SIMPLIFIED BUILDINGS FRAGILITY FUNCTIONS FOR REGIONAL SEISMIC RISK ASSESSMENT

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ABSTRACT

One of the challenges in regional seismic risk assessment studies is to generate a reliable inventory of the exposed buildings. To decrease the potential errors in identification of structural load carrying systems, a simplified building classification scheme is proposed with: one reinforced concrete building class Cs which regroups generic building classes indicated as C1, C2 and C3; and a steel building class Ss combining S1, S2, S4 and S5 generic building classes. Simplified fragility curves (SFC) representative for these combinations were developed by fitting lognormal curves through individual damage estimates for the generic classes. The average absolute deviations measured for each SFC were below 3.6\%, which is considerably lower than errors observed in the building inventories, \~20\%. Knowing that significant effort is needed to generate accurate regional inventories, this simplified method offers reasonable accurate damage estimates for reduced building classification scheme.

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Simplified building fragility functions for regional seismic risk assessment

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One of the challenges in regional seismic risk assessment studies is to generate a reliable inventory of the exposed buildings. To decrease the potential errors in identification of structural load carrying systems, a simplified building classification scheme is proposed with: one reinforced concrete building class Cs which regroups generic building classes indicated as C1, C2 and C3; and a steel building class Ss combining S1, S2, S4 and S5 generic building classes. Simplified fragility curves (SFC) representative for these combinations were developed by fitting lognormal curves through individual damage estimates for the generic classes. The average absolute deviations measured for each SFC were below 3.6%, which is considerably lower than errors observed in the building inventories, ~20%. Knowing that significant effort is needed to generate accurate regional inventories, this simplified method offers reasonable accurate damage estimates for reduced building classification scheme.

Introduction

Identification of the pertinent building class whether it is done by visual screening or by interpretation of the information available in the municipal property assessment databases involves significant uncertainties in the order of 20%, in particular for a large inventory of buildings [1]. In many cases, the gravity and lateral load carrying system is hidden behind the façade and the internal walls, making difficult the distinction between frame, wall or braced frame buildings. The identification of the structural system should therefore require detailed on-site checks and consultation of as built plans, a tedious and time-consuming process. Recently, an integrated web-application, referred to as ER², has been developed for interactive user-friendly regional seismic risk assessment [2]. The damage assessment in ER² relies on sets of fragility curves for the 128 generic building classes as adopted by FEMA’s Hazus [3]. The ER² fragility curves were determined as explicit functions of the input intensity measures (IM) determined with spectral accelerations Sa(0.3s) and Sa(1.0s) [4,5]. This allows running seismic scenario within minutes. To further increase the efficiency and reduce the potential inventory uncertainties, a simplified building classification scheme is proposed herein. Sets of simplified fragility curves (SFC) representative for these combinations of the generic building classes are also proposed. This paper presents the approach applied to regroup the building classes according to their structural material, load carrying system and potential dynamic behavior, and the generation of the SFCs as functions
of the magnitude and Sa(1.0s).

**ER² database of damage probabilities**

The maximal structural response of a specific building class, referred to as the ‘performance point’, is obtained using the capacity spectrum method [3,6,7]. To avoid the time consuming iterative process usually involved in the determination of the performance point, fragility curves in ER² are expressed as explicit functions of the earthquake magnitude and the input IMs [4,5]. A database of pre-computed damage estimates for IMs of the magnitude-distance-site condition scenarios was generated for each of the 128 standard generic building classes defined in Hazus [3]. One hundred earthquake scenarios were generated by permutations of 4 magnitudes (M5, M6, M7, M8), 5 distances (10, 20, 30, 40 and 60km) and 5 site classes (A, B, C, D, E). Then, performance points, respective probabilistic damage states and associated IMs were tabulated in tables for different ground motion prediction equations: two for Eastern North America (ENA) and one for Western North America (WNA) [8,9,10], for a total of 153,600 combinations. These databases can be used for assessing the expected building damage state and corresponding economic and social losses for any potential level of seismic shaking (magnitude-distance-site condition scenarios).

**Optimization approach**

To reduce the uncertainties related to the building inventory, a simplified building classification scheme is introduced herein. The most frequent structural systems that are expected to have similar seismic vulnerability (e.g., same construction material, similar height and design code level) were regrouped together. Proposed are (i) reinforced concrete building class Cs which regroups lateral force resisting systems indicated initially as C1, C2 and C3, and (ii) steel building class Ss which regroups lateral force resisting systems indicated as S1, S2, S4 and S5. Table 1 presents the simplified classification for concrete and steel structures, where the combination of the height and design code level (low-code and pre-code) produces 12 classes compared to the 42 generic building classes defined in Hazus. The new building classes Cs and Ss have the same height and design code as the generic classes. The major assumption was that for aggregated building inventories the vulnerability of C1, C2 and C3 generic classes, found in the same census tract, can be averaged given they have comparable height and design code.

Table 1. Proposed simplified building classes.

<table>
<thead>
<tr>
<th>Material</th>
<th>Description / Lateral force resisting system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Buildings</td>
<td>Concrete moment frame (C1), Concrete shear walls (C2), Concrete frame with unreinforced masonry infill walls (C3)</td>
</tr>
<tr>
<td>Steel Buildings</td>
<td>Steel moment frame (S1), Steel braced frame (S2), Steel frame with cast in place concrete shear walls (S4), Steel frame with unreinforced masonry infill walls (S5)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Label</th>
<th>Height</th>
<th>Code Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cs</td>
<td>Low-rise</td>
<td>Pre-code</td>
</tr>
<tr>
<td></td>
<td>Medium-rise</td>
<td>Low-code</td>
</tr>
<tr>
<td></td>
<td>High-rise</td>
<td></td>
</tr>
<tr>
<td>Ss</td>
<td>Low-rise</td>
<td>Pre-code</td>
</tr>
<tr>
<td></td>
<td>Medium-rise</td>
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</tr>
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<td></td>
<td>High-rise</td>
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</tr>
</tbody>
</table>

Before generating the SFC for the proposed building classification, comparative analyses were conducted to determine which IM represents better the seismic scenario in terms of risk assessment and exhibits less scatter to the magnitude-distance-site class scenarios for a given building class. The displacement demands at the performance points for the scenarios extracted from the ER²
global database were compared to the performance points in terms of both $\text{Sa}(0.3\text{s})$ and $\text{Sa}(1.0\text{s})$ for the generic buildings classes. Each scenario generated 1275 data points per building class. It was observed that in general, data points of the considered scenarios show considerably less scatter to the full magnitude-distance-site class scenarios when correlated to $\text{Sa}(1.0\text{s})$ when compared to $\text{Sa}(0.3\text{s})$. $\text{Sa}(1.0\text{s})$ was therefore selected as the only IM. The optimization process continued with the development of SFC for the proposed combined building classes, Cs and Ss, expressed in terms of the earthquake magnitude and a single IM, $\text{Sa}(1.0\text{s})$, which incorporates the epicentral distance and local soil class. Fig. 1 shows the ranges of damage probabilities for the four damage states for the two groups of generic building classes separately: low-rise pre-code C1, C2 and C3 (Fig. 1a) and low-rise pre-code S1, S2, S4 and S5 (Fig. 1b). It also shows the corresponding fragility functions for the proposed combined building classes Cs and Ss.

The discrete data points in Fig. 1 were extracted from the ER$^2$ global database for ENA earthquake scenarios. There are between 2000 and 2800 data points for each damage state in each graph. The SFCs are presented in terms of two magnitude ranges: $M<5.5$ and $5.5<M<7.5$, which generate short and medium strong motion duration, respectively [7]. Average absolute deviation was calculated for each SFC as a measure of the fitting efficiency. As can be observed in Fig. 1, the maximum values are generally below 2% for extensive and complete damage states and below
2.5% for moderate damage state. They are the highest for the slight damage state, yet below 3.6%.

Conclusions

A simplified building classification scheme was proposed for a combination of the generic reinforced concrete building classes (C1, C2, C3) and of the steel building classes (S1, S2, S4, S5). The objective was to reduce the significant effort in generating regional building inventories aggregated mainly at a census tract level. Respective simplified fragility functions were obtained by fitting lognormal curves into the damage estimates of the generic building classes for selected seismic scenarios. The generated errors were below 3.6%. This is considerably lower than the errors observed in the inventory of the exposed buildings obtained by visual screening or by interpretation of the municipal property assessment databases, which can amount to 20%. The authors acknowledge that grouping different structural systems under a single category does not imply that the seismic behavior would be identical or narrowly similar. Knowing that significant effort is needed to generate accurate regional inventories, the objective was rather to provide a simplified method that will generate reasonable accurate damage estimates for reduced building classification scheme.

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