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An integrated framework for seismic performance of reinforced concrete building

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SUMMARY

A procedure is established to integrate seismic environment and site condition into the framework of earthquake damage assessment. The model has four stages: i) probabilistic seismic hazard assessment at rock site, ii) site response analysis, iii) the seismic response estimation for reinforced concrete building, and iv) structural damage assessment. The equivalent linear analysis method for site seismic response analysis and the equivalent lateral force method for structure seismic analysis are incorporated to investigate the site effects on building fragility information. A 15-story shear wall-structure is selected as an application to demonstrate the procedure. By comparing the damage distribution under the acceleration response spectra with 63%, 10%, and 2% probability of exceeding in 50 years at rock site and specified site, it can observed that the site effect is very important, then seismic environment and site condition should be considered at same time when seismic performance is estimated

1. INTRODUCTION

The estimation of probable future damages is very importance to those responsible for physical planning on an urban, economic planner on a national scale, the insurance company, reinsurance company, responsible for civil protection and those who own or manage large numbers of buildings, and who draft building regulation or codes in earthquake-prone regions[1].

The soil plays a very important role in determining the characteristics of the damage distribution. The influence of local soil conditions on the nature of earthquake damage has been recognized for many years. As early as 1906, during the great San Francisco earthquake it was realized that damage was more severe at downtown situated on a soft ground than the surrounding areas [2]. The 1967 Caracas, Venezuela earthquake total destroyed a number of high-rise buildings. All the buildings of over 14 storeys which collapsed in the earthquake were in a single suburban area, Los Palos Grandes, which lies close to the deepest layer of alluvium underlying the city [3]. The 1985 Mexico City earthquake caused only moderate damage in the vicinity of the Pacific coast of Mexico, but caused extensive damages some 350 km away in Mexico City. Structural damages in Mexico City were also highly selective. Large parts of the city

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experienced no damage while areas underlain by 38-50 m of soft soil suffered pronounced damages [4]. Subsequent studies showed very clear relationships among the depth of alluvium, natural period and structural damage probability. Damage levels are very high, as would be expected when the natural period of vibration for soil and building are close [5]. Although the seismologists and geotechnical earthquake engineers have worked towards the development of quantitative methods for predicting the influence of local soil conditions on strong ground motion, the study of the site effects on damage probability distribution are not popular. In this paper, the procedure incorporates the probabilistic seismic hazard assessment, site-specific seismic response analysis and structural seismic response estimation into an integrated framework to estimate the seismic performance and seismic damage.

2. THE INTEGRATED FRAMEWORK OF SEISMIC DAMAGE ASSESSMENT

2.1 Probabilistic seismic hazard assessment

Probabilistic seismic hazard analysis (PSHA) provides a framework in which uncertainties in the size, location, and rate of recurrence of earthquakes and in the variation of ground motion characteristics with earthquake size and location can be identified, quantified, combined in a rational manner to provide a more complete picture of the seismic hazard. The site hazard can be evaluated by four-step process: identification and characterization of earthquake sources; characterization of the seismicity or temporal distribution of earthquake recurrence; determination of the ground motion produced at the site by earthquakes of any possible size occurring at any possible point in each source zone; calculation of the exceeding probability of the ground motion parameter. The seismic hazard can be calculated as following:

$$P\left[Y > y^*\right] = \iint P\left[Y > y^* \middle| m, r\right] f_M(m) f_R(r) dm dr \tag{1}$$

where $P\left[Y > y^* \middle| m, r\right]$ is obtained from the predictive relationships and $f_M(m)$ and $f_R(r)$ are the probability density functions for magnitude and distance, respectively. In this paper, the seismic hazard is specified in terms of spectral acceleration.

2.2 Site-specific response analysis

One-dimensional equivalent linear approach is used to evaluate ground surface motions for development of site response spectra. They will be used to assess the seismic damage of the building shown in Fig.1. The evaluation of the bedrock motion characteristics at the site is based on probabilistic seismic hazard analysis. Based on one-dimension ground response model, which the soil and bedrock surface are assumed to extend infinitely in the horizontal direction, the responses of the soil deposit to the motion of bedrock immediately beneath it are determined. The nonlinearity of soil behavior is taken into consideration, by equivalent linear approximation of nonlinear response.

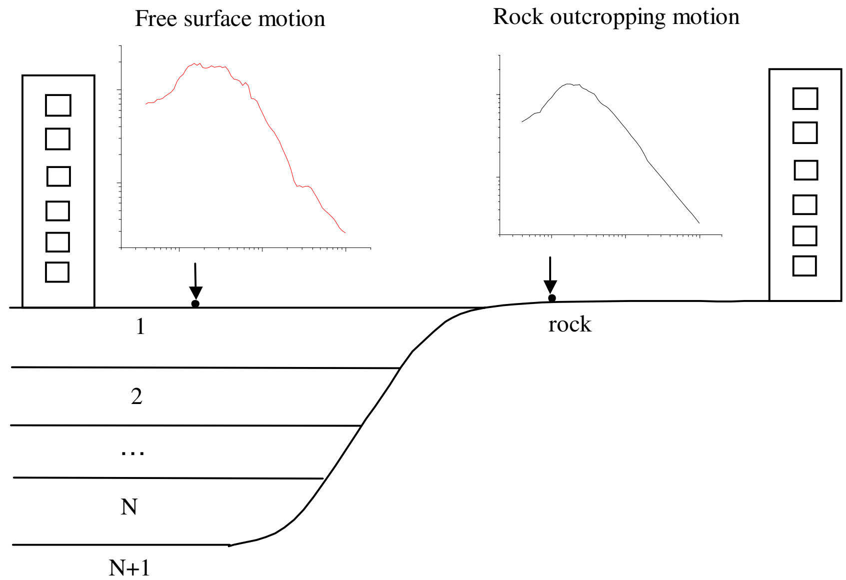


Fig. 1 The model of site response analysis and seismic damage assessment

2.3 Structural seismic response analysis

2.3.1 Seismic story shear

The structure is modeled as multidegree-of-freedom system, which is subject to ground motion. It is assumed for building that the mass of the structure is lumped at the center of mass of the individual story levels. The main lateral resisting structural elements are provided by columns, shear walls. By applying the equivalent lateral force method, the shear force at the x story is given by summing all lateral seismic forces above that story, i.e.

$$Q_x = \sum_{i=x}^{n} \frac{G_i H_i}{\sum_{j=1}^{n} G_j H_j} G_{eq} \cdot S_a(T) \cdot (1-\delta_n) + \delta_n \cdot G_{eq} \cdot S_a(T) \qquad (2)$$

where $S_a(T)$ is the site response spectral acceleration in g units corresponding to the fundamental natural period, and G_i, G_j, H_i, H_j are the weight and height at the level i and j of the building respectively, n is the total of number of stories of the building. δ_n is the additional seismic action coefficient, and G_{eq} is the total equivalent weight of a structure.

2.3.2 The mean story yield shear coefficient

The mean story yield shear coefficient, which shows that the nonlinear deformation concentration, is obtained by Eq. (3)[6]

$$R = \frac{Q_{yx}}{Q_x} \tag{3}$$

Where Q_{yx} is yield shear of story x. For frame structure with shear walls, it can be estimated as

$$Q_{yx} = 0.2 F_C A_{wx} \tag{4}$$

Where: F_C is compressive strength of concrete and A_{wx} is total sectional area of columns and shear walls which are parallel to the earthquake action in story x. Many studies show that, non-linear deformation will concentrate at the weakest stories, which correspond to the minimum R in Eq. (3).

2.3.3 Structural response ductility factor

The maximum story ductility factor is a key parameter indicating building damage. The story with minimum yield shear coefficient experiences the maximum deformation and attains the maximum ductility factor. In the linear range, the story yield shear coefficient-ductility relations can be obtained by the ductility factor definition, beyond the elastic range, the elastoplastic relations between ductility factor and story yield shear coefficient may be rationally obtained by the equivalence of the energy between the elastic and the inelastic system. The following formula for the maximum mean ductility factor μ_0 of frame structure with shear wall:

$$\mu_0 = \begin{cases} \dfrac{1+R^2}{2R^2} & R \le 1 \\ \\ \dfrac{1}{R} & R > 1 \end{cases} \tag{5}$$

where R is the minimum yield story shear coefficient calculated for Eq. (3). This formula can further be refined by adding correction factors C_i to the maximum mean ductility factor:

$$\bar{\mu} = \mu_0 \left(1 + \sum C_i\right) \tag{6}$$

One is interested primarily in the probabilistic nature of maximum structural response to ground motions. Earthquake ground motion is stochastic, structural response is random too. Naturally, a higher maximum mean ductility implies a more severely damaged building. But, due to the uncertainties involved in the estimation of ground motion input as well as in the analysis of structural response, the ductility as well as the damage state is better represented in terms of probability functions. It is found that ductility factor distribution satisfies a lognormal probability distribution. The probability density function can be measured in terms of story ductility factor by log-normal distribution given by Eq.(7), when the building is subjected to different level ground motions[6].

$$f(\mu) = \frac{1}{\sqrt{2\pi}\xi\mu} \exp\left[-\frac{(\ln \mu - \lambda)^2}{2\xi^2}\right] \tag{7}$$

where

$$\lambda = \ln \overline{\mu} - \frac{1}{2}\xi^2, \qquad \xi^2 = \ln\left(1 + \frac{\sigma^2}{\overline{\mu}^2}\right) \tag{8}$$

in these equations, $\overline{\mu}$ and σ are, respectively, the maximum mean value estimated from Eq. (6) and standard deviation of ductility factor of the story. In this study we assume that the main uncertainty in the ground motion input. Thus, the value of $\sigma/\overline{\mu}$ is deduced from attenuation relationship used.

2.4 Damage probability distribution

The representation of the possible damage distribution depends on the approach of defining the earthquake hazard. It is proposed to characterize seismic hazard using specified probability of exceeding 63%, 10% and 2% in 50 years against which the fragility information is developed.

The ductility factor is selected as damage indices. Five damage states are adopted. For frame structure with shear walls, the threshold ductility factors for the onset of slightly damaged, moderately damaged, extensively damaged and completely damaged states are 1.0, 1.5, 3.0 and 5, respectively [6]. Using the threshold values of the ductility factor as integration limits, the probability of various damage states for specified seismic input can be integrated as:

$$P[D_j] = \int_{\mu_j}^{\mu_{j+1}} \frac{1}{\xi\mu\sqrt{2\pi}} \exp\left[\frac{-(\ln\mu - \lambda)^2}{2\xi^2}\right] d\mu \tag{9}$$

where μ_j and μ_{j+1} is respectively the threshold of ductility factor for damage state D_j and D_{j+1}.

3. ILLUSTRATIVE EXAMPLE

To illustrate the application of the integrated framework seismic performance estimate, an example is given in this section. Based on the study of seismicity, geology, tectonics, and attenuation relationships in the region, seismic hazard on the bedrock is specified in terms of response spectra. Figure 2(a) is spectral acceleration on rock having a 63%, 10% and 2% probability of exceeding in 50 years. Figure 2(b) is the spectral acceleration at free surface having 63%, 10% and 2% probability of exceeding in 50 years, which are obtained from equivalent linear approach using the site model characterized by measured shear wave velocity and soil density profile listed in Table 1. Figure 3 shows a schematic plan section and evaluation of a 15 story reinforced concrete structure on a site in Beijing which was designed according to the provisions of GBJ 11-89 seismic code and its seismic design level is seismic intensity of VIII. Fig.4(a) and Fig. 4(b) is the fragility information for the structure subject to specified probability of exceeding ground motions on rock and free surface. They clearly illustrate the importance of local soil conditions on damage probability distribution, especially for seismic hazard level specified by 2% probability of exceeding.

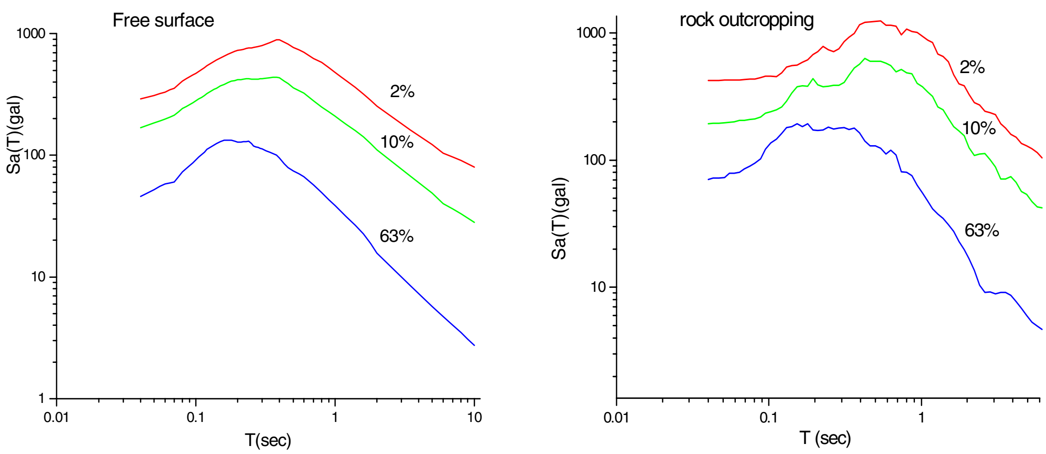
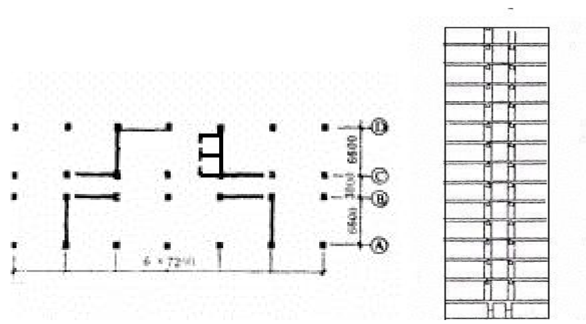


Fig.2 ground motion input in terms of response spectra on rock (a) and free surface (b)



(a) (b)

Fig. 3 Schematic plan section (a) and elevation (b) of 15-storey RC frame-shear wall

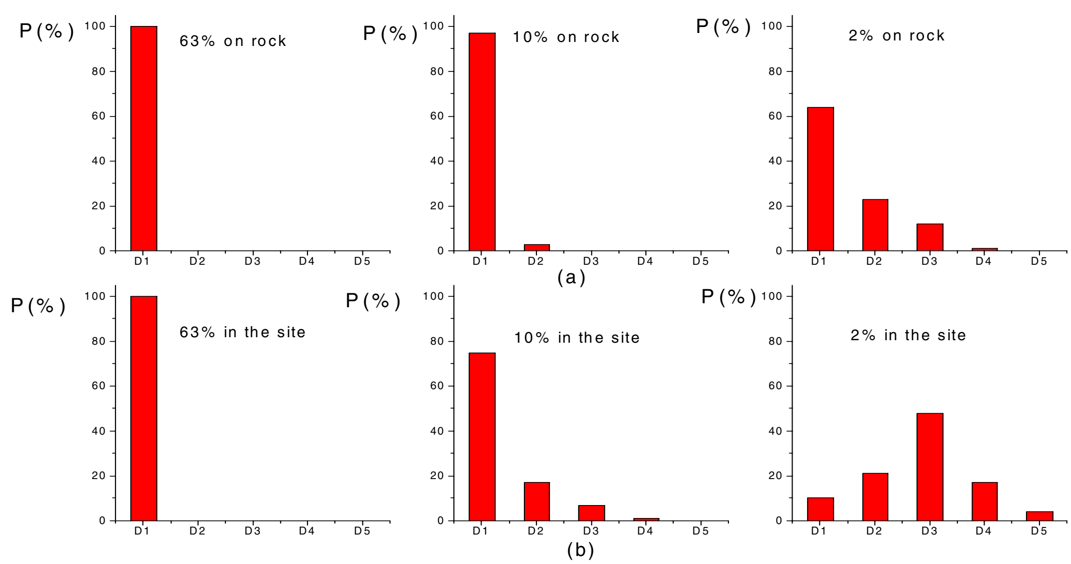


Fig. 4 The fragility information for the RC subject to 63%,10% and 2% probability of exceeding ground motions in 50 years on rock (a) and free surface (b)

Table1. The shear wave velocity and density profile of the model

Depth of soil layer (m)	Velocity(m/s)	density(kg/m^3)
0.0¡«2.7	165	1970
2.7¡«6.9	185	2030
6.9¡«11.8	210	2020
11.8¡«14.2	240	1970
14.2¡«17.6	280	1890
17.6¡«21.2	310	2020
21.2¡«25.3	345	2020
25.3¡«33.2	380	2000
33.2¡«34.7	410	1980
34.7¡«39.3	450	2000
39.3¡«40.4	420	1950
40.4¡«42.9	400	1960
42.9¡«45.2	410	1970
45.2¡«53.5	420	2000
53.5¡«58.1	445	1820
58.1¡«65.0	465	2000
65¡«70	490	2000
70¡«	530	2000

4. DISCUSSION AND CONCLUSION

Local soil conditions can have great effects on earthquake damage. They can profoundly influence the important characteristics –amplitude, frequency- of strong ground motions. The extent of their influence depends on the geometry and material properties of the subsurface materials, on site topography, and on the characteristics of the input motions. Heavy damages often occur because of selective amplification of ground motion at the frequencies critical to structure response. It is important to take site effects and rock input motions into a seismic performance and seismic damage estimate.

The procedure is integrated seismic hazard assessment, site seismic response analysis, and structural seismic response analysis into a framework of seismic performance estimation which could be considered the effects of seismic environment and site condition on seismic damage. It can consider the frequency characteristics of seismic environment, soil and the structures on damage and loss estimation. This integrated procedure can reveal the seismic damage selectiveness.

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