

Study on Effect of Openings in Seismic Behavior of Masonry Structures

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Abstract: From beginning of civil construction masonry structure has a leading role due to its low cost, high fire-resistant capacity, good sound and mainly easily availability. This type of buildings is very vulnerable during earthquake and sometimes the entire structure may have collapsed. So, in earthquake prone areas proper monitoring should be given for the masonry structures. Various analytical and experimental studies are carried out in this field.

The main aim of this study is to find the effect of opening in the URM structures corresponding to the seismic action. For this different length to breadth ratio ($L=B$, $L=1.2B$, $L=1.4B$, $L=1.6B$, $L=1.8B$, $L=2B$) of 1150 sq. Ft. biaxially asymmetric buildings plans are taken. Here in this plans the built-up area of all structures are same but the percentage of the opening will change according to the type of plan. These plans are modelled and analyzed with the help of 3MURI software. Then the performance point of all the building is determined with the help of pushover curve obtained from the software and a comparative study of all buildings were carried out.

Key Words: Unreinforced Masonry, Effect of Opening, Pushover Analysis, Performance Point.

1 INTRODUCTION

Masonry is a composite material, which contains both brick units and mortar. It is one of the main techniques used to construct the building units from olden days. The masonry constructions are very durable and often require little maintenance that makes them very useful for the construction purpose. As similar to concrete, masonry structures have high compressive strength and low tensile strength. Generally, masonry is a non-elastic, non-homogeneous and anisotropic material composed of two different materials, bricks and mortar. It is very weak in tension due to the weak bond between them. The strength and the durability depend on the quality of materials, mortar and the workmanship.

The masonry structures are commonly classified as

- Unreinforced masonry
- Reinforced masonry
- Confined masonry

An unreinforced masonry building (Figure 1: UMB, URM building) is a building where load bearing walls or other structural members are made of bricks which are binded together by cement mortar that are not provided with reinforcing material. URM structures are vulnerable to collapse in an earthquake, they will produce cracks when comes under earthquake. They have little ability to withstand lateral force during heavy rain and wind.

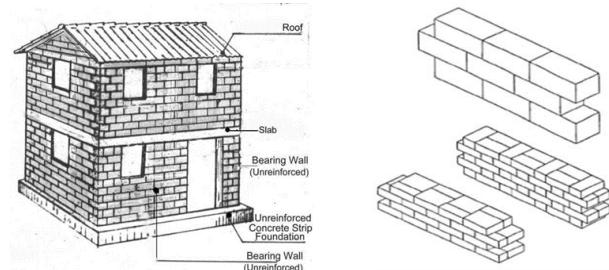


Fig1: Unreinforced masonry

Reinforced masonry construction (figure:2) consisting of load-bearing walls into which suitable metal (normally steel) are introduced and bonded together to get a composite material capable of resisting the compressive stresses, tensile and shear stresses which obtain in a structure. Reinforcement in walls are at required intervals both horizontally and vertically is used. The size, quantity, spacing etc. of the reinforcement is calculated by the upcoming loads on the structure.

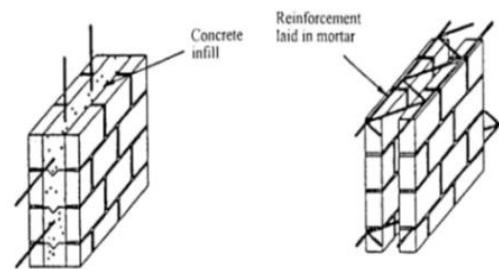


Fig 2: Reinforced grouted cavity masonry construction system

Confined Masonry (figure:3) is a building technology with a different construction sequence and system. The masonry walls carry the seismic loads and RC confining elements are used to confine the walls in this type of construction methods. For the earthquake safety of a building the RC confining is very critical. These elements are

effective in enhancing the stability, integrity, and ductility of the masonry walls and lead to better seismic performance of masonry buildings compared to other forms of construction.

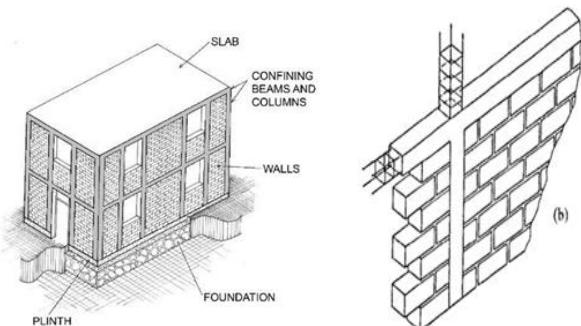


Fig 3: (a) A confined masonry building unit (b) Reinforced concrete bond beams and columns

1.1 Types of Failures

Vibrations caused by the earthquakes generate additional loading on the structure and the Shear stresses developed will cause damage to structural elements. The masonry is under compression and weak in resisting bending and shear, hence the final result will be the collapse of the structure. The different failures modes of masonry are:

- a) Sliding shear failure
- b) Diagonal cracks
- c) Non-structural failure
- d) Failure due to overturning

2. LITERATURE REVIEW

M. Shariq et.al 2007 [1] studied the influence of openings on seismic performance of masonry structures. In that study finite element analysis were carried out on a single storied masonry building unit with varying aspect ratios and different opening positions. The variation of maximum tensile stress and maximum shear stress are studied to compare the behavior of the structure. In the study it was observed that the maximum principal tensile stress occurs in short wall and maximum shear stress occurs in long wall.

N. Augenti and A. Romano 2008 [2] The paper discusses about some seismic design methods using three software's RAN, SAM and 3MURI. The study analyses the basic hypotheses, the calculus procedures, the criteria and the applicative capabilities of these three. After comparing it was found out that the main difference in these software's are obtained at the modelling stage itself. The RAN method allows a linear static seismic analysis for each story of the building, SAM Method uses the nonlinear static analysis and the 3MURI method allows to carry out linear and non-linear static analyses.

A. Penna, et.al. 2008 [3] the paper studied non-linear macro-element analyses that are used for the analysis of masonry structures under seismic loads. This modelling method has been implemented in the TREMURI software with non-linear static and dynamic analysis procedures. In this paper, modelling strategies are presented with an accurate macro-element approach without heavy computational load and are developed for the analysis of both building and bridge structures. An experimental comparison was also done using a building from Barcelona. The result of this study shows that the non-linear macro-element modelling of 3-dimensional masonry buildings supplies reliable results in comparison with experimental data. Its seismic analysis capabilities make the TREMURI program a valid tool both for research activity and engineering practice.

Fulvio Parisi and Nicola Augenti 2013 [4] In this paper the effects of irregularities on the seismic capacity of unreinforced masonry (URM) walls with openings are studied. Their regular masonry walls include (i) openings of different sizes, (ii) openings misaligned in the horizontal and/or vertical direction, or (iii) a variable number of openings per story. The irregular buildings lead to non-uniform distribution of gravity loads and also resulting in premature collapse of the building. The methodology of this paper includes the macro- element modelling of URM walls with openings. There are different macro- elements such as (i) Pier panels (ii) Spandrel panels (iii) Joint panels and the failure modes of the macro-elements mainly depend on the relative strength between masonry components, applied axial forces and the boundary conditions. In this paper a Static Push over Analysis is conducted on a two-story URM wall with openings. The results of the study show that the seismic capacity of the URM walls significantly reduces with increase in the geometric irregularity.

Sharmin Reza Chowdhury, et.al. 2012 [5] the study was conducted using finite element software, ETABS. The results show that the Stiffness of the structures is affected by the size of the openings as well as their locations. The opening placed in plane of loading is more critical than that of opening in shear wall placed out of plane of loading.

V. Vysakh et.al. 2013[6] this paper study about different methods of determination of performance point in capacity spectrum method. The capacity spectrum method is one of the widely accepted method used for the calculation of performance point. There are three capacity spectrum methods named A, B and C. Method A is the direct application theory while method B is based on the assumption of constant post yield slope, which are used in software's like ETABS and SAP2000. Procedure C is purely graphical method.

Narayanan S P, Sirajuddin M 2013[7] this paper study about the properties of brick masonry components which are important in the finite element analysis of masonry structures. Main masonry codes that taken into study are ACI

530-02, IBC 2000, NZS 4230:1: 1990, Eurocode 6 and IS 1905-1987. When comparing the properties of brick units in different places India shows relatively lower strength values. Experimental studies were carried out, here three different types of brick units and three mix proportions of mortar were considered for the study. In bricks, two types of wire cut bricks and one type of country burned bricks were used for the investigation. The results obtained that the mechanical properties of mortar reduce with lower mix proportions of mortar.

3. METHODOLOGY

After a brief description of the adopted models ($L=B$, $L=1.2B$, $L=1.4B$, $L=1.6B$, $L=1.8B$, $L=2B$) and analytical validation, this paper focus on the effect of openings on biaxially asymmetrical URM structures during an earthquake. Different types of analysis methods are there for the study of masonry structures. Finite element modelling analysis is a most suitable method to analyze the structure because it gives more finite and accurate result. Inelastic strength and deformation demands can be determined by using nonlinear static analysis or push over analysis. Here 3-dimensional modelling and analysis of the structure is going to do by using the software 3MURI. The displacement and shear of the building will get from the pushover curve this helps to find the performance point of the building. It will help to compare the performance of all models and can identify which building has more performance against earthquake.

4. MODELING AND ANALYSIS OF URM STRUCTURE USING 3MURI

3MURI is an analytical software developed for the structural and seismic analysis of masonry building. It is mainly based on the equivalent frame modelling approach incorporating several macro-element models for the simulation of masonry and non-masonry structural members. The macro-element analysis mainly consists of masonry piers, spandrel strips. It will give all possible failure mechanisms like composed flexural and axial load, tensile shear and sliding shear. The reduction of the section (induced by cracking) helps to evaluate the stiffness degradation which involves the panels stress variation generated by external actions. Both nonlinear static and dynamic analyses of a 3D building can be done by using this software and this also provide a clear understanding result.

The building considered for the numerical analysis is a biaxially asymmetric building plan. It is a one-story building with a total height of 3m. (in Figure 4) shows the $L=B$ plan view. According to this modify the plans to $L=1.2B$, $L=1.4B$, $L=1.6B$, $L=1.8B$, $L=2B$ are modelled and analyzed by using 3Muri software. The wall thickness is 24 cm.

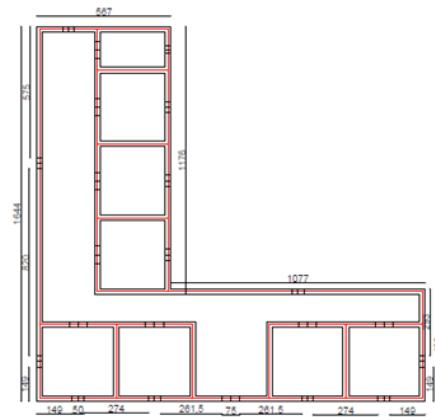


Fig 4: building plan1

The center of mass and center of rigidity of all plans are calculated. These are depending on the story height, shape of the structure and the openings. The difference of center of mass and center of rigidity will give the eccentricity of the building.

The rigidity of walls in X and Y direction and the center of gravity of corresponding walls will give the eccentricity in that particular direction.

$$\text{COR} = \frac{\sum_{\text{o}}^n kx}{\sum_{\text{o}}^n k} \quad (1)$$

Here K and x are the rigidity of individual walls and center of gravity respectively

Mass of the building and corresponding CG gives the COM of the building

$$\text{COM} = \frac{\sum_{\text{o}}^n Mx}{\sum_{\text{o}}^n M} \quad (2)$$

Here M and x are mass of the walls and floors and corresponding CG respectively.

The material properties of all plans are same and that are given below:

Table 1: Building parameters

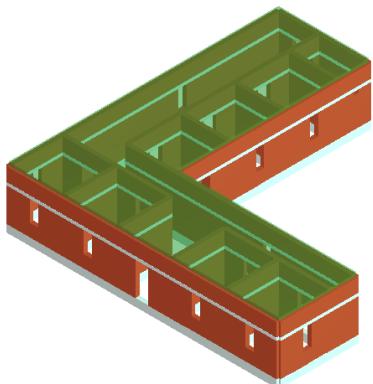
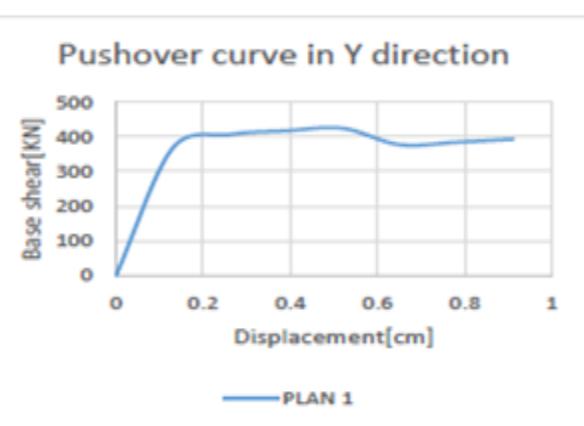
Description	Values
Unit weight of masonry	1920 kg/m ³
Safety factor, Y _m	3
The compressive strength of mortar, f _m	2.96 N/mm ²
The compressive strength of masonry, f _k	2.46 N/mm ²
Initial shear strength, f _{vko}	0.29 N/mm ²
Shear strength limit, f _{vlim}	2.2 N/mm ²

Young's modulus, E	1800 N/mm ²
Rigidity modulus, G	250 N/mm ²
Floor finish	1 kN/m ²
Dead loads, G _k	1.0 kN/m ²
Accidental loads, Q _k	2.0 kN/m ²

Table 2: size of openings provided

	1	2	3	4
WINDOWS	500 X 1350m	100 X 1350	150 X 1350	200 X 1350
DOORS	750 X 2100	900 X 2100	1050 X 2100	1200 X 2100
VENTILATIONS	300 X 300	300 X 300	300 X 300	300 X 300

By using the parameters given in table (1) the plan is modelled in 3MURI software. The meshes are generated automatically and after completing the analysis we will get a pushover curve in terms of force and displacement. It is a plot of base shear vs lateral displacement.


Fig 5: 3D model of plan 1

Fig 6: Pushover Curves in X and Y direction

4.1 PERFORMANCE POINT

It is a point where capacity curve and demand curve coincide. Both of these curves are mutually dependent. In the case of a capacity spectrum, where displacement increases the period of the structure lengthens. At the performance point both the capacity and demand are equal. So, there is a need of covert them in to a common scale i.e. Spectral acceleration vs. spectral displacement. This format of plotting is known as Acceleration – Displacement Response Spectra (ADRS). Each point on a response spectrum curve has associated with unique spectral acceleration, S_a , spectral velocity S_v , spectral displacement S_d and period T . To convert from S_a vs. T found in building codes to ADRS format, it is necessary to determine the value of S_d for each point on the curve using the following equation;

$$S_{d_i} = \frac{T_i^2}{4\pi^2} S_{a_i} g \quad (3)$$

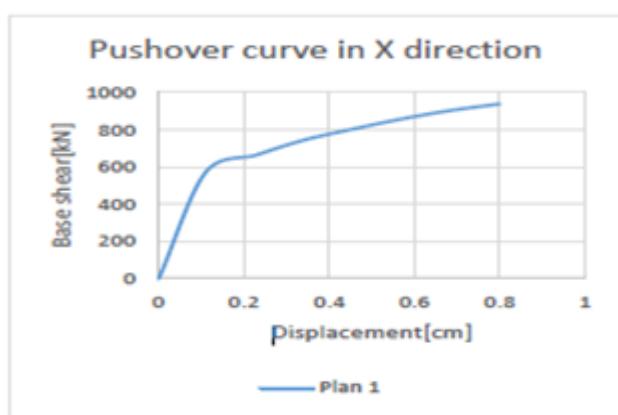
Based on push over curve, base shear (V) and roof level displacement (δ) is converted to points S_{a_i} and S_{d_i} respectively.

$$S_{a_i} = V_i / W \sqrt{\alpha_i} \quad (4)$$

Where, α_i is the modal mass coefficient

$$S_{d_i} = \frac{\delta_i}{PF_1 \times \phi_1 \text{ roof}} \quad (5)$$

Where, PF_1 is the participation factor and ϕ_1 is roof level amplitude at first mode.



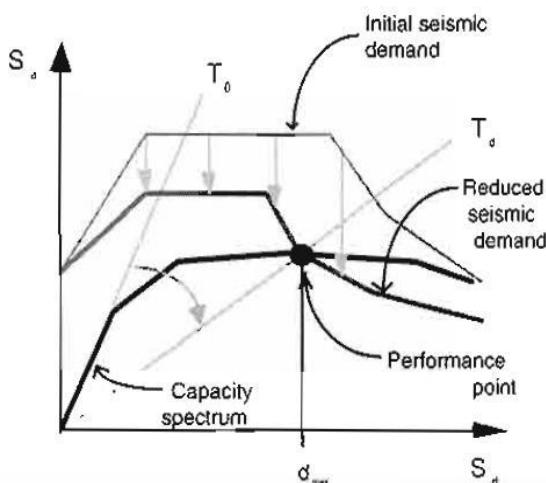


Fig 7: capacity vs. demand curve

5. RESULT AND DISCUSSION

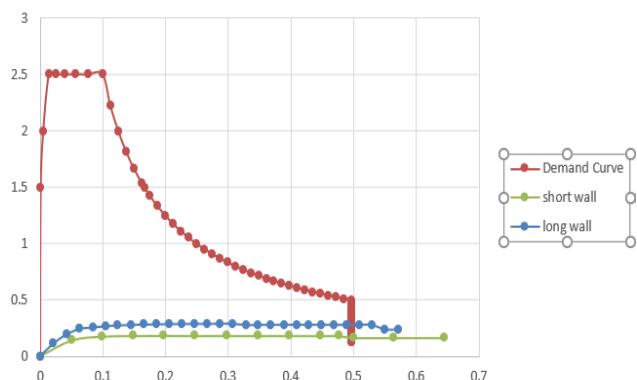


Fig 8: Comparison of performance of building in long and short wall direction

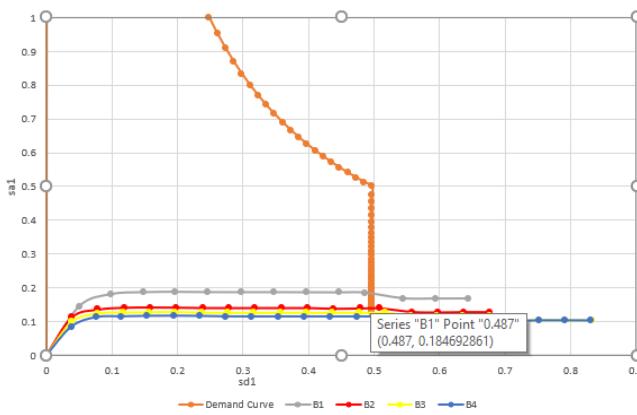


Fig 9: Biaxially asymmetric buildings with varying opening size

6. CONCLUSIONS

The seismic analysis helps to study about the behavior of building under earthquakes. This work includes the seismic response of biaxially asymmetric building with different opening sizes and position. The findings are listed below:

- To make the masonry walls resistant to the earthquake we have to give proper attachments between the masonry panels at their junctions.
- The seismic capacity of the URM walls significantly reduces with increase in the geometric irregularity.
- The symmetrical buildings have high performance during earthquake than asymmetrical or biaxially asymmetric buildings
- The Biaxially asymmetric building shows better performance than other buildings in their long wall direction
- When opening percentage in wall increases from 3 to 7, 40% reduction in the shear carrying capacity
- The buildings with openings at the center of walls have 30-40% higher performance than the buildings with openings at other positions
- The buildings with small openings withstand higher range of loads than the buildings with large opening sizes
- Failure mechanism depends on the eccentricity, wall openings, Presence of encirclements, wall density ...etc.

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