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Seismic Performance Assessment by Fragility and Loss Estimation

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Summary

A methodology for assessing the seismic performance of a system with structural and nonstructural components is developed using fragility analysis and loss estimation. System properties, seismic hazard characterization and performance criteria are required to calculate system fragility, and estimate losses and recovery times. A structural/nonstructural system located in New York City is used to demonstrate the methodology. Fragility surfaces for different limit states and cost histograms are obtained.

Introduction

Several methods are available for calculating component fragility information. In HAZUS (1999), lognormal distributions are used for structural and nonstructural component fragility. Fragility of components may also be obtained through testing. In Badillo-Almaraz (2003), experimental fragility curves are obtained for suspended ceiling systems using short period spectral acceleration as the intensity of the ground motion. System fragility information can also be obtained by Monte Carlo simulation and system reliability analysis. A methodology for calculating the reliability of nonstructural systems from the fragility of their components is presented in Grigoriu and Waisman (1998), in which components are assumed to have random independent properties and behave statically. Once the fragility of the system is obtained and the lifetime is selected, the seismic performance can be evaluated using a seismic hazard model and a financial model. A methodology is presented in this paper for assessing the seismic performance of a system by its fragility analysis and loss estimation.

Methods

Figure 1 illustrates the framework of the methodology presented. System definition (structural, nonstructural, geotechnical), characterization of the seismic hazard (a seismic activity model, a seismic ground acceleration model, lifetime) and performance criteria (limit states, a financial model) are used to evaluate the seismic performance of the system through fragility analysis and loss estimation. System performance and available resources can be further used to calculate the restoration time. The overall objective is to enhance the seismic resiliency which is characterized by reduced probability of system failure, reduced consequences due to failure and reduced time to system restoration.

Seismic performance assessment by fragility and loss estimation consists of two main steps. First, system fragility information is obtained. Then, the loss is estimated through a cost-benefit analysis consisting of (1) a time horizon, (2) seismic hazard at the site of interest and (3) cost functions including, for example, retrofit and repair costs, loss of use, and loss of life, as well as some potential monetary benefits of retrofit, such as rent increase.

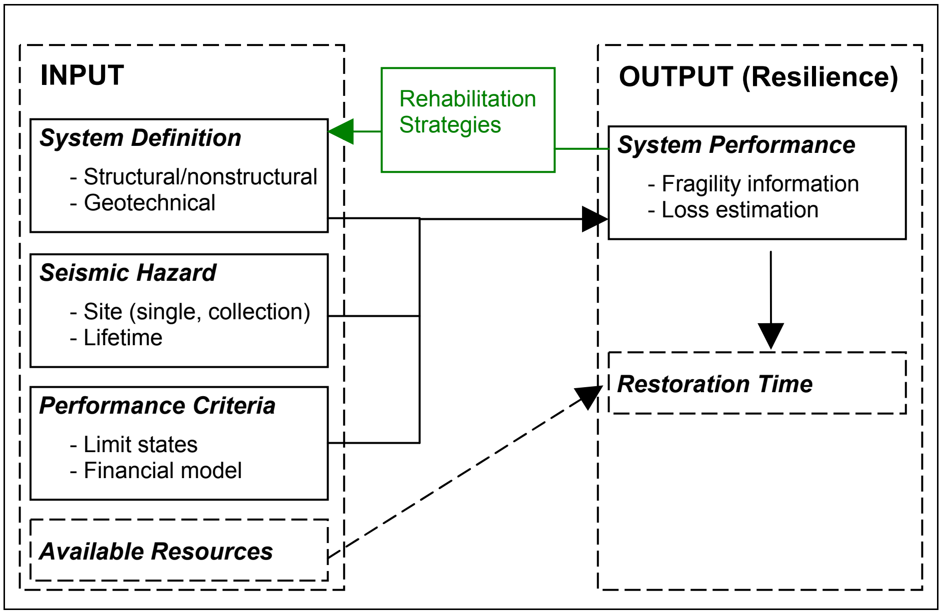

Figure 1. Framework of the methodology

Suppose that a system experiences an earthquake with magnitude m, occurring at a seismic source at distance r from the system site. Following the earthquake, the system enters a damage state, $d_s(m;r)$, with a probability, $p_s(m;r)$, given by the system fragility surfaces. Suppose also that the system is repaired so that it is brought to its initial state immediately following this earthquake. Denote by c_s the cost of bringing the system from damage state, $d_s(m;r)$, to its initial state. This elementary cost structure presented here for illustration can be augmented to include the components mentioned above. Consider now a sample of the seismic hazard at the system site. Let $(m_i;r_i)$ denote the values of $(m;r)$ corresponding to earthquake i in a sample of the seismic hazard. The corresponding damage states, $d_s(m_i;r_i)$, and their probabilities, $\mathrm{p}_\mathrm{s}(m_i;r_i)$, result from the system fragility surfaces. Denote by c_s the repair cost associated with the damage state, $d_s(m_i;r_i)$. Since damage state s has the probability, $p_\mathrm{s}(m_i;r_i)$, the repair cost for the seismic event i is $C_i = \Sigma_s\, c_s\, p_s(m_i;r_i)$. The total cost for this sample of the seismic hazard is $C = \Sigma_i\, C_i$. The cost C is a random variable, whose properties can be estimated from a collection of seismic hazard samples.

Numerical Example

Denote by S the structural system and NS the nonstructural system (e.g., water distribution system) consisting of two components, C_1 and C_2 (such as a water tank and piping system) of a health care facility located in New York City (see Figure 2). The assumptions for the system are as follows, (i) soil-structure interaction is not considered, (ii) all systems are linear, (iii) cascade analysis applies and (iv) S is highly reliable compared to NS. The specific barrier model (Papageorgiou and Aki, 1983a and b) is used to characterize seismic ground accelerations at the site. Linear random vibration theory, Monte Carlo simulation and crossing theory for stochastic vector processes (Veneziano et al., 1977) are used for the analysis.

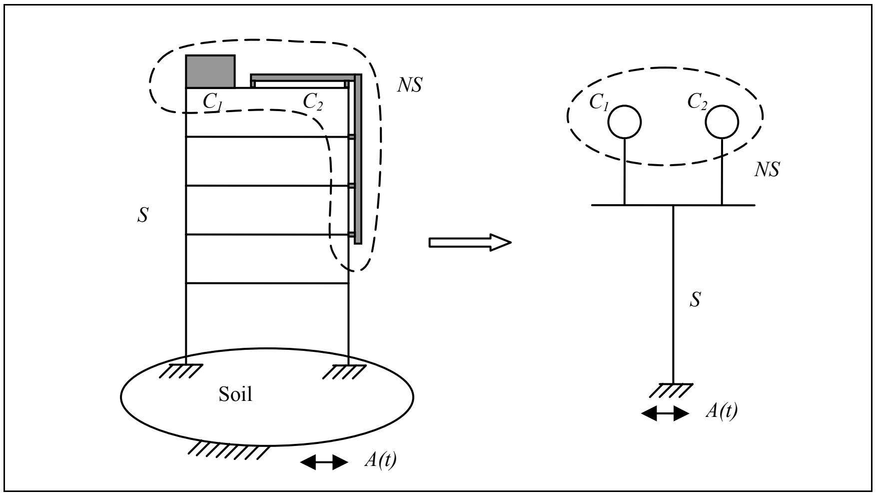

Figure 2. Structural and nonstructural systems

Two rehabilitation strategies are considered, system with *no rehabilitation* and system with *rehabilitation*. Properties of the two systems are given in Table 1.

Table 1. System definition

	S	C_1 **(no rehab)**	C_2 **(no rehab)**	C_1 **(rehab)**	C_2 **(rehab)**
Natural frequency	5	11	12	18	17
Damping ratio	0.050	0.015	0.020	0.020	0.025

Figure 3 shows the seismic activity matrix and a sample of the seismic hazard in NYC assuming that the lifetime of the hospital is 50 years.

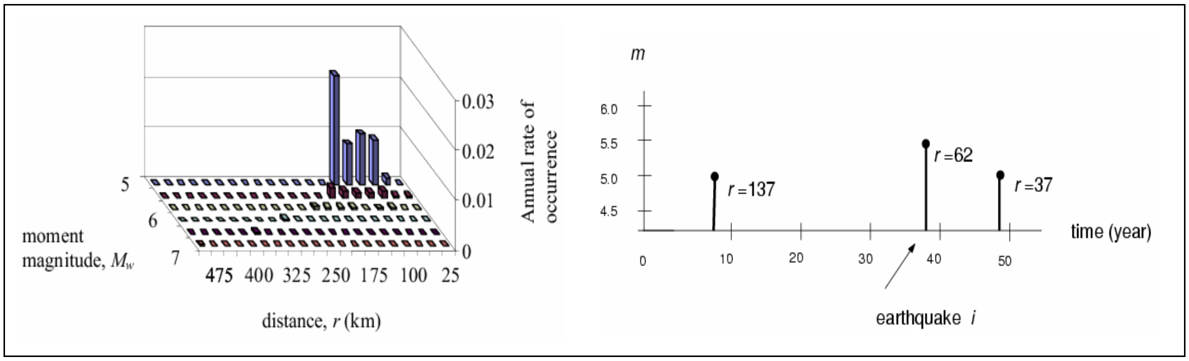

Figure 3. Seismic hazard for NYC

Two limit states, representing moderate and extensive damage, for the responses of components C_1 and C_2, are given in Table 2.

Table 2. Performance criteria

Damage state	Displacement response of C_1	Velocity response of C_2
Moderate	0.5	0.4
Extensive	1.0	0.8

The parameters of the financial model are shown in Table 3.

Table 3. Financial model

Interest rate (%)	Discount rate (%)	Percent financed	Repair costs ($) Moderate	 Extensive	Rehabilitation costs ($)
0.12	0.15	0.60	25,000	75,000	50,000

Results

The fragility surfaces for the components C_1 and C_2 and for the nonstructural system NS are obtained for the two rehabilitation alternatives for each damage state. Fragility surfaces for the *no rehabilitation* case and for *extensive* damage state are shown in Figure 5. Cost histograms for the two rehabilitation strategies are given in Figure 6.

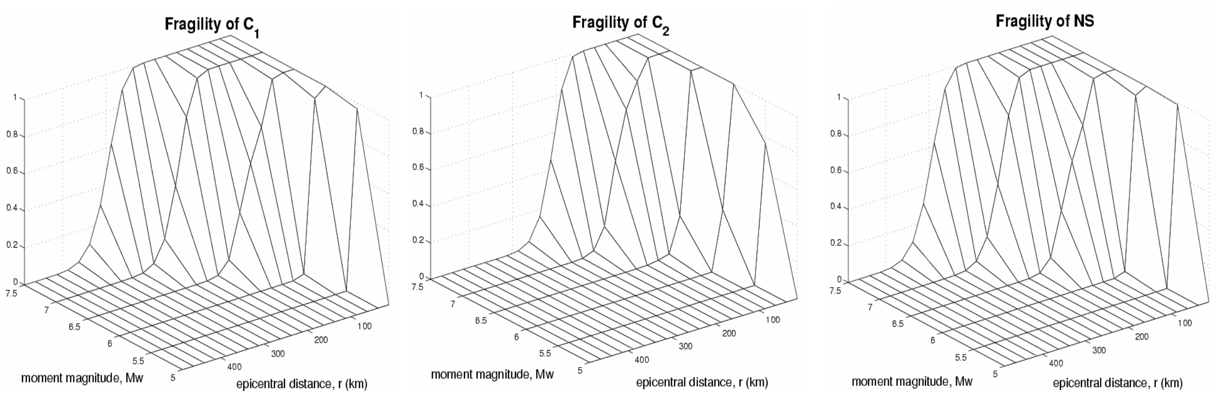

Figure 5. Fragility surfaces

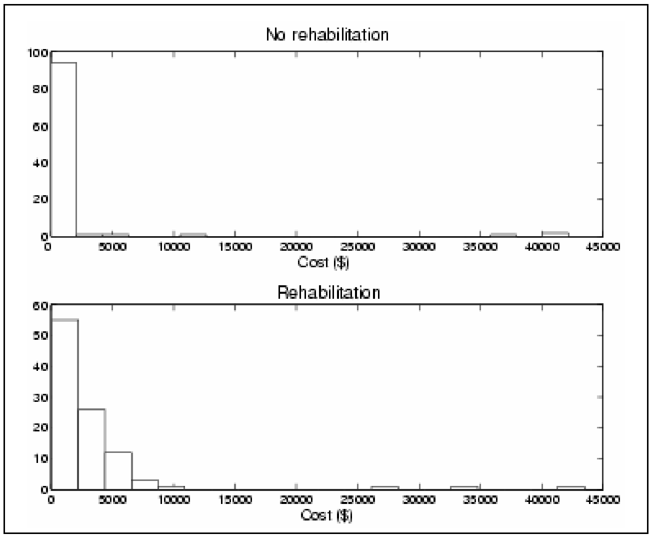

Figure 6. Cost histograms

Conclusions

A methodology for assessing the seismic performance of a system with structural and nonstructural components is presented. The methodology uses system properties, characterization of the seismic hazard, and performance criteria to assess the system performance through fragility analysis and loss estimation. A numerical example is presented. Two retrofitting strategies for the nonstructural system, representing a water distribution system, are considered: *no rehabilitation* and *rehabilitation*.

The optimal strategy for the water distribution system is *no rehabilitation*.

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