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SELECTING BUILDING VULNERABILITY FUNCTIONS FOR EARTHQUAKE LOSS ESTIMATION STUDIES

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ABSTRACT

In many cases, earthquake loss estimation (ELE) studies are conducted by selecting existing seismic vulnerability models (fragility/vulnerability functions) that had been originally derived for similar building typologies in other parts of the world rather than to develop customized functions that address the peculiar structural and non-structural characteristics of the respective building stock. The reasons for this are either to reduce the calculation efforts, especially when studies are conducted for large portions of the building stock, lack of available resources, or lack of information that would allow a detailed survey and data acquisition.

The present work illustrates the strength of the fragility/vulnerability functions' representativeness on the outcomes of ELE studies. Based on a test bed located in a seismically exposed region a comparison study between existing (collected, assigned) and user-defined (generated, customized) vulnerability functions is conducted.

INTRODUCTION

Vulnerability functions, which are one of the major component of earthquake loss estimation (ELE) studies, represent the structural capacity and behaviour of a certain building typology and define the probability of suffering a certain level of damage along a given ground motion intensity parameter.

In many cases, ELE studies are conducted by selecting existing vulnerability functions that had been originally derived for similar building typologies in other parts of the world rather than to develop customized functions that address the peculiar structural and non-structural characteristics of the respective building stock. The reasons for this are either to reduce the calculation efforts, especially when studies are conducted for large portions of the building stock, lack of available resources, or lack of information which does not allow for a detailed survey and data acquisition (D'Ayala and Meslem, 2013).

However, the selection of vulnerability functions that represent the peculiarities of the building stock can be the most challenging task in order to ensure a reliable earthquake loss assessment. For instance, HAZUS vulnerability functions (FEMA 2003) that were derived for buildings in the U.S. only, have been used in conducting ELE studies in many parts of the world: Romania (Vacareanu et al., 2004), India (Gulati, 2006), Algeria (Boukri et al., 2013), Venezuela (Bendito, 2014), among others. Typically, differences in construction techniques and detailing between different countries are significant, even when buildings are nominally designed according to similar code provisions.

Furthermore, most of these existing vulnerability functions from literature were generated using simplified assumptions to reduce the calculation efforts, e.g. by using 2D models, or ignoring, in case of infilled RC frame buildings, the contribution of infill panels in the seismic response by modelling them as bare frame structures. However, these assumptions may highly decrease the reliability and accuracy of the obtained results introducing significant epistemic uncertainties into the vulnerability function construction process.

The main scope of this article is to illustrate the sensitivity of the outcomes of ELE studies to the representativeness of vulnerability functions. This is done exemplarily for the city of Guwahati, capital of the state Assam in Northeast India, for which a comparison study between existing (collected, assigned) and user-defined (generated, customized) vulnerability functions is conducted.

CASE STUDY: GUWAHATI CITY, ASSAM STATE, NORTHEAST INDIA

For the evaluation of the vulnerability functions' sensitivity on the outcomes of ELE studies, the city of Guwahati (state of Assam, Northeast India) was chosen as the test bed (Figure 1). Guwahati is one of the most rapidly growing cities in India, at the same time being the most important hub of Northeast India. In 1971, the city's population was just 200,000 while the 2011 census revealed a population of more than 960,000 and population density of more than 2010 persons/km2. According to the zoning map of the Indian seismic building code IS 1893 (Part 1): 2002 (BIS 2002), Guwahati falls into the highest seismic zone (Zone V). In addition to the seismic risk, unplanned land use patterns of surrounding hills as well as a number of hillocks that are located within the city contribute to an additional landslide risk.

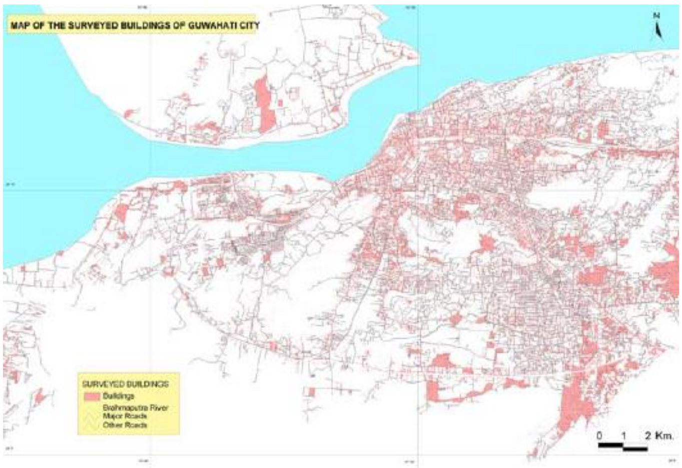


Figure 1. Existing building stock of the Guwahati Metropolitan Area (Pathak 2008)

BUILDING CLASSIFICATION SCHEME

The building classification scheme that is described herein resulted from various inventory surveys in Guwahati conducted by Assam Engineering College (AEC) in recent years as well as more recent investigations on the prevalent building stock. A more detailed description on the building typologies is provided in Pathak and Lang (2013). The compiled building classification scheme reflects the building typologies and materials identified in the Guwahati urban area as well as in several revenue villages around the city.

In the semi-urban and rural areas around the city, the traditional Assam-type houses had been and are still being replaced by confined masonry houses while a wide range of variations (especially with respect to used building materials) can be observed.

Table 1. Building typology classes observed in Guwahati City (reproduced from Pathak and Lang, 2013)

Guwahati Building Taxonomy								HAZUS–MH (FEMA 2003)
Classification		Lateral Load-Resisting System		Roof	Floor	STR-ID	Number of Storey	
		System Type	Material	System & Material	System & Material			
Wood	Load-Bearing Timber Frame	Ikra (Assam-type, wattle and daub)	Large timber frames with wattle-and-daub infills, cement plaster	Timber or steel truss, CI sheet	Timber or steel truss, CI sheet	IK-IGW	1 (2)	–
Masonry	Brick Masonry	Load-Bearing Wall	Unreinforced masonry wall made of rectangular fired clay bricks, with cement mortar	Timber or steel truss, CI sheet	Timber or steel truss, CI sheet	UMW11L-IGW	1	–
	Confined Masonry	Load-Bearing Wall	Masonry wall made of rectangular fired clay bricks, in cement mortar with reinforced concrete confinements	Timber or steel truss, CI sheet,	Timber or steel truss, CI sheet,	CMW11L-IGW	1-2 (3)	–
Reinforced Concrete	RC Moment Resisting Frame	Ductile moment resisting frame	RC frames, with unreinforced masonry infills made of rectangular fired bricks	RC slabs, (for low-rise: timber/steel trusses, CI sheets)	RC slabs, (for low-rise: timber/steel trusses, CI sheets)	RCF11L-IGW	1--3	C1L
						RCF11M-IGW	4--6	C1M
						RCF11H-IGW	7+	C1H
		Nonductile moment resisting frame	RC moment frame with unreinforced masonry infills made of rectangular fired bricks	RC slabs, (for low-rise: timber/steel trusses, CI sheets)	RC slabs, (for low-rise: timber/steel trusses, CI sheets)	RCF21L-IGW	1--3	C3L
						RCF21M-IGW	4--6	C3M
		Nonductile moment resisting frame with Open ground floor	RC moment frame with unreinforced masonry infills made of rectangular fired bricks	RC slabs, (for low-rise: timber/steel trusses, CI sheets)	RC slabs, (for low-rise: timber/steel trusses, CI sheets)	RCF22L-IGW	1--3	C3L
						RCF22M-IGW	4--6	C3M
	Dual System	Shear Walls with moment frames	RC shear walls and RC moment frames with unreinforced masonry infills made of rectangular fired bricks	RC slabs, (for low-rise: timber/steel trusses, CI sheets)	RC slabs, (for low-rise: timber/steel trusses, CI sheets)	RCD11L-IGW	1--3	–
						RCD11M-IGW	4--6	–
						RCD11H-IGW	7+	–
Steel	Light Metal Frame	Steel metal frames	Steel light frames	Steel trusses with CI sheets	Steel trusses with CI sheets	SLF-IGW	1 (2)	S3
	Moment Resisting Frame	Moment Resisting Frame	Steel frame with unreinforced masonry infills made of rectangular fired bricks	Steel trusses with CI sheets	Steel trusses with CI sheets	SF11L-IGW	1 (2)	S5L

However, these houses can also be found in large numbers in urban areas. The urban and sub-urban housing stock is dominated by reinforced-concrete frame buildings (with fired clay brick masonry infill walls) up to 8 stories high. There are a few commercial buildings with greater story numbers, i.e. ranging from ground floor plus 8 (G+8) to 10 stories (G+10). The observed construction technology and workmanship for these buildings are considered to be fairly good. The description of available building typologies is summarized in Table 1 along with the corresponding HAZUS (FEMA, 2003) typologies.

GENERATED (CUSTOMIZED) VULNERABILITY FUNCTIONS

The vulnerability functions have been generated based on the use of nonlinear static-based approaches, taking into account the dispersion due to the uncertainty in structural characteristics-related parameters, building-to-building variability, as well as the record-to-record dispersion in ground motion. The analyses have been based on the implementation of more than thirty 3D models. In the present paper, the study is limited to reinforced concrete (frame and dual) systems. Wood, masonry as well as steel buildings have not been considered so far.

Assuming a lognormal distribution, fragility curves are defined as the conditional probability of being in or exceeding a particular damage state ds_i given the spectral displacement S_d.

$$P\left[ds \geq ds_i \mid S_d\right] = \Phi\left[\frac{1}{{}_{ds_i}} ln\left(\frac{S_d}{\overline{S_{d,ds_i}}}\right)\right] \tag{1}$$

where, $\overline{S_{d,ds_i}}$ is the median value of spectral displacement at which the building reaches the threshold of damage state ds_i ; ${}_{ds_i}$ is the standard deviation of the natural logarithm of spectral displacement for damage state ds_i ; Φ is the standard normal cumulative distribution function. The resulted vulnerability parameters (medians and total dispersion) are shown in Table 2. The generated fragility curves are illustrated in Figure 2.

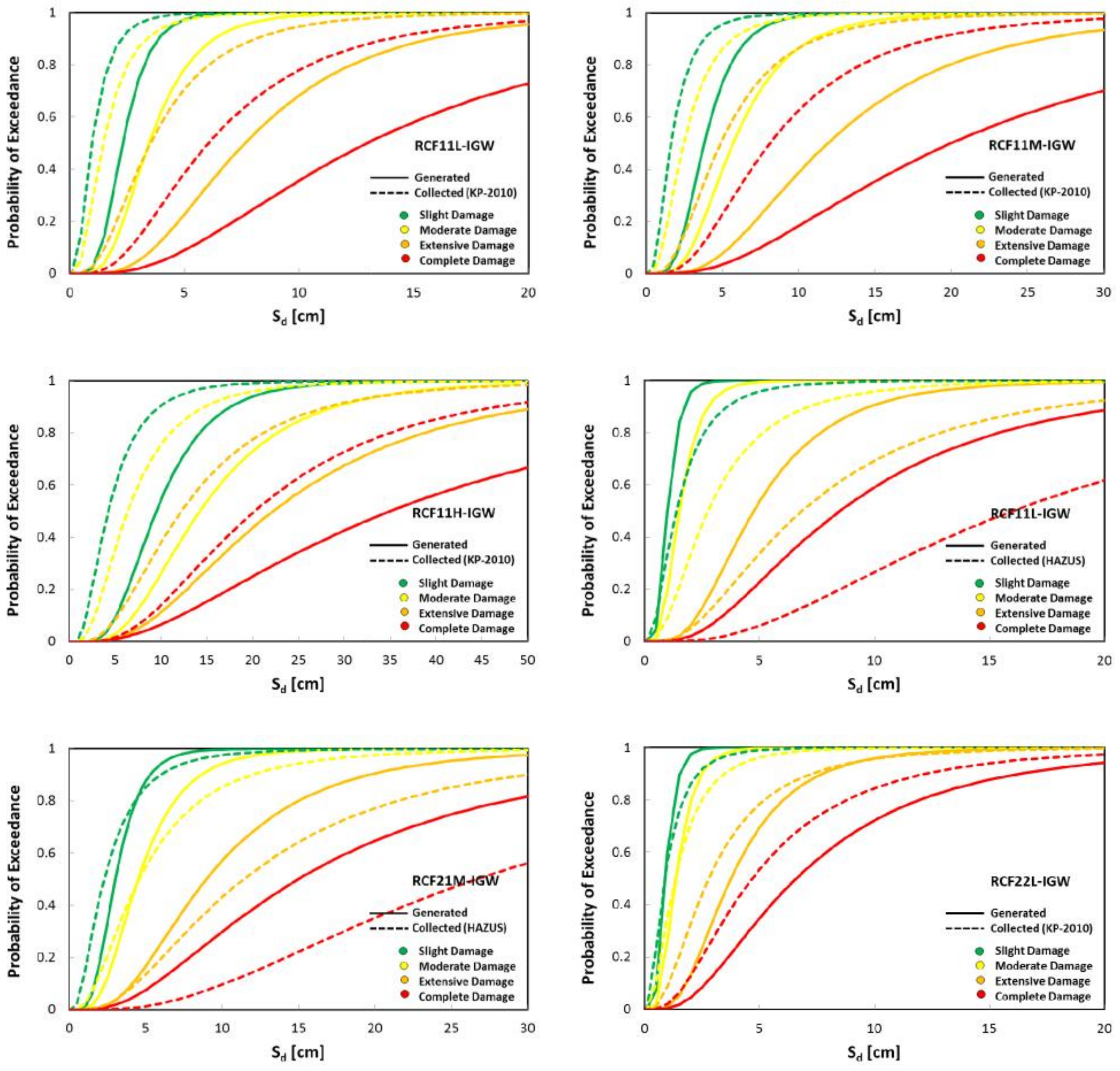
Table 2. Generated fragility functions for the existing RC buildings in Guwahati

Lateral Load-Resisting System		**STR-ID**	**Fragility Functions**							
			Slight Damage		**Moderate Damage**		**Extensive Damage**		**Complete Damage**	
			Median S_d [cm]	**β**	**Median S_d [cm]**	**β**	**Median S_d [cm]**	**β**	**Median S_d [cm]**	**β**
RC Moment Resisting Frame	Ductile moment-resisting frame	RCF11L-IGW	2.3	0.40	3.45	0.47	7.65	0.57	13.00	0.71
		RCF11M-IGW	3.8	0.44	5.70	0.51	11.90	0.61	20.00	0.77
		RCF11H-IGW	9.5	0.48	14.25	0.55	22.25	0.66	35.00	0.83
	Nonductile moment-resisting frame	RCF21L-IGW	1	0.40	1.50	0.47	4.75	0.57	8.50	0.71
		RCF21M-IGW	3	0.44	4.50	0.51	9.00	0.61	15.00	0.77
	Nonductile moment-resisting frame with Open ground floor	RCF22L-IGW	0.9	0.40	1.35	0.47	3.75	0.57	6.60	0.71
		RCF22M-IGW	2.5	0.44	3.75	0.51	7.25	0.61	12.00	0.77
Dual System	Shear walls with moment frames	RCD11L-IGW	2.8	0.40	4.20	0.47	11.85	0.57	20.90	0.71
		RCD11M-IGW	4.2	0.44	6.30	0.51	14.60	0.61	25.00	0.77
		RCD11H-IGW	9.5	0.48	14.25	0.55	27.25	0.66	45.00	0.83

COLLECTED (ASSIGNED) VULNERABILITY FUNCTIONS

A recently conducted extensive literature review (D'Ayala and Meslem, 2014) shows that there is a wealth of existing analytically derived fragility curves that can be used for future applications. However, the main challenge in using these functions is how to identify suitable ones in order to ensure a reliable earthquake loss assessment. In general, these existing functions have been derived using a variety of approaches, assumptions and methodologies that employ diverse structural modelling and analysis techniques. A range of sampling methods has also been applied to parameters of the structural models and seismic demand to account for uncertainties and intrinsic differences observable in the building stock and its response to seismic loading. It can therefore be difficult to appraise existing vulnerability functions, even when derived for the same structural typology class.

In the present study, two sets of fragility functions have been selected. The first set has been provided by HAZUS-MH (FEMA, 2003) which had been originally derived for similar building typologies prevalent in the United States. The second set of fragility functions has been provided by Kappos and Panagopoulos (2010; henceforth called KP2010) which had been originally derived for similar building typologies in Greece. Figure 2 compares between the generated (customized) fragility curves and the collected (existing, assigned) curves as provided by HAZUS-MH and KP2010 for each building typology considered in this study, respectively.



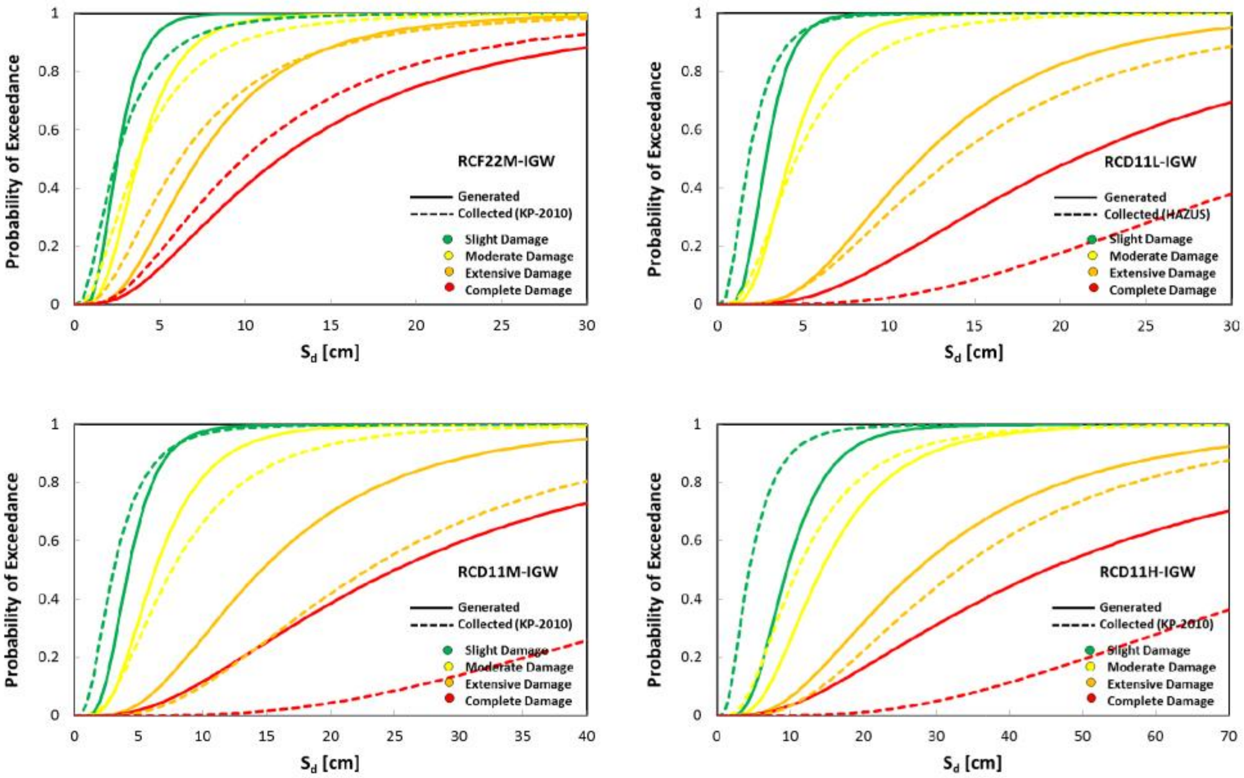


Figure 2. Comparison between the generated (customized) fragility curves and the collected (existing, assigned) fragility curves as provided by HAZUS-MH (FEMA, 2003) and KP2010 (Kappos and Panagopoulos, 2010)

RESULTS AND DISCUSSION

The result of this preliminary investigation indicates that the generated and collected vulnerability models may lead to significant differences in terms of earthquake damage and loss estimates. In terms of median capacity, the difference varies by a factor of 2.5 especially at the level of Extensive to Complete Damage. In terms of percentage of damage (damage ratio), the expected difference may reach a factor of 2 in most cases. Typically, differences in construction techniques and detailing between different countries are significant, even when buildings are nominally designed according to similar code provisions.

The selected sets of fragility curves from HAZUS as well as from KP2010 might not be considered as compatible with the Guwahati building stock and construction practice. In other words, the two sets of models cannot be used in the earthquake loss estimation (ELE) studies of Guwahati with sufficient/acceptable level of accuracy/confidence. This observation clearly indicates that vulnerability functions may have a very significant effect on the earthquake loss estimates.

CONCLUSIONS

This article presents results of a research study conducted within the framework of the EQRisk project “Earthquake Hazard Assessment and Risk Reduction on the Indian Subcontinent” funded by the Royal Norwegian Embassy to India. The main scope of this article is to illustrate the strength of the vulnerability functions representativeness on the outcomes of ELE studies. Based on a test bed from an earthquake-prone region in Northeast India, a comparison study between existing (collected, assigned) vulnerability functions and user-defined (generated, customized) vulnerability functions was carried out.

With respect to collected data, two sets of vulnerability functions were used. The first set of vulnerability functions had been originally derived for similar building typologies in the US. The second set of vulnerability functions had been originally derived for similar building typologies in Greece.

The comparison of the generated functions with the collected ones has shown a remarkable bias, leading to a significant difference in predicting the seismic performance of the building, and hence, earthquake damage and loss estimates. Typically, differences in construction techniques and detailing between different countries are significant, even when buildings are nominally designed according to similar code provisions.

The result from this study has clearly indicated that vulnerability functions may have a very significant effect on the earthquake loss estimates. Hence, special care should be given when selecting the existing vulnerability models that are available from literature, in order to ensure a reliable earthquake loss assessment.

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