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Sensitivity and Reliability Analysis of Masonry Infilled Frames

Avadhoot Bhosale, Robin Davis P., Pradip Sarkar

***Abstract*—**The seismic performance of buildings with irregular distribution of mass, stiffness and strength along the height may be significantly different from that of regular buildings with masonry infill. Masonry infilled reinforced concrete (RC) frames are very common structural forms used for multi-storey building construction. These structures are found to perform better in past earthquakes owing to additional strength, stiffness and energy dissipation in the infill walls. The seismic performance of a building depends on the variation of material, structural and geometrical properties. The sensitivity of these properties affects the seismic response of the building. The main objective of the sensitivity analysis is to found out the most sensitive parameter that affects the response of the building. This paper presents a sensitivity analysis by considering 5% and 95% probability value of random variable in the infills characteristics, trying to obtain a reasonable range of results representing a wide number of possible situations that can be met in practice by using pushover analysis. The results show that the strength-related variation values of concrete and masonry, with the exception of tensile strength of the concrete, have shown a significant effect on the structural performance and that this effect increases with the progress of damage condition for the concrete. The seismic risk assessments of the selected frames are expressed in terms of reliability index.

***Keywords*—**Fragility curve, sensitivity analysis, reliability index, RC frames.

I. Introduction

INFILL walls confined by RC frames on all four sides play a vital role in resisting the lateral seismic loads on buildings. It has been shown experimentally that infill walls have a very high initial lateral stiffness and low deformability. Thus introduction of infill walls in RC frame changes the lateral-load transfer mechanism of the structure from predominant frame action to predominant truss action which is responsible for the reduction in bending moments and increase in axial forces in the frame members. Infill walls are used in RC frames in almost all types of building construction in many parts of the world because of low cost material, good sound and heat insulation properties and local availability.

The response of infilled RC frame at the design stage is difficult to predict with certainty due to its non-linear nature and uncertain input parameters [12].

With regard to the structural analysis, there are a number of uncertainties involved in the estimation of the performance of the building for given levels of intensity. These uncertainties concerned both the capacity modelling of the examined building and the demand modelling. The most sensitive variables (structural properties and loading conditions) that can affect the performance of the structure can be found out from the sensitivity analysis [14]. In the present study to examine the most sensitive random variable, Pushover analysis was carried out for infilled RC frame using OpenSees software [15]. To study the variation in response of a building, 5%, mean and 95% probability value of random variables are considered. Based on the Tornado Diagram Analysis (TDA) method, it can be easily determined how changes in that variable will impact the structural response of a building. In addition to these, the effects of probability of exceedance of damage are expressed in terms of a reliability index for the selected frames.

Avadhoot Bhosale, Ph. D Scholar, Robin Davis P., Assistant Professor, and Pradip Sarkar, Associate Professor, are with the National Institute of Technology Rourkela, India, 769008 (e-mail: avadhoot11@gmail.com, robind@nitrkl.ac.in, sarkarp@nitrkl.ac.in).

II. Literature Review

An extensive literature review has been conducted to understand the subject and to know the current status of the research in this area. Literature review has been divided in two different parts as discussed below:

A. Literature Review on Sensitivity Analysis

Evaluation of seismic risk assessment of RC Masonry infilled frames involves a sensitivity study and modelling of infill walls. Kwon and Elnashai [7] studied the sensitivity of random variables, compressive strength of concrete (f_{ck}) and yield strength of steel (f_y) as random variables using a tornado diagram (TD). Celik and Ellingwood [10] considered additional parameters, such as modulus of elasticity of steel (E_s), damping ratio (β), bond slip factor, joint shear strength, shear strain of concrete at first cracking, yielding, maximum and residual levels. Kim et al. [9] conducted a sensitivity study for steel frames using pushover analysis and the variable yield strengths of steel (f_y) and damping ratio. Mitropoulou et al. [11] studied sensitivity analysis for an "L" shaped RC frame structure using random variables as the mass of the structure. Celarec and Dolsek [13] conducted sensitivity analysis for infilled frame and bare frame by considering additional infilled parameters, in addition to bare frame like shear cracking strength (τ_{cr}), Modulus of elasticity of masonry (E_m), Shear modulus of masonry (G_m). Panandikar and Narayan [17] performed sensitivity analysis for capacity curve considering material strength and geometric modelling parameters.

B. Literature Review on Seismic Risk Assessment

Structural fragility curves are said to be the key component while quantifying the seismic risk assessment. Fragility curves are usually defined as the probability of exceeding a specific

limit state of a building for a given level of ground motion intensity.

Singhal and Kiremidjian [1] developed fragility curves for low, mid, and high rise RC frames that were designed using seismic provisions. Monte Carlo simulations were considered to quantify the uncertainties in structural capacity and demand. Cornell et al. [2] developed a probabilistic framework for seismic design and assessment of structures in a demand and capacity format addressing the uncertainties in hazard, structural, damage, and loss analyses. Kim and Shinozuka [4] developed fragility curves of two sample bridges before and after column retrofit for the southern California region. Lupoi [5] has developed empirical fragility curves for free standing equipment based on experimental test and regression analyses. Kircil and Polat [6] developed fragility curves for mid-rise RC buildings in the Istanbul region designed according to the Turkish seismic design code. Lagaros [8] conducted fragility analyses for two groups of RC buildings. The first group of structures was composed of fully infilled, weak ground story and short columns frames and the second group consists of building frames designed with different values of behavioral factors. Celik and Ellingwood [10] studied the effects of uncertainties in material, structural properties and modelling parameters for gravity load designed RC frames.

III. Selected Frames

In the present study, bare frame 4S2B and Infilled frame 4S2B-F, considered for sensitivity and fragility analyses, are designed for zone V with PGA of 0.36g as per Indian standard IS 1893 [3] for medium soil conditions having N-value lies between 10 to 30. The characteristic strength of concrete and steel were taken as 25 MPa and 415 MPa, respectively. The present study is limited to RC multi-storey framed buildings that are regular in plan, and hence, representative single plane frame is considered along one direction. All the selected building frames 4S2B and 4S2B-F have four bays with a uniform bay width of 5 m and story height 3.2 m. The dead load of the slab for 5 m × 5 m panel with floor finishes is taken as 3.75 kN/m^2 and live load as 3 kN/m^2. More details about the design of the frames are presented in Davis *et al.* [16]. Modulus of elasticity and thickness of infill wall are considered as 2300 MPa and 230 mm, respectively. Fig. 1 presents the configurations of all the selected frames.

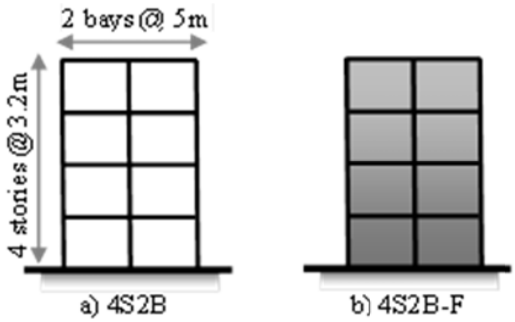

Fig. 1 Selected building frames

IV. Sensitivity Analyses of Bare & Infill Frames

The purpose of sensitivity analyses is to find the most sensitive parameter that affect the structural response of any building. The sensitivity Δy is defined as:

$$\Delta y = \frac{y(P_n) - y(P_{mean})}{y(P_{mean})} \times 100 \ (\%) \quad (1)$$

where, $y(P_n)$ is response at the nth percentile value of variable (5th or 95th percentiles) and $y(P_{mean})$ response considering the mean value of the variables.

There are different types of uncertainties which include material properties of concrete, steel and infill wall. Damping is another source of uncertainty that can affect the dynamic response of a building. It is important to incorporate the uncertainties in all potential material and modelling parameters in the computational model to deliver a naturalistic representation of the responses in a probabilistic judgment. The strength of concrete, yield strength of main steel, elastic modulus of concrete and steel, compressive and shear cracking strength of infill are considered as random variables for sensitivity and reliability analysis are given as in Table I.

TABLE I
Details of Random Variables Considered in the Seismic Risk Assessment

Material/Property	Variable	Mean	COV (%)	Distribution
Concrete compressive strength	f_{ck}	30.28 MPa	21.0	Normal
Yield strength of steel	f_y	468.90 MPa	10.0	Normal
Global damping ratio	ξ	5%	40.0	Normal
Concrete tensile strength	ft	2.2	22	Normal
Shear strength of masonry infill	τ_{cr}	0.2041 MPa	12.0	Normal
Elastic modulus of concrete	*Ec*	29000	15	Lognormal
Elastic modulus of steel	*Es*	2.1×10^5	5	Lognormal

Pushover analysis is used in present study to examine the most sensitive random variable. Pushover analyses are carried out for bare and infilled frame by using OpenSees software [15]. To study the variation in response of a building, 5%, mean and 95% probability value of random variable are considered. A representation using TD is used to present the sensitivity of the various variables involved.

V. Seismic Risk Assessment

An accepted probability based approach is used in the present study. The seismic risks are computed in the terms seismic fragility curves and reliability indices.

A. Fragility and Reliability Analyses

A fragility function represents the probability of exceedance of a selected engineering demand parameter (*EDP*) for a selected structural limit state (*LS*) for a specific ground motion intensity measure (*IM*). The fragility curve represents cumulative probability distribution that indicates the

probability that a component/system will be damaged to a given damage state or a more severe one, as a function of a particular intensity measure. The SAC-FEMA method, which is a simplified method for the calculation of seismic risk introduced by [2], is used in the present study for the fragility evaluation. The seismic fragility, $F_R(x)$ can be expressed in closed form equation as:

$$P(D \geq C \mid IM) = \phi\left(\frac{\ln \frac{S_D}{S_C}}{\sqrt{\beta_{D|IM}^2 + \beta_c^2}}\right) \quad (2)$$

where, D is the drift demand, C is the drift capacity, SD and SC are the median demand and capacity at the chosen limit state (LS), respectively. The dispersion, βD/IM, of inter-storey drifts (di) from the time history analysis can be calculated as:

$$\beta_{D|IM} \cong \sqrt{\frac{\sum\left[\ln(d_i) - \ln(aIM^b)\right]^2}{N-2}} \quad (3)$$

where a $(IM)^b$ represents the mean inter-storey drift and N is the number of building models. Dispersion in limit state capacities recommended by different standards and literatures are not in agreement.

VI. Results

A. Sensitivity Analysis

Sensitivities of all parameters that affect the seismic response of building are plotted, as shown in Figs. 2 and 3.

Base shear at yield is considered as the seismic response for sensitivity analysis. It can be observed from the TDs that the f_y, f_{ck}, Ec and Es are sensitive variables for a bare frame and f_y, f_{ck}, Ec, Es and τ_{cr} are the sensitive variables for infilled frame. The percentage change of the base shear (at yield) response from the mean value, affected by the change of the selected parameters from 5% to 95% probability values can be read from Figs. 2 and 3.

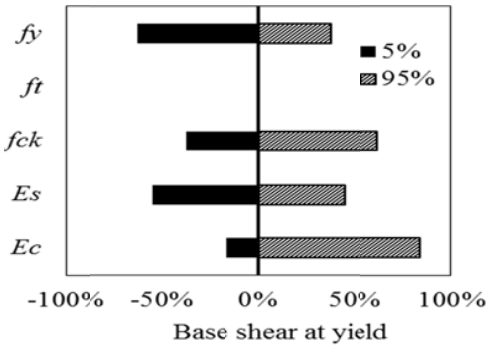

Fig. 2 TD for 4S2B bare frame

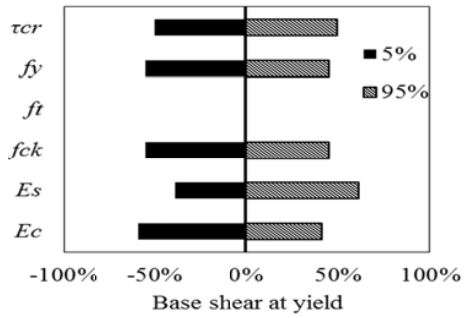

Fig. 3 TD for 4S2B Infilled frame

B. Fragility and Reliability Analysis

Fragility curves for the four-storeyed frames, 4S2B and 4S2B-F, are plotted for two performance levels (IO and CP) as shown in Figs. 4 and 5. It is found that the probability of exceedance of the 4S2B (bare frame) is more than that of 4S2B-F (infilled frame). Infill walls reduce the probability of exceedance of inter-storey drift in a building. Figs. 6 and 7 show the reliability curves for different performance levels (IO and CP) for four-storey frames in the Manipur region. It can be seen that bare frame yields the lowest values of reliability index for all PGAs. The Infilled frame 4S2B-F shows relatively higher values of reliability index compared to the 4S2B bare frame.

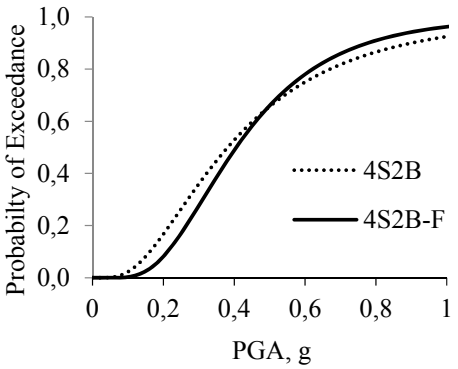

Fig. 4 Fragility curve – IO level

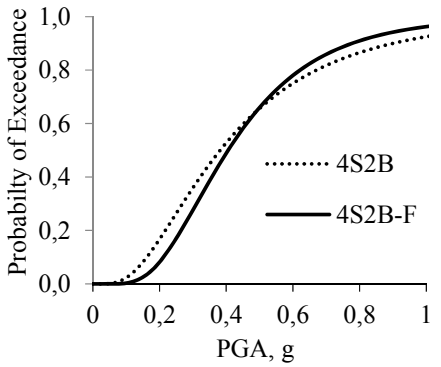

Fig. 5 Fragility curve – CP level

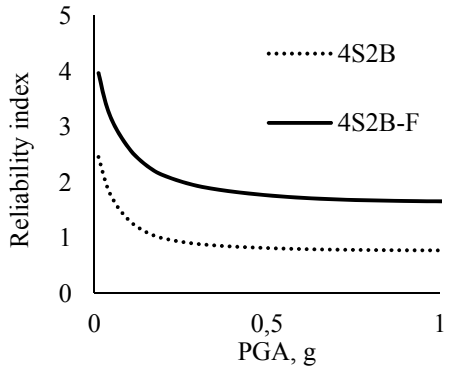

Fig. 6 Reliability curve – CP level

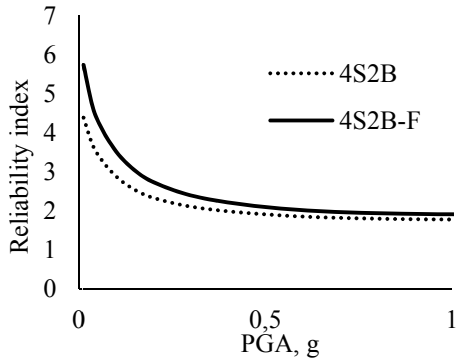

Fig. 7 Reliability curve – CP level

VII. Conclusions

The salient conclusions of this study are as follows:

1. The sensitivity analyses were performed based on the nonlinear pushover for four-story bare and infilled frame models. It was clearly observed that special care should be given when assigning values to represent the structural characteristics, especially the material characteristics-related values. Concrete and masonry strength-related variation values have shown a significant effect on the building capacity.
2. Infilled frame are less fragile as compared to bare frame building because of additional stiffness in the form of infill. Also, the reliability index for infilled frames is higher than bare frame buildings, which indicates that infilled frame buildings having less probability of failure during an earthquake.

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Avadhoot Bhosale was born in Kolhapur, Maharashtra, India, in 1986. He received the B.E. degree in civil engineering from the Shivaji University, Kolhapur, India, in 2007, and a M. Tech. degree in structural engineering from the National Institute of Technology (NIT) Rourkela, Orissa, India, in 2012. In 2012, he joined the Department of Civil Engineering, TKIET College of Engineering, as a Asst. Professor, and in 2013 as Junior commission officer (JCO) in Military Engineering Services, Government of India. Since January 2014, he has been with the Department of civil Engineering, NIT Rourkela, where he is PhD Scholar. His current research interests include earthquake engineering, structural dynamics and earthquake resistance structures.

Robin Davis P was born in Thissur, Kerala, India, in 1978. He received B. Tech degree in civil engineering from the Govt. Engineering College, Thrissur, India, in 1999, and the M. Tech. degree in structural engineering from the PSG College of Technology, Coimbatore, India, in 2002. He received PhD degree in civil engineering from the Indian Institute of Technology Madras, Tamil Nadu, India, in 2009. He joined the Department of Civil Engineering, National Institute of Technology (NIT)

Rourkela, Orissa, India as Assistant Professor in 2012. His current research interests include probabilistic earthquake engineering and structural dynamics. Dr. Davis is a member of Intuition of Engineers (India).

Pradip Sarkar was born in Mohoboni, West Bengal, India, in 1975. He received the B.E. degree in civil engineering and the M.E. degree in engineering mechanics from Bengal Engineering College, Shibpur, India, in 1999 and 2002, and the Ph. D. degree in civil engineering from the Indian Institute of Technology Madras, Tamil Nadu, India, in 2009. In 2009, he joined the Department of Civil Engineering, National Institute of Technology (NIT) Rourkela, Orissa, India as Associate Professor. His current research interests include earthquake engineering, structural dynamics and earthquake resistance structures. Dr. Sarkar is a member of Intuition of Engineers (India).