \cdot m}, \tag{4}$$

and

$$R = \frac{f_e}{f_y(D_{PA}, \ldots)}, \tag{5}$$

where f_y is obtained from equation (3) for specified value of D_{PA} and other parameters; C_y and R are the yield base-shear-coefficient (BSC) and the reduction factor, respectively; f_e is the maximum base shear of a structure in its elastic response subjected to the same ground motion (PGA is normalized to 1g). In the traditional seismic design procedures, the yield base-shear-coefficient was obtained by $C_y = f_e / (\mathrm{PGA} \cdot m)$. The spectra of dimensionless design parameters, C_y and R, can be generated from equation (4) and (5) through statistical analysis.

5. Probabilistic scenario earthquake

The major advantage of scenario earthquake is that it enables one to simulate a realistic scenario and to study its effects on the regional disaster mitigation planning. Scenario earthquakes are hypothetical earthquakes designed for engineering use by specifying their magnitudes and epicentral locations. The procedure of the method is explain by Kameda:[2-3]

1) Divide the seismically active region surrounding the site into several source areas taking into account the regional seismicity. Probabilistic scenario earthquake is to be determined for each of these source-areas.
2) Perform probabilistic seismic hazard analysis for the site and generate the hazard curves. Determine the ground motion, intensity $y(P_0)$ corresponding to a target probability level p_0. Peak ground motion, spectral amplitude, or whatever else, can be used to characterize the ground motion intensity.
3) Determine the contribution factor $c_k(P_0)$ for the source-area k by using
$$c_k(p_0) = w_k(p_0)/\sum_k w_k(p_0) = w_k(p_0)/p_0$$
where $w_k(p_0)$ is the annual occurrence rate of events in the source-area k such that $Y \geq y(p_0)$. Note that the contribution factor $c_k(p_0)$ has been defined as the conditional probability that given the ground motion intensity Y exceeding $y(p_0)$ at the site in an earthquake, the earthquake has occurred in the source- area k.
4) Identify important source areas that have large values of the contribution factor $c_k(p_o)$ for a prescribed value of p_0. They are regarded as those having dominant influence on the site under the probability level p_0.

5) Define the probabilistic scenario earthquake for the selected source-areas. This is achieved by determining the hazard-consistent magnitude $\overline{M}_k(p_o)$, hazard-consistent distance $\overline{\triangle}_k(p_0)$ and hazard-consistent azimuth $\overline{\Theta}_k(p_0)$ for the selected source-area k. This method had been applied to both Kyoto city and Taipei city.[3]

6. Conclusions

This paper summarizes the framework of National Science and Technology Program for Seismic Hazard Mitigation. The research works related to this program were emphasized and described in this paper. This seismic hazard mitigation and earthquake loss estimation methodology will provide local and regional officials with the tools necessary to plan and simulate efforts to reduce risk from earthquakes and to prepare for emergency response and recovery from an earthquake. The methodology may be implemented using integrated geographic information system technology provided in a software package in the near future.

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