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SENSITIVITY ANALYSIS OF URM BUILDINGS SUBJECTED TO SEISMIC LOADING AND DEVELOPMENT OF THEIR FRAGILITY CURVES

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ABSTRACT: URM structures are normally utilized in creating nations like India for low ascent developing to two story in country region. Harm to those structures brings about death toll and social legacy. The primary target of the current proposition is to know the horizontal conduct of URM structure, and comprehend the idea of equal casing demonstrating (EFM). In the current work upset triangular and uniform dissemination horizontal burdens are utilized to consider the nonlinear conduct of workmanship. There are a few techniques to do Static Pushover (SPO) investigation of URM, however Equivalent Frame Modeling is the straightforward one. EFM is being utilized for displaying the non-direct conduct of stone work by giving fl and shear pivots in the model. EFM is only expecting divider with opening as blend of level and vertical individuals. The plastic pivots were utilized in SPO examinations since they permit the client to precisely follow the auxiliary execution past as far as possible at each progression of the steady investigation. Completely inflexible plastic pivots were accepted as suggested in writing audits and demonstrating is done in SAP2000 programming. So as to know which property of stone work is delicate to parallel conduct, affectability examination is completed. Affectability examination was completed by shifting all boundaries with 5%, mean and 95% worth. Twister outline is utilized to speak to the consequences of affectability. It was discovered that with the exception of compressive quality every other boundary are influencing the parallel conduct.

The delicacy can be viewed as one of the most significant device for execution based plan of structures. The delicacy bends are created by utilizing HAZUS approach. Distinctive harm levels, for example, slight, moderate, broad and complete harm state are considered to speak to fluctuation in seismic execution of building and fi delicacy bends were gotten for three harm state quality degrees of workmanship dependent on otherworldly relocations and harm likelihood. It is seen that the structure have greater likelihood for moderate harm. Diff t block masonries are thought of, to analyze the consequences of the sucker.

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

I. OVERVIEW

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 poses 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.

The structure is modified for decreased stiffness of the yielded members and the loads are again increased until a controlled displacement is reached or the structure becomes unstable. For Pushover analysis, non-linear hinges are required to be inserted in the model. The non- linear properties of these hinges are based on the failure mechanisms occurring in the masonry. The various failure mechanisms are shown in the Fig. 1.3 are described as follows:

- Rocking: It is a flexure-dominated failure in which flexural cracks are developed at the bottom and top of a wall.
- Diagonal shear: It is described by stair-stepped cracks along head and bed joints or horizontal cracks along bed joints.
- Diagonal tension: Failure due to shear with diagonal cracking in the centre of the wall.
- Toe Crushing: It is characterized by crushing of masonry at high compression zone, which is generally located at the base end of the wall.

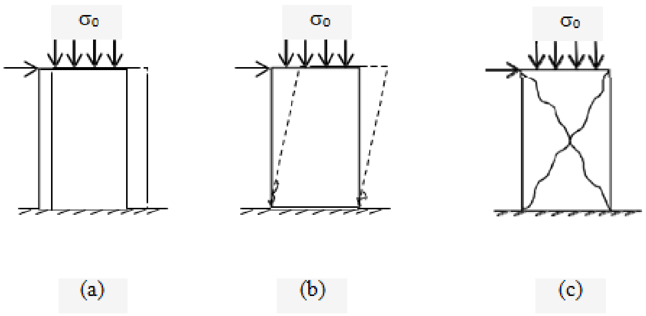

Fig. Various types of failure in masonry pier:

(a) sliding shear, (b) rocking and (c) diagonal shear cracking

There is a great threat of earthquake damage to URM building since it is weak in carrying lateral loads. There are many URM historical important structures as well as housing units in India which may damage due to the earthquake. Still, it is difficult to predict the post-earthquake performance of such structures. SPO analysis is an important tool to evaluate the seismic performance of the building**.**

Objectives

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

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

Pushover Analysis

There are several outputs obtained from pushover analysis listed below:

- Estimate force at which yielding of member takes place and ultimate force at which failure of structure takes place.
- Estimate yield displacement at which fine cracks develop and ultimate displacement at which failure takes place.
- To ascertain the sequential yielding of the members and the progress of the overall capacity curve.
- By knowing the sequence of member yielding one can identify the critical regions, where the inelastic deformations are expected to be high and identification of strength irregularities (in the plan or in elevation) of the building.

Final summary of pushover analysis

This chapter describes the SPO analysis procedure and various technical terms used in SPO. EFM is simple, easy method to carry out SPO analysis of URM masonry. In order to validate the EFM, the analysis is done and results are compared with the results of Pasticier *et al*., 2007. Present equivalent frame model presents the strength and displacement in close agreement with literature. Therefore, the present model can be considered as valid.

II. STRUCTURAL MODELLING

Geometric Modelling 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 plan and elevation of the wall is as shown in Fig All windows are of the same size and having a wall thickness equal to 0.25m.

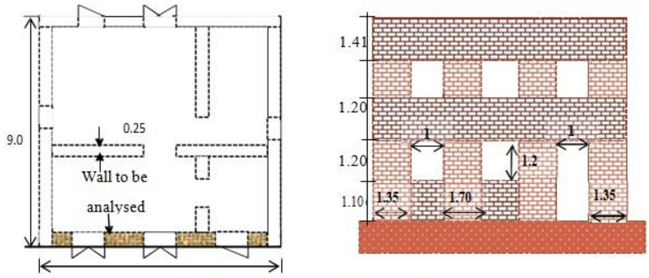

Fig. Plan and elevation of masonry wall

(All dimensions are in metres.)

Modelling in SAP2000

Three hinges are provided for each pier i.e. 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 behaviour with final brittle failure was assumed for all these plastic hinges. The hinge properties in terms of the ultimate moment and ultimate rotation or ultimate shear and ultimate shear displacement were calculated as per equations

Summary

This chapter begins with description of wall which is to be analysed. The same wall is analysed considering different masonry through-out the study. Details of all masonry properties required for the analysis are given in this chapter along with the source. SPO analysis is carried out for two different loading conditions. Uniform lateral distribution always shows higher base shear strength estimation compare to inverted triangular distribution. In terms of top displacement, both distribution of seismic forces lead to nearly the same value. Obtained SPO curves shows that clay masonry will perform well compare to Fly ash, CLC and AAC masonry as shown in Table. 4.5. Also the effect of cement: mortar ratio on lateral behaviour shows that, for grade CM1 and CM2 there is not much variation in base shear whereas for grade CM3 shear strength is about 20% more compare to CM1 and CM3.

Table Variation of base shear and top displacement

Lateral Load Pattern	Base Shear (kN)		Top Displacement (mm)	
	SPO1	SPO2	SPO1	SPO2
Clay Masonry	67.963	96.884	8.22	8.27
Fly Ash Masonry	55.908	73.69	8.57	8.92
CLC Masonry	35.56	50.692	8.21	8.25
AAC Masonry	20.54	29.281	8.16	8.3

III. SENSITIVITY ANALYSIS

There are several advantages of sensitivity analysis which are listed below:

- To reduce the uncertainty in the model by knowing the parameters (input) that results in significant change in output.
- By knowing the sensitive parameters one can focus on these parameters results in less computational effort and time-saving.
- In order to know the relationship between input and output variables.
- In the presence of uncertainty to test the reliability of the model.
- Reduction in uncertainty, through the identification of model inputs that cause significant uncertainty in the output and should, therefore, be the focus of attention in order to increase reliability.
- By detecting the abrupt relationship between output and input errors in the model can be predicted.
- To simplify the model by knowing the non-sensitive parameters so that one can fix that model inputs.

Summary

This chapter gives the overall idea about what the sensitivity analysis means along with its advantages. Later on sensitivity analysis is carried out by considering 5% and 95% probability value of a random variable in the masonry properties. Result of sensitivity is represented in Tornado Diagrams. Results 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.

Performance Assessment Using Fragility Curve

Fragility curve is useful to 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. 6.1. _

Most of the studies regarding performance-based seismic design are based on deterministic approach. But since lots of uncertainties are associated with material strength and earthquake loads so a probabilistic approach seems to be a more rational way for performance assessment of a structure. The HAZUS methodology has been widely used for estimating the potential losses of an existing building caused by earthquake ground shaking for the purpose of quantifying seismic risk in a region or an urban area. Often nonlinear pushover analysis of typical buildings is required for establishing building capacity and fragility curves. This chapter presents a procedure for establishing the required fragility curves for various damage states, in particular for the more severe damage states, based on nonlinear pushover analysis results.

Modelling and Analysis

20 different combination of properties were generated based on the mean and COV given in Table 5.1 using LHS sampling. Then 20 models were generated for the same wall and nonlinear static analysis (pushover) is carried out using SAP2000 for inverted triangular distribution. This pushover analysis method is mostly used to obtain quantitative limit state values. The critical points like yield and ultimate response and initiation of a collapse mechanism are obtained from the pushover curves (in the form of base shear versus roof displacement) using bi-linear idealization as shown in Fig. 6.3.

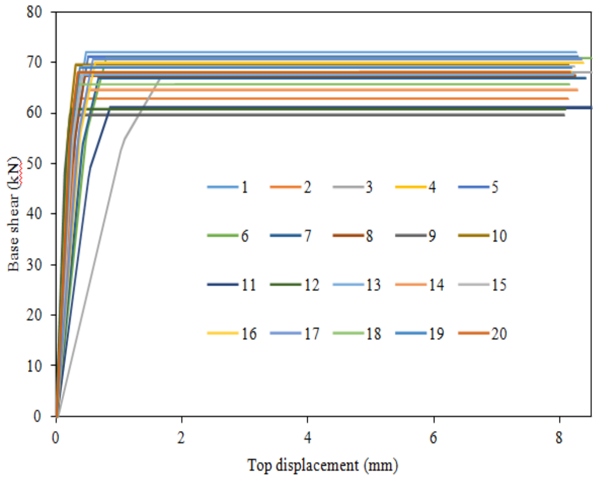

Fig. 6.3: Pushover curve for 20 different combinations of masonry properties

Using above pushover curve 20 values for yield and ultimate spectral displacement found out from the capacity spectrum. After getting this values, median yield and ultimate spectral displacement for different damage states are obtained. For the present wall median yield spectral and median ultimate spectral displacement was found to be 0.35mm and 8.23 mm respectively. Only damage state Gr2, Gr3 and Gr4 are considered in the present study for developing the fragility curves. From the spectral displacements obtained for 20 cases, median spectral displacement (sds) are obtained. Median spectral response shows the threshold limit of a given damage state. Then using the normal distribution function probability of equal or exceeding a given damage state can be obtained.

Performance of URM Masonry Wall

Fragility curves for two-storey masonry wall is developed as per methods discussed above for three damage states Gr2, Gr3 and Gr4. The slope of fragility curve developed depends on the lognormal standard deviation value of β. A Smaller value of β indicates the lesser variability of damage state and hence steeper fragility curve is generated. So the Gr2 curves are stiffer than Gr3 curves (β of Gr2 = 0.95, Gr3 = 1.05 and for Gr4, it is 1.05).

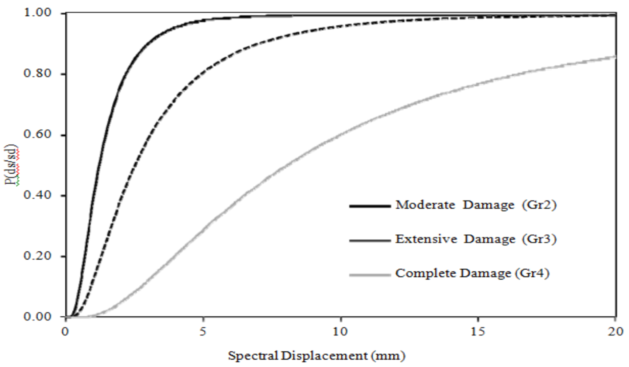

Fig. 6.4: Fragility curves for 2-storey clay masonry wall for different damage states

Summary

This chapter illustrate the step by step procedure for the development of fragility based on Hazus methodology for different damage states. Four damage state are considered in the present study defined by Barbat *et al.* (2006). Fragility curve developed for two storey clay masonry wall for 3 damage state. It is observed that the there is great probability of moderate damage compare to complete damage. Since for Gr3 and Gr4 damage state all other parameters being constant the probability of reaching or exceeding that state depends only on the median spectral displacement.

Final 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 of EFM and reliability of method, validation was done. In order to observe the lateral behaviour of URM, a wall with opening is selected and analysed throughout the present study. Same wall with different masonry properties were analysed for two different lateral loadings. Results of SPO analysis shows the higher strength estimation for uniform lateral load. Same wall was analysed 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 or ground motion intensity (PGA). In the present study HAZUS 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.

IV. CONCLUSIONS

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

- Pushover 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.

Limitation and Future Scope of Present Study

In the present study single wall is analysed 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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