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A RAPID VISUAL SEISMIC ASSESSMENT PROCEDURE FOR RC FRAME BUILDINGS IN INDIA

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ABSTRACT

There is a need to develop suitable screening methods for seismic safety of existing buildings relevant to Indian building typologies so that prioritization may be undertaken on the deficient buildings. Based on systematic studies on damage data of 270 buildings in Ahmedabad during the 2001 Bhuj (M7.7) earthquake, a rapid visual screening procedure is proposed for RC frame buildings in India. An expression has been developed for assigning Performance Scores to buildings based on presence or absence of some very general, broad based, and easily observable vulnerability parameters that can be seen from a sidewalk type survey.

Introduction

Though there have been some efforts in India towards developing rapid visual screening methods—Sinha and Goyal (2004), and Appendix to Draft IS 13935 (2004)—neither have been calibrated on actual building damage data from an Indian earthquake. At the same time, India has a huge stock of vulnerable buildings as recent earthquakes have clearly demonstrated. Hence there is an urgent need to develop rapid visual seismic evaluation tools for Indian buildings. Similar methods developed in other countries such as USA (FEMA 2002) and Turkey (BU-ITU-METU-YTU 2003) may not be applicable to Indian buildings in view of substantial variations in Indian construction practices resulting in different choices of vulnerability parameters and corresponding performance points. This paper summarizes a study conducted on 270 multistory RC frame buildings in Ahmedabad that were damaged during 2001 Bhuj (M7.7) earthquake in India. Based on detailed statistical analyses, a screening procedure has been proposed requiring a sidewalk survey from outside the building.

The state of Gujarat in India was impacted by the Bhuj Earthquake of January 26, 2001. The built environment performed very poorly in this earthquake with entire towns such as Gandhidham, Bhuj, Anjar, Bachau and Rapar being reduced to rubble with many fatalities and

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injuries (e.g., Jain et al. 2002a). Of particular significance was the collapse of 130 RC frame buildings in Ahmedabad city located around 250 kms from the epicentre. The building damage in Ahmedabad city was documented in the post-earthquake building surveys and this data was made available for the present study. The RC frame buildings of Ahmedabad are fairly good representative of RC frame design and construction practices in a major part of the country.

Sample Surveys

Around 6670 buildings of Ahmedabad were surveyed by a team from Centre for Environmental Planning and Technology (CEPT) University, Ahmedabad after the earthquake. These buildings were assigned different damage grades based on some qualitative criteria ranging from G0 implying no damage to G5 implying collapse. A smaller subset of 3720 RC frame and load bearing masonry buildings from the original survey was available with CEPT University. 101 and 169 RC frame buildings were shortlisted from this data set in two phases of survey, Phase I and Phase II, respectively. A third sample, combining the cases from Phase I and Phase II, referred to as Combined Sample was also considered for the statistical analyses. While the Phase I survey included detailed building information through extended site visits and study of architectural and structural drawings, in Phase II, a rapid visual survey was undertaken wherein survey teams of 2-3 members visited each building site for 10-15 minutes observing the vulnerability parameters from the ground floor only. Table 1 shows the distribution of different damage grades in the two samples, where G1 is no damage/slight non-structural damage, G2 is slight structural damage, G3 is moderate structural damage, G4 is severe structural damage, and G5 is structural collapse (Jain et al. 2002b).

Table 1. Buildings in different damage grade categories in Phase I and Phase II Samples

Damage Grade Category	**Number of Buildings**	
	Phase I	Phase II
	101	169
G1	30	44
G2	24	59
G3	46	65
G4	01	01
G5	00	00

Selection of Parameters

In the sample surveys of Phase I and Phase II, eight parameters were considered. These are presence or absence of basement (determined through access ramps leading into it), number of storeys (where buildings with 5 and less number of storeys were considered as low-rise and above 5 storeys as high rise), quality of maintenance, symmetry of staircase location in the building plan, reentrant corners or horizontal offsets, open storey, stub (or floating) columns, and short columns. Each parameter was assigned a vulnerability score. When a parameter was present in a building, it was assigned a score of 1, and 0 otherwise with two exceptions. For the parameter "quality of maintenance," scores of 1, 0.5, and 0 were assigned for good, moderate and poor quality of maintenance, respectively. Very little correlation was found between the observed performance and number of storeys (3, 4 etc.), if low rise or high rise buildings were considered separately. Hence, for the storey height parameter, buildings above 5 storeys were considered as belonging to one group and assigned a score of 1 while those of 5 storeys and less were assigned a score of 0 (Table 2).

Table 2. Vulnerability parameters and scores

Parameter	**Title**	**Score**
x_0	Basement	Absent = 0, Present = 1
x_1	Number of Storeys	($N \leq 5$) = 0, ($N > 5$) = 1.
x_2	Maintenance	Good = 0, Moderate = 0.5, Poor = 1
x_3	Staircase asymmetry with respect to plan	Absent = 0, Present = 1
x_4	Re-entrant corners	Absent = 0, Present = 1
x_5	Open Storey	Absent = 0, Present = 1
x_6	Stub Columns	Absent = 0, Present = 1
x_7	Short Columns	Absent = 0, Present = 1

Proposed Model

The buildings belonging to the different damage groups were assigned values of Observed Performance Scores (OPS) of 100, 85, 70, 50, 25 and 0 for buildings in damage groups G0, G1, G2, G3, G4 and G5, respectively.

A detailed statistical analysis was performed on the Combined Sample. Several variable selection techniques were employed to identify statistically significant vulnerability parameters. Based on these, only six of these eight parameters x_0, x_1, x_2, x_4, x_5 and x_7 were included in further analysis. The following multiple linear regression equation is fitted to the Ahmedabad damage database for predicting the expected performance scores (*EPS*):

$$EPS = A + C_0x_0 + C_1x_1 + C_2x_2 + C_4x_4 + C_5x_5 + C_7x_7 \quad (1)$$

Here, the vulnerability parameters, x_i, are as defined in Table 2. It was felt that the Combined Sample did not adequately represent the building inventory of Ahmedabad as only few of the surveyed buildings had suffered very high or very low level of damage. SAS software was used to perform multiple imputation (MI) analysis (e.g., Rubin 1987) using parametric regression method, to account for inadequately represented cases of G0, G4 and G5 damage category buildings by adding a fixed number of missing cases to each of the three damage categories. It was observed that parameter estimates did not vary much as number of added missing cases was varied from 10 to 50. Details of the regression analysis can be found elsewhere (Jain et al. 2010). Based on these analyses, the following model is proposed to predict the *EPS*:

$$EPS = 85 + 10x_0 + 10x_1 - 20x_2 - 10x_4 - 10x_5 - 10x_7 \quad (2)$$

Consideration for Building Use

Building usage is often a governing factor in design and architectural considerations, requiring a departure from the regular structural patterns (e.g., residential buildings where grid layouts tend to become less regular). To study the effects of building usage, a linear regression analysis between OPS and building occupancy (=0 for residential buildings, and 1 otherwise) was performed on data of 2566 buildings. The expression for performance score was obtained as Performance Score = 77.3 + 3.2x_8 indicating that non-residential buildings had performed better in the earthquake. This is accounted for in the model by giving non-residential buildings a benefit of 5 points on the Basic Score.

Correctness of the Model

Correctness of fit between the EPS obtained by the proposed method, as compared to their OPS, was determined to check the level of correctness of the method. In order to get an idea as to how well the model predicts vulnerability, buildings of the Sample were classified based on their EPS. An EPS above 77.5 was considered as G1, between 60 and 77.5 as G2, between 37.5 and 60 as G3, and less than 37.5 was considered as belonging to G4 damage group. It was found that for the Combined Sample, the method has predicted the damage category correctly in 46% of the buildings and within one level of incorrectness for the 88% buildings. Further, only 16% buildings have not been classified conservatively. The rate of correct prediction was found to be higher for the higher damage grade categories, making the method quite suitable as an effective tool in prioritizing a large building stock for seismic safety assessment. The histogram of average absolute percentage error obtained using 1000 bootstrap samples drawn from the Combined Sample indicates that the errors range from 17% to 25%, with mean of the error being about 20%. Considering that the building performance is being assessed by very crude visual inspection, potentially by non-experts, without entering the building and without looking at the building plans or structural drawings, the proposed method is considered quite acceptable, and therefore could serve as an effective tool in prioritizing a large building stock for seismic safety assessment.

Summary and Conclusions

Reinforced Concrete (RC) frame buildings in India during past earthquakes performed very poorly. Identification of such seismically vulnerable buildings is a necessary first step in developing effective disaster mitigation programs for the community. The present study aims to develop a methodology for rapid visual assessment of a large building stock in India. A statistical analysis is performed on damage data of RC buildings during 2001 Bhuj earthquake using a set of six vulnerability parameters and a rapid visual screening procedure is proposed for seismic evaluation of frame buildings in India.

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