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Demeanour of Unreinforced Masonry under Various Loads

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ABSTRACT: Unreinforced Masonry (URM) structures can simply defined as structure without any reinforcement. URM is a common material for building construction but is known for its ability due to its heavy weight, high stiffness and negligible strength. URM structures are commonly used in developing countries like India for low rise building up to two stories in rural area. Damage to those structures results in loss of life and cultural heritage. The main objective of the present thesis is to know the lateral behavior of URM structure, and understand the concept to (EFM). In the present work inverted triangular and uniform distribution lateral load sari used to study the nonlinear behaviour of masonry. There are several methods to carry out Static Pushover (SPO). The plastic hinges were used in SPO analyses in cathead low the user to accurately follow the structural performance beyond the elastic limit at each step of the incremental analysis. Perfectly rigid plastic hinges were assumed as recommended in literature reviews and modelling is done in SAP2000software.

Keywords: URM; EFM; SPO; Seismic performance; sensitivity; fragility.

I. INTRODUCTION

Unreinforced masonry (URM) is common construction practice in a large number of places in the world. It is very popular primarily due to economy, easily availability, good thermal insulation and fire protection, durability and no super skill is required to its construct. Normally, masonry is designed for vertical loads since it has good compressive strength. Due to good compression strength, the structures will behave well when loads are gravity load only but when lateral horizontal earthquake forces act, they start to develop shear and flexural stresses as shown in Fig. 1.1 and Fig. 1.2. Since less research and technical development is done in this field and due to little intelligence required, URM construction is usually done without any technical information. Hence URM construction pose threat to earthquakes damages and is the reason for the replacement of URM construction with steel and RCC. The existing URM construction possesses a risk during earthquakes. Therefore, for performance-based earthquake engineering concepts need for non-linear static analyses arises. In recent years, non-linear methodologies like Pushover Analysis are being used for retrofitting and rehabilitating existing buildings. Pushover analysis is an approximate analysis method in which the building model is subjected to a predefined load pattern and the loads are increased monotonically until some members yield.

Fig. 1: Combined in-plane and out-of-plane failure mode in Kashmir 2005 (Naseer et al. 2010)

1.1 Objectives

Principal objectives of the present study are as per the following:

a) To study the behaviour of URM buildings using nonlinear analysis of equivalent frame concept
b) To ascertain the results obtained from the Equivalent Frame Analysis and the current code provisions FEMA 356 for URM structures subjected to seismic loading
c) To develop fragility curves for URM building
d) To carry out a sensitivity analysis.

1.2 Scope of the Study

Due to lack of experimental data, the present review is constrained to medium strength clay brick, fly ash brick, AAC and CLC brick masonry. However, variation in properties of masonry in a different region is not considered and hollow block masonry is kept outside the extent of the present study. Two-dimensional wall panel switched door and window opening are used for analysis to define in-plane lateral load-deformation behaviour of the wall panel. Rigid wall i.e. without opening is not considered in present study.

II. LITERATURE REVIEW

Krishna and Chandra (1965) and Krishna et al. (1966) carried out a study on SPO analysis. The static in-plane strength of walls with and without reinforcement was studied Various masonry properties required for determining the lateral behaviour are first to determine and later on failure reasons with various methods for strengthening the masonry houses. Key points obtained from results like URM structure results in brittle failure and its energy absorbing capacity limited by elastic deformation. Stronger the mortar grade results in high resistance to the earthquake.

Scrivener (1972) has done a review of the harm to old URM work structures in earthquake zones around the world. Results shows that monotonically increasing load like SPO analysis gives some idea about deformation and initial strength of URM but for detailed seismic analysis dynamic loading gives more accurate results about stiffness reduction, ductility and energy dissipation.

Rai and Goel (1996) Lateral behaviour of URM structure mainly depends on pier and spandrel which can be effectively improved by providing steel frame of vertical and horizontal members around the wall with openings. It was concluded that pier with steel member results in 2.5% more displacement with crumbling shows the ductile response. In this paper, only the in-plane behavior of masonry piers were considered and strengthening results shows better change in stiffness and ductility.

A report by Navalli (2001) in Uttaranchal suggested utilizing flat timber groups at some vertical interim to enhance the integrity of the brickwork structure. These houses undergo little damages during the October 1991 Uttarkashi earthquake as compare to masonry structure without horizontal timber band.

Duan and Pappin (2008) give a procedure for establishing the required fragility curves for various damage states, in particular for the more severe damage states, based on nonlinear push over analysis results. A solution is proposed for overcoming the difficulty encountered when determining the median spectral displacements forth more severed am gestates. An example is given to illustrate the entire process. The proposed procedure has been successfully applied by the authors in recent seismic loss estimate studies of modern cities with densely populated buildings in regions of moderate seismicity.

Rota et al. (2010) has proposed a new analytical method for the development of fragility curves for URM buildings. It is the probabilistic approach in which mechanical properties are considered as random variables. Since variation in masonry properties is also important for seismic performance. This method is based on nonlinear stochastic analyses of building prototypes. The mechanical properties of the prototypes are considered as random variables, assumed to vary within appropriate ranges of values. Monte Carlo simulations are then used to generate input variables from the mean and coefficient of variance. The model created and nonlinear analyses are performed. In particular, nonlinear static (pushover) analyses are used to define the probability distributions of each damage state whilst nonlinear dynamic analyses allow determining the probability density function.

Lagomarsino et al. (2013) carry out non linear analysis of unreinforced masonry building by using equivalent frame modelling method in TREMURI program. They found that equivalent frame method easy and simple because it permits the user-friendly analysis of complete 3D URM structure with less computational efforts and this method is also suitable for engineering practical use.

A paper by Sonekar and Bakre (2015) presents a comparative study on the non-linear behaviour of masonry frame structures when subjected to earthquake excitation under different lateral loading pattern. Equivalent Frame Model

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(EFM) is being used for modelling the non-linear behaviour of masonry by providing flexural and shear hinges in the model. Higher strength estimates are obtained for uniform load pattern along the height of the structure out of three lateral load pattern while mode and parabolic lateral load patterns are found to be always equivalent (i.e. around 15% higher).

Bhosale et al. (2016) carry out the sensitivity analysis of structure with masonry infill. The variation in material properties greatly affects the seismic performance of the structure. They found out that how much lateral behavior is sensitive to various properties of masonry. The main reason to carry out the sensitivity analysis is to find out the most sensitive parameter that affects the lateral response of the building. In this paper sensitivity analysis is carried out by considering 5% mean and 95% probability value based on mean and coefficient of variance of a random0variable in the in-fills characteristics.

Hazus et al., (2018) is the technical and user's manual developed by department of home land Security Federal Emergency Management Agency (FEMA). This code also gives the probabilistic method for the development of fragility curve which is based on the several variables for different damage state. It gives uncertainty associated with different damage state. In order to avoid the complex convolution process, Hazus has given pre-calculated values for total variability used for the development of fragility for different damage states.

Park et al. (2019) carried out seismic analysis of low rise unreinforced masonry building. Develop fragility curve for two stories URM in the region of southern US. They proposed structural modelling method that can be effectively used for fragility analysis without a significant increase in computational time, and maintains an acceptable level of accuracy in representing the nonlinear behaviour of the structures.

III. PUSHOVER ANALYSIS

Pushover analysis is defined as a nonlinear static method of analysis where a mathematical model directly incorporates the nonlinear load-deformation characteristics of individual components and elements of the structure which are subjected to monotonically increasing lateral loads representing inertia forces in an earthquake until a 'target displacement' is exceeded. Although it is a nonlinear static method, it is stepwise linear because lateral load increases monotonically at the same time stiffness matrix get modified for the reduced stiffness in between this two steps it behaves as linear.

3.1 Pushover Analysis Procedure

The stepwise procedure is as follows:

- Creating a model as per the geometry of structure
- Defining the load patterns i.e. various loads acting on the structure and a nonlinear static load pattern for SPO analysis
- Assigning the hinges to vertical and horizontal members, for RCC and Steel members hinge properties are already defined in SAP2000
- Distributingthelateralloadoneachstoreyasperthe considereddistributionpattern.

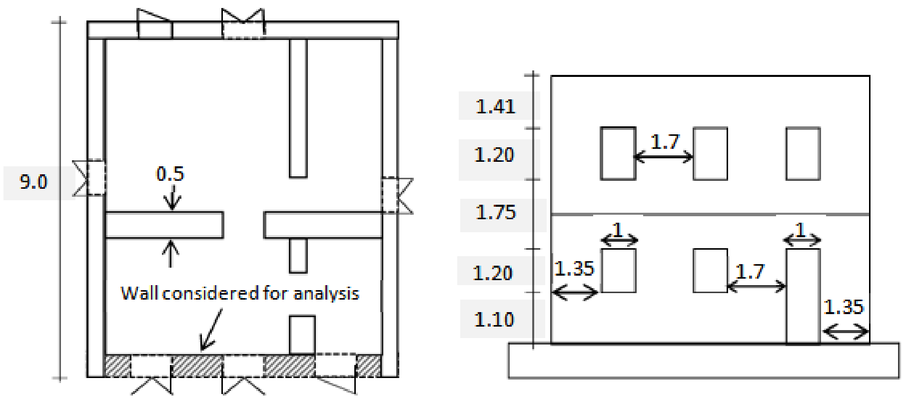

Fig. 2: (a) Plan and (b) Elevation of selected stone masonry building (Pasticieret al. 2008)

3.2 SPO Analysis for Validation

The selected wall described in above section was analyzed by EFM and results were compared with the results from the literature. The EFM with hinges assigned to it is shown in Fig. An initial linear analysis of a model for dead loads is done to get an axial load on each pier and vertical pressure coming on them. The cross section properties of each pier are determined. The push over curves were obtained forth different lateral loadings(a) inverted triangular distribution (SPO1), (b) uniform distribution (SPO2), as recommended by recent codes of practice and regulations

Aspect shear(V)	Axial moment	Ultimate Ultimate ƒ	Ultimate Pier shear	ratio	stress	Ultimate rotation (( )	Ultimate lateral deflection
	D	(kN/sq.m)	(kN-m)	(kN)	(kN)	(radian)	δu(mm)
P1	1.465	92.711	36.482	37.861	17.844	0.016	7.912
P2	1.465	186.563	61.682	48.883	32.832	0.016	7.912
P3	1.282	109.765	66.504	57.682	28.027	0.017	8.720
P4	1.282	216.118	106.519	74.633	49.400	0.017	8.720
P5	1.282	109.765	66.504	57.682	28.027	0.017	8.720
P6	1.282	216.118	106.519	74.633	49.400	0.017	8.720
P7	1.465	92.711	36.482	37.861	17.844	0.016	7.912
P8	1.992	186.563	61.682	35.958	28.438	0.022	10.756

Table1. Flexural and shear hinges properties

3.3 Validation Results

Result from Pasticier et al., (2007) and obtained from the analysis are shown in Table 2. The top displacement was almost the same that detected by Pasticier et al., (2007) with maximum 7.8% of error in the base shear result for inverted triangular distribution. Failure pattern for different load pattern is as shown in table 2.

Base shear (kN)	Inverted Triangular	Uniform
Pasticieret al., (2007)	126.54	157.15
Present study	136.51	159.65
Error in Base shear	7.8%	1.5%

Table 2. Comparison of Base Shear

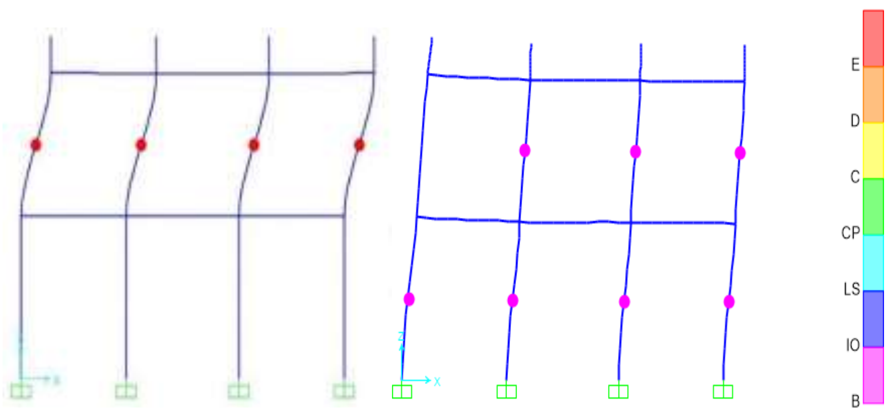

Figure 3. Deformed shape and hinge formation (a) SPO1 analysis with inverted triangular distribution and (b) SPO2 analysis with uniform distribution

IV. STRUCTURAL MODELLING

4.1 Geometric Modelling of Masonry Wall

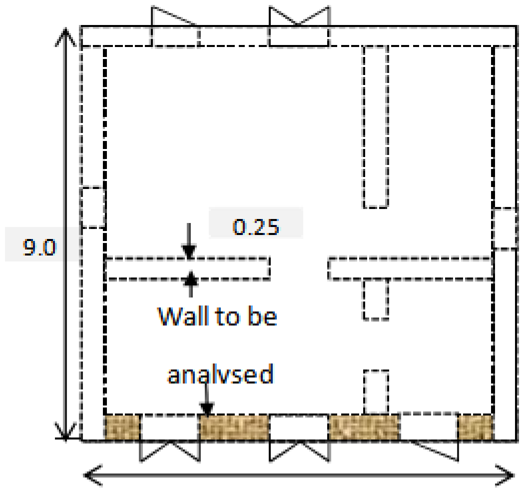

Figure 4. Plan and elevation of masonry wall

A detailed pushover analysis of the two story unreinforced masonry having door and window openings is carried out, by using equivalent frame modelling. Modelling of the wall is done as per described in Chapter 3.The planed elevation of the wall is as shown in Fig. 4
All windows are of the same size and having a wall thickness equal to 0.25m.

4.2 Modelling in SAP 2000

Three hinges are provided for each puerile. One shear hinge at centre and two rocking hinges at the end of the pier. In case of spandrel one shear hinge is provided at the centre. Perfectly rigid plastic behavior with final brittle failure was assumed for all these plastic hinges.

Fig 5: Unreinforced AAC structures
(Source: http://www.yourhome.gov.au/materials/autoclaved-aerated-concrete, Last Accessed: 26 March 2019)

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V. SENSITIVITY ANALYSIS

Variation in the material properties like physical and mechanical properties affects the lateral behaviour of building. In order to find out which parameter of URM is sensitive to the earthquake response sensitivity analysis is carried out. In the present work sensitivity analysis is carried out by considering 5% and 95% probability values of input properties of masonry. By knowing the abrupt changes in output due to change in input errors in the model can be predicted. This chapter presents a sensitivity analysis carried out to obtain a reasonable range of results representing a wide number of possible situations that can be met in practice by using push over analysis.

Property Variable						Distribution
		AAC	CLC	AAC	CLC	
Density (kN/m^3) γ		5.58	9.7	0.26	0.21	Normal
Masonry compressive	f_N	2.23	2.42	0.26	0.21	Normal
Masonry shear strength (MPa)	f_{vOd}	0.22	0.23	0.28	0.29	Normal
Elastic modulus (MPa)	Em	1610	2418	0.25	0.19	Normal
Shear modulus (MPa)	Gm	643	964	0.25	0.19	Normal

Table 3. Details of random variables of AAC and CLC masonry used in analysis (Bhosale, 2018)

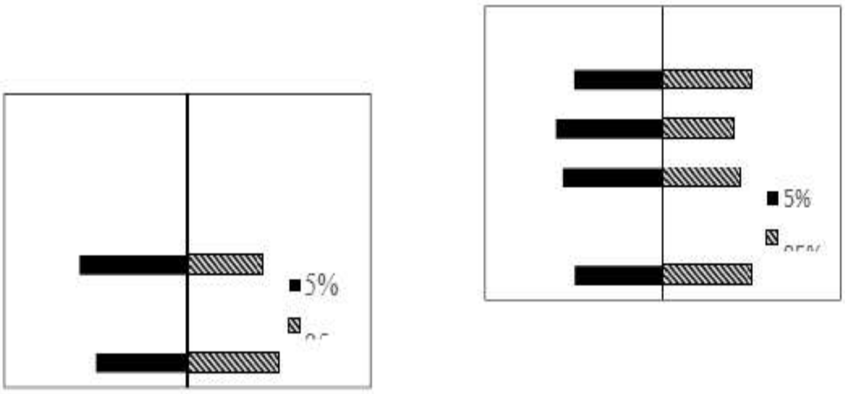

Fig. 6: TD for AAC masonry wall

VI. PERFORMANCE ASSESSMENT USING FRAGILITY CURVE

Fragility curve is use felt predict the possible level of damage when the earthquake comes. URM buildings are most sensitive to earthquake damages because of its high stiffness, heavy weight and low ductility. Although URM structures are common in the rural area in developing country like India. For URM catastrophic failure results in complete collapse of the structure as seen in Bhuj earthquake in 2001 in India shown in Fig. 7.

A number of approaches are available for developing the fragility curves for different types of the building considering either the empirical data from past earthquakes or using the data obtained from analytical simulations.

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Fig.7: Bhuj earthquake damage to URM, 2001

6.1 Variability Parameter (þ$_{dc}$)

The total variability of structural damage can be taken as combining the three damage variability given in the above equation using the complex convolution process. HAZUS- MR1 has provided pre-computed values of β to avoid complex numeric calculations. The variability values are shown in Table 4. For the parameters assumed in the study. However, HAZ US has defined uniform moderate variability for damage state threshold (þ$_{M(dc)}$) as 0.4 And capacity curve variability (þ$_{c}$) as 0.3. The variability due to post-yield degradation for Gr3 damage states considering minor degradation is 0.9 and for Gr4 damage states, considering major degradation is 0.5. So the total variability (þ$_{M(dc)}$) for Gr2 damage state is 0.95, Gr3 1.05 and for Gr4 taken as 1.05.

Table 4. Damage state definition (Barbatet al. 2006)

Damage grade	Damage state	Spectral displacement
Gr1	Slight damage	$0.7S_{dy}$
Gr2	Moderate damage	S_{dy}
Gr3	Extensive damage	S_{dy}
Gr4	Complete damage	S_{du}

VII. SUMMARY AND CONCLUSIONS

7.1 Summary

Extensive literature review, were carried out in order to establish the objectives of the present research work. EFM method is used to understand the lateral behaviour of URM. First of all, to understand the concept to EFM and reliability of method, validation was done. In order to observe the lateral behaviour of URM, a wall with opening is selected and analyzed throughout the present study. Same wall with different masonry properties were analyzed for two different lateral loadings. Results of SPO analysis show the higher strength estimation for uniform lateral load. Same wall was analyzed for different cement mortar ratio. Higher grade of cement mortar results in higher strength estimation. Considering 5%, mean and 95% of masonry properties (random variables) based on its mean and COV values, sensitivity analysis is carried out. Base shear at yield and ultimate base shear are considered as sensitivity parameter in present study. Results of sensitivity analysis are shown in Tornado Diagram for different masonry.

Seismic fragility curves are used for assessment of seismic losses for post-earthquake recovery programs as well as for pre-earthquake disaster planning. It provides the probability of structural response when subjected to earthquake load as function of ground displacement PGA .In the present study HAZ US methodology used for the development of fragility curve. Fragility curve were developed for URM wall for three damage states. In the present study fragility curve is developed only for the clay masonry. Various conclusions obtained from present study, future scope of present study are given in this chapter.

7.2 Conclusions

Following are the major conclusions that are obtained from present study:

- Push over curve: Results obtained from SPO analysis it can be conclude that clay masonry will behave good as compare to Fly Ash, AAC and CLC masonry in case of earthquake. Higher grade of cement mortar will result in higher response of URM structure. Higher strength estimation is obtained for uniform lateral load distribution compare to inverted triangular distribution. Main reason for failure of URM was due to formation of shear hinges in the structure. For inverted triangular distribution story mechanism is occurring in top story whereas, story mechanism is occurring in ground story for uniform lateral load. For both the distribution, ultimate displacement is near about same.
- Sensitivity analysis: Results obtained from sensitivity analysis shows that base shear at yield level is sensitive to shear strength and density of masonry whereas ultimate base shear is sensitive to all properties with exception to the compressive strength of masonry.
- Fragility curve: In present study fragility curve is developed only for clay masonry wall for three damage states. It is observed that the there is great probability of moderate damage compare to complete damage. Probability of damage will decrease with increase of severity of damage.

7.3 Limitation and Future Scope of Present Study

In the present study single wall is analyzed considering different masonry properties. The present work can be extended by considering different walls with different geometry, different orientations in openings. This work is limited for in-plane strength (2-D). For more accurate result the effect of out of plane strength (3-D) should be include in this modelling. Rigid wall without openings is kept out of this study. There is great variation in physical and mechanical properties of URM in different regions so in order to have more accurate results determining these properties precisely, is very important. Fragility curve is developed only for clay masonry.

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