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FRAGILITY ANALYSIS OF MULTISTORIED CONTAINMENT REINFORCED MASONRY BUILDING

Akhil Badrinath Berad[1], Amrut Anant Joshi[2]

[1]*AuthorPG student, School of Civil Engineering, MIT-WPU, Pune, India.*

[2]*Assistant Professor, School of Civil Engineering, MIT-WPU, Pune, India.*

***Abstract*— Containment reinforcement is a novel earthquake resistant feature for masonry building. Present study explores fragility curves for containment reinforced multistoried building. A typical G+2 masonry building has been modelled in commercial finite element software ABAQUS SIMULIA version 6.14-1. Material model employed in present study has already been validated through experiments on masonry assemblages and masonry building model. In the present study, drift ratios corresponding to immediate occupancy, life safety and collapse prevention damage state have been obtained through pushover analysis of G+2 masonry building under consideration. Subsequently, the masonry building was analyze under ground motions with varying Peak Ground Accelerations (range 0.08g to 0.54g). Probability of exceedance of particular damage state versus PGA has been plotted as an outcome of this analysis. These fragility curves confirm effectiveness of containment reinforcement provided in very small percentage, in mitigating seismic risk.**

Keywords*— *Containment reinforcement, fragility curves, masonry modelling, finite element analysis.

1. INTRODUCTION

In developing countries like India, URM buildings up to two to three storeys is still dominant form of construction due to ease of construction and cost effectiveness. But URM buildings are vulnerable to severe damage in seismic events, and exhibit a life threatening brittle collapse. However, reinforced masonry buildings have performed well in most of the past earthquakes Reinforced masonry has been common in construction practice since 1950s and it contributes greatly in seismic performance of structural systems.

Jagdish et. al. introduced an innovative way of reinforcing masonry called 'containment reinforcement' and showed that it demonstrably improves Behavior of masonry under dynamic loads [5,6].Additionally, experimental and analytical investigations of static and dynamic behaviour of reinforced masonry is presented by Joshi [10]. It includes detailed investigation of tensile and compressive strength, shear under in-plane loading, inter-storey drift and finite element analysis of two storey symmetric/asymmetric structure of containment reinforced masonry. Jagdish et al. suggested containment reinforcement to be provided in one of the following two ways [2].

a) The vertical reinforcement can be provided on the surface of masonry wall and held in the position by horizontal ties at every/alternate bed joints. Horizontal ties will ensure integral behaviour of masonry and containment reinforcement. However, exposed containment reinforcement needs protection against corrosion. (Fig.1)

b) Grooved masonry unit can be laid in such a way that a continuous vertical groove is created to accommodate the vertical reinforcement. The vertical groove can later be grouted (Fig.2).

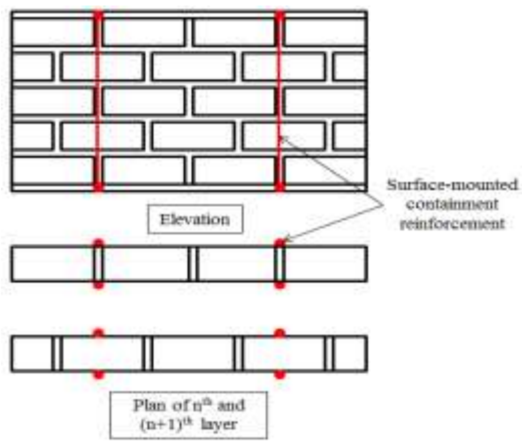

Figure 1 Surface mounted reinforcement

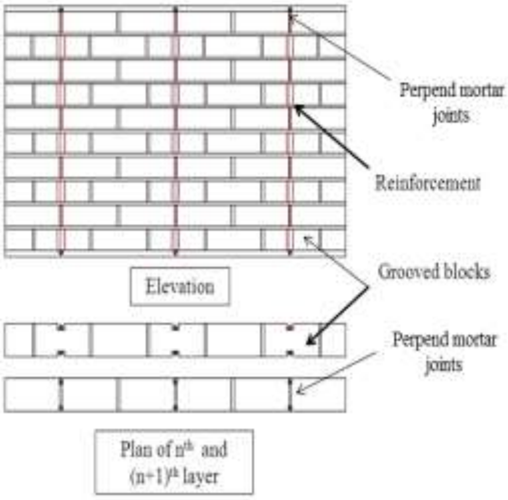

Figure 2 Near surface mounted reinforcement.

Severe earthquake damage the existing structure with major fatal losses as well as economical losses in earthquake prone areas periodically. Therefore to mitigate such risk, seismic assessment of building before occurrence of earthquake event is useful. In vulnerability assessment of reinforced masonry building fragility curve is an effective tool. The fragility curve, which is developed from the finite element model of reinforced masonry building and spectral compatible time histories, is a graphical representation of the probability of exceedance of particular damage state versus peak ground acceleration or arias intensities.

2. SCOPE AND OBJECTIVES

In this paper, role of containment reinforcement in fragility analysis of three storey building for the three damage state; immediate occupancy, collapse prevention and life safety is evaluated through the non-linear FEA. Material modelling parameters for containment reinforced masonry are calibrated using experimental tests performed on unreinforced/reinforced masonry assemblages at Indian Institute of Science, Bangalore, India [10]. Finite element model used in this study is validated by experimentally obtained various results of containment reinforced and unreinforced masonry assemblages/ buildings [10]. Various earthquake time history records from strong motion database and its spectral compatible time histories as per IS 1893 (part-1), zone 2 are obtained. Following the spectral compatible time histories, the non-linear finite element model is extended for fragility analysis of three storey containment reinforced masonry building. The objectives of the present work can be stated as follows

a) To examine the performance of containment reinforced three storey building by developing non-linear Finite Element model.

b) Exploring seismic fragility analysis of containment reinforced masonry building for 7 spectral compatible earthquake time histories for range of peak ground acceleration.

3. EARTHQUAKE AND TIME HISTORY DATA

For the fragility analysis of reinforced masonry building, earthquake time histories are used. Which are Northridge, Landers, Trinidad, Imperial valley, Friuli, Kobe and Holister etc. spectral compatible time histories for seismicity zone 2, Ground type C and importance class as critical category of IS 1893 (part-1) has been obtained from base acceleration record using program SeismoMatch (2020). Which are further scaled to the following PGAs; 0.15g, 0.25g, 0.35g and 0.45g etc.

4. FINITE ELEMENT MODEL DESCRIPTION.

In this present work, composite material and heterogenous masonry is used. For low computational cost the macro modeling strategy is chosen to model masonry owing to its capability of predicting reasonably accurate global response of masonry buildings subjected broad loading scenarios as described by Lourenco [11]. Containment reinforcement is modelled as smeared layer in masonry.

4.1 DESCRETIZATION

Using the commercial finite element software Abaqus masonry building is modelled. S4R, a 4-noded general purpose, quadrilateral, stress/displacement shell element with reduced integration and a large-strain formulation is used for discretization. Reinforcement is modeled using rebar layer option of Abaqus [12]. The rebar layer represents the smeared reinforcement layer with a constant thickness, t. Thickness is calculated by, reinforced bar area (A) divided by the spacing (s).

4.2. MATERIAL MODELLING AND CALIBRATION

Material library of Abaqus provides following material models for quasi-brittle materials: (a) concrete smeared cracking, (b) cracking model for concrete and (c) concrete damaged plasticity (CDP). For monotonic loading at slow strain rates concrete smeared cracking model is suitable. For concrete assumes linear elastic compressive behavior cracking model. CDP can be used to model non-linear response under cyclic loading protocols. As it has capacity to model nonlinear-plastic compressive behavior it outperforms the other two material models.

Containment reinforcement is modeled as elastoplastic material of Abaqus [12] material library. Bauschinger effect is neglected and behavior of steel in uni-axial compression is assumed to be the same as its behavior in tension.

5. FE MODEL VALIDATION

FE model is validated by the data obtained from examining the static and dynamic behavior of reinforced masonry at different levels (from micro to macro), namely, investigations at material level, global seismic behavior of reinforced masonry buildings and characterization of elemental level behavior.

a) In-plane shear behavior of unreinforced and containment reinforced masonry samples[7]. b) The material behavior investigations from containment reinforced single storey structure on shock table[5,10].

c) Flexure behavior of containment reinforced masonry assemblages under monotonic and cyclic loading[8].

Due to space constraints detailed investigation of containment reinforced masonry is not mentioned in this paper. However, details of this experimentation are elaborately described in [5,7,8,10].

Experimentally recorded acceleration at a particular location compared well with that acceleration response at same locations on the building model obtained by FE analysis. FE analysis of scaled reinforced masonry building subjected to shock-table motions showed a reasonable agreement with experimentally observed failure/crack patterns[10].

6. REFERENCE STRUCTURE

Pushover analysis and dynamic response analysis is performed on the three storey containment reinforced masonry building with bricks having stretcher bond and having smeared layer of reinforcement on either face.

A model is prepared in Abaqus simulia with three story. For pushover analysis story drift is calculated for single storey with time history data up to 40 mm displacement.

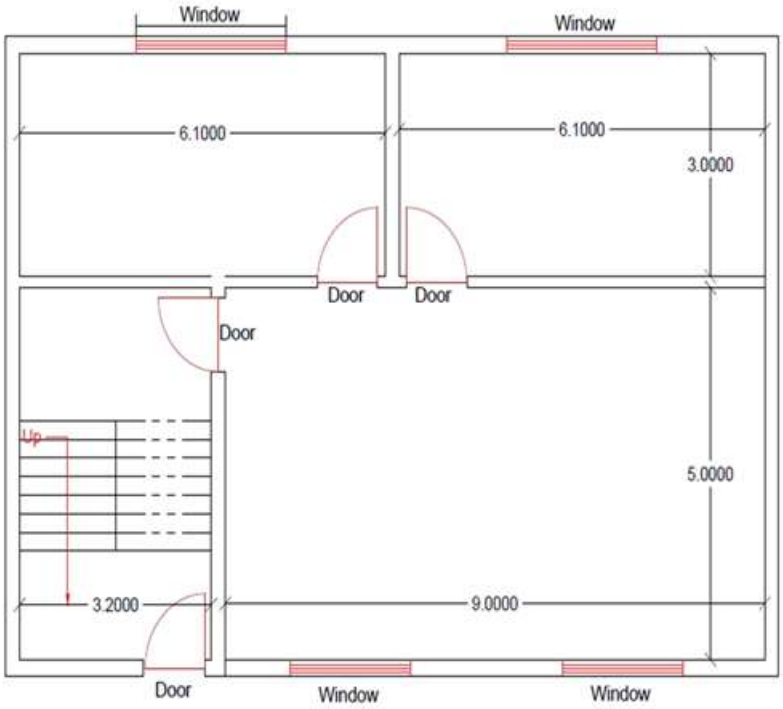

Figure 3 PLAN of three storey building

In this present work, in order to obtained the fragility curves, spatial displacement at the top 4 corner nodes of the model are calculated by the FE analysis in earthquake direction (short dimension direction) in this particular study. This spatial displacement is calculated for earthquake time histories compatible with zone 2 spectra of Indian code, for the peak ground acceleration values of matched acceleration values of matched accelerogram mention as follows

7. PUSHOVER ANALYSIS

A simplified non-linear technique is used to obtain structural deformation due to the seismic forces is called as pushover analysis. A single storey model having same shear wall and cross-wall property as per in dynamic analysis. Fixing all the ground nodes, a static time history having increment of 0.01 second is applied to top nodes of a single storey model. Analysis is carried out till failure of the model. Limiting percent of drift for each damage state is obtained from static analysis. Based on the pushover analysis capacity curve or pushover curve is obtained. Which represents non-linear behaviour of the building model. Limiting drift have mentioned table I.

Vol 11, Issue 8, August/2020

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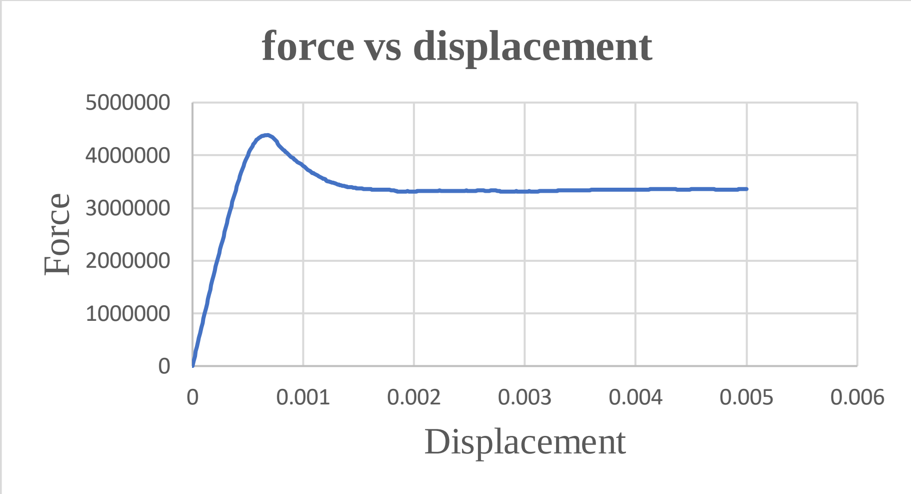

Figure 4 Pushover curve for single storey model

7. FRAGILITY CURVE

In this investigation fragility curves were derived from non-linear FE model analysis. A three dimension model that represents the ordinary 3 stories containment reinforced masonry buildings was considered for this purpose.

Probability of drift ratios of peak ground acceleration exceeding the particular damage state obtained by pushover static analysis (Immediate occupancy, life safety and collapse prevention) is plotted. Limiting percentage of drift ratios as per static analysis are as follows

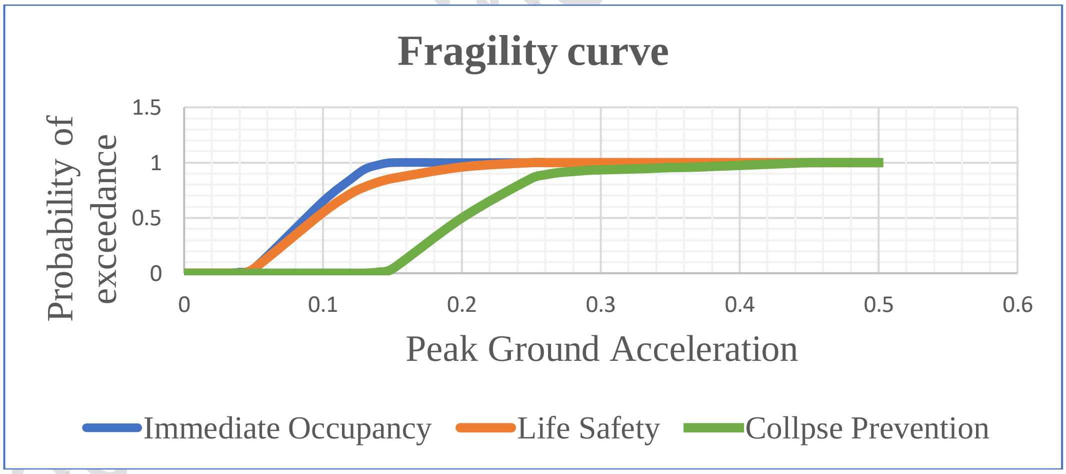

Figure 5 Fragility curve showing probability of exceedance for three damage state.

Table II. original and zone compatible PGA values.

Earthquake	Original PGA(g)	Zone-II compatible PGA(g)
Friuli	0.35130	0.11987
Holister	0.19480	0.12212
Imperial Valley	0.3150	0.08614
Kobe	0.34470	0.08524
Landers	0.78030	0.08443
Northridge	0.56830	0.09604
Trinidad	0.19360	0.10285

Journal of Engineering Sciences

Vol 11, Issue 8, August/2020

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Table III limiting drift of masonry buildings subjected scaled time histories.

Performance level	Limiting drift by static analysis	% Drift Ratio by Static analysis
Immediate occupancy	0.15 mm	0.005
Life safety	0.29 mm	0.00967
Collapse prevention	0.68 mm	0.02267

7. RESULT AND DESCUSSION

Systematic analysis has been carried out to examine the static as well as dynamic analysis of containment reinforced masonry building. A static analysis is conducted and limiting drift ratios have been decided based on the analytical data. As well as detailed analysis of reinforced masonry building is also conducted which gives, how the reinforced building model behaves under scaled earthquake excitation on every floor level. The scaled time histories for 0.35g PGA. Likewise scaled time histories for 0.15g, 0.25g, 0.35g, and 0.45g PGA have been obtained and containment reinforced masonry building is analyzed.

7.1. SUMMARY OF PUSHOVER ANALYSIS RESULTS

For static loading scenario a macro model is used to obtain the response of reinforced masonry model. Concrete damaged plasticity (CDP) material model in Abaqus library in employed and non-linear behaviour is modelled. Finite element model predicted the actual after loading scenario of the reinforced masonry model. Finite element model shows reasonably predicted load-displacement capacity curves. Limiting values drift obtained from pushover analysis can be used to predict the probability of exceeding particular damage state of containment reinforced masonry buildings. Detailed of these static analysis mentioned in chapter 4. From the research available in literature, this model found adequate to predict global response of reinforced masonry building, limiting values of % drift ratios can be used in the study of seismic behaviour of reinforced masonry building model with considering various parameters of earthquake ground motions.

7.2. SUMMARY OF NON-LINEAR DYNAMIC ANALYSIS RESULTS

Macro model is used for the purpose of non-linear dynamic analysis of reinforced masonry model. And CDP material model is used from material library of Abaqus finite element software. A detailed investigation inter storey drift and % drift ratio of reinforced masonry building is carried out and it is further compared with that of limiting drift calculations. Average displacement of all 4 corners of the each and every floor of reinforced masonry building is calculated for all seven scaled earthquake excitation.

Probability of exceedance of particular damage state against limiting percentage drift is calculated and fragility curve is established for all three damage state. Probability of exceedance is mentioned below

Table IV Probability of D.R. for immediate occupancy

PGA	Probability of exceeding drift ratio
0.15	1
0.25	1
0.35	1
0.45	1

Table V Probability of D.R. for Life safety

PGA	Probability of exceeding drift ratio
0.15	0.857142857
0.25	1
0.35	1
0.45	1

Table VI Probability of D.R. for Collapse prevention

PGA	Probability of exceeding drift ratio
0.15	1
0.25	0.857142857
0.35	0.857142857
0.45	1

7. CONCLUSIONS

In this paper the FE model based fragility curves versus PGA of a 3-storey containment masonry building is presented. The FE model models were verified by experimental models in previous studies. Finally with obtaining the probability of reaching or exceeding the particular damage state is possible. The trend of fragility curves for each damage state is acceptable

From the fragility curves, it is got that even under PGA, 0.15g occurrence of the probability of immediate damage state doesn't reach to 1. But, after PGA 0.15g the probability of occurrence remains constant to 1.

It is also got that even under PGA, 0.25g occurrence of the probability of damage state of life safety does not reach to 1. As it is increasing exponentially to one and after PGA 0.25g it remains constant to one.

For the third damage state of collapse prevention, probability of percent inter storey drift crossing limiting percent drift reaches to one at PGA of 0.45g. Until 0.45g PGA probability is continuous increasing non-linearly.

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REFERENCES

[1] Bureau of Indian Standards IS 1893 Part I (2002), *Criteria for earthquake resistant design of structures*. 5th revision, New Delhi.

[2] Raghunath S, Rao K S N, Jagdish K S, (2012): Ductility of brick masonry beams with containment reinforcement. *Journal of Structural Engineering*, **39** (4), 399-408.

[3] Rao K S N, Raghunath S, Jagdish K S, (2004): Containment reinforcement for earthquake resistant masonry buildings. *Proceedings of 13th World Conference on Earthquake Engineering*, Vancouver, Canada.

[4] Rao K S N, Raghunath S, Jagdish K S, (2010): Response of full-scale walls subjected to out-of-plane soft impact loads. *Proceedings of 8th International Masonry Conference*, Dresden.

[5] Jagdish K S, Raghunath S, Rao K S N, (2002): Shock table studies on masonry building model with containment reinforcement. *Journal of Structural Engineering*, **29** (1), 9-17.

[6] Jagdish K S, Raghunath S, Rao K S N (2003): Behavior of masonry structures during the Bhuj earthquake of January 2001. *Proceedings of Indian Academy of Sciences (Earth and Planetary sciences)*, **112** (3), 431-440.

[7] Nanjunda K. S. Rao and Joshi Amrut Anant (2019): Exerimental investigations on in-plane shear behavior of unreinforced and reinforced masonry panels. *13th North American Masonry Conference*, Salt Lake City, USA.

[8] Nanjunda K. S. Rao and Joshi Amrut Anant (2019): Flexure behavior of reinforced masonry assemblages under monotonic and cyclic loading. *13th North American Masonry Conference*, Salt Lake City, USA.

[9] Nanjunda K. S. Rao (2019): Dynamic behavior of box type scaled stabilized earth and fired clay block masonry building models. *13th North American Masonry Conference*, Salt Lake City, USA.

[10] Joshi Amrut Anant (2015): *Static and dynamic behavior of reinforced masonry: experimental and analytical investigations*. Doctoral thesis, Indian Institute of Science, India.

[11] Lourenco (1998): Experimental and numerical issues in the modeling of the mechanical behavior of masonry. *Structural Analysis of Historical Constructions II*, CIMNE, Barcelona.

[12] Simulia (2011): *ABAQUS/Standard User's Manual*. Version 6.10.1, ABAQUS. Inc., Pawtucket, RI.

[13] SeismoMatch (2013), *Seismosoft*. Earthquake Engineering Software Solutions, available at www.seismosoft.com

[15] Federal Emergency Management Agency (1996): *FEMA 273*. NEHRP guidelines for seismic rehabilitation of buildings, Washington, D. C.