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Seismic Performance Assessment of Buildings Made of Brick Masonry with Mud Mortar in Kathmandu Valley

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Abstract
Ancient and poorly built unreinforced masonry structures are susceptible to earthquakes, as numerous historical earthquakes have demonstrated. Because the existing assessment techniques for masonry or reinforced concrete framed buildings with rigid diaphragms are not immediately applicable to buildings with flexible diaphragms, seismic analysis and assessment of these buildings are difficult. Behaviour of the in-plane walls and out-of plane walls are different for structures with flexible diaphragm. In this study, a simple method is used for seismic performance assessment of unreinforced masonry buildings using the finite element method. This methodology includes the segregation of both in-plane as well as out-of-plane behavior in the analysis. Incremental dynamic analysis method is performed using Diana. The results obtained are evaluated in terms of lateral displacement for a particular peak ground acceleration and in terms of the maximum inter-story drift ratio for each in-plane and out-of-plane wall for a particular peak ground acceleration. Fragility functions are generated separately for both types of walls to encompass their behavior. This method is applicable to both rigid and flexible diaphragms.

Keywords
Masonry Building, Incremental Dynamic Analysis, Fraglity Function

1. Introduction

Earthquakes are major natural phenomena which results in huge loss of life and property. Nepal is situated in between two tectonic plates- Indo- Australian plate and Eurasian plate and due to the tectonic movement of the Indo-Australian plate, Nepal is prone to massive earthquakes.It has been observed that even with mild to moderate earthquake motion, aged and badly built unreinforced masonry (URM) constructions are vulnerable to partial damage or collapse [1]. The degree of connection between the horizontal structures and URM walls is an important construction characteristic in URM buildings that impacts their seismic performance [2]. The out-of-plane (OOP) response is weaker than the in-plane (IP) response when individual URM walls are taken into account. This is mostly because only the tensile capacity is mobilized, which is based on cohesion, as opposed to the shear capacity, which is dependent on both cohesion and friction.

Lower stiffness impacts the out of plane behaviour and this is even significant in case of slender walls where P-Delta effects comes into play. On the other hand, because of the frictional resistance at the cross-wall connection and the displacement constraint offered by the horizontal structures, the walls acting in the OOP direction in 3-D global building configurations, where cross-walls are connected to each other as well as to the horizontal structures, have better seismic behavior than a single detached wall [3]. D'Ayala and Speranza provide a thorough summary of the various OOP failure mechanisms of URM walls in existing buildings [4].

Due to lack of proper connection between floors and roofs to the URM walls or if they do not have sufficient in-plane rigidity, the floors or roofs behave as a flexible diaphragm. As a result, the assumption made in case of rigid diaphragm that all vertical members at a given storey level will displace equally is false [3]. Hence, the results that are obtained through conventional pushover analysis does not hold true. An alternative is required to generate proper result, hence the main goal of this paper is to use a valid method for seismic performance assessment of URM buildings independent of the diaphragm type [5, 6, 7].

Global seismic analysis is easily performed in masonry structures with rigid diaphragm as the building's behavior is idealized as a single degree of freedom (SdoF) system. However, in unreinforced masonry structures with flexible diaphragm, there is huge difference in stiffness and displacement capacity of the walls acting in IP and OOP directions. Also there is a deviation in natural frequencies of vibration as well as mode shapes, and hence it is erroneous to model the whole building with one SdoF system. Instead, component based method is proposed where at first all the IP and OOP elements of a structure is distinguished and analysis is performed and results are obtained for each component separately.

2. Building typology

A four storey building from Patan is considered for the analysis. English bond pattern is used for the construction of the walls and the structural elements such as horizontal tying elements like seismic bands as well as corner reinforcements are absent. Long walls have large openings and they are usually located near the corners of the wall.

Figure 1, 2, 3, and 4 represent the floor plans of the building.

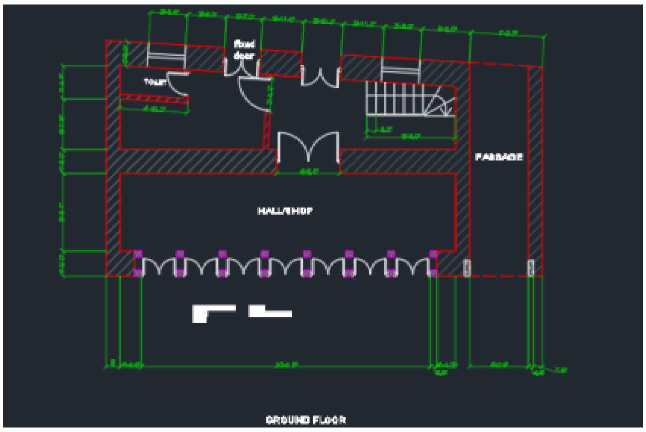

Figure 1: GF plan

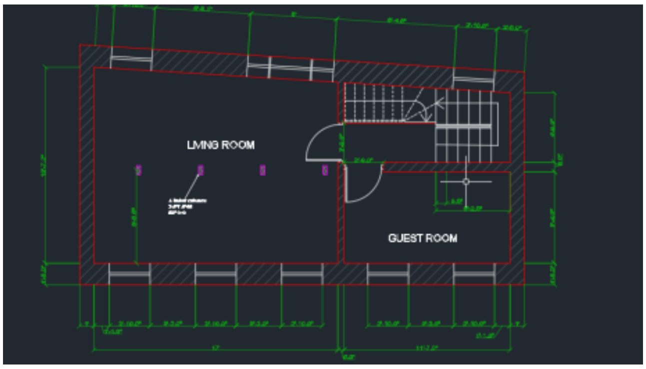

Figure 2: 1F plan

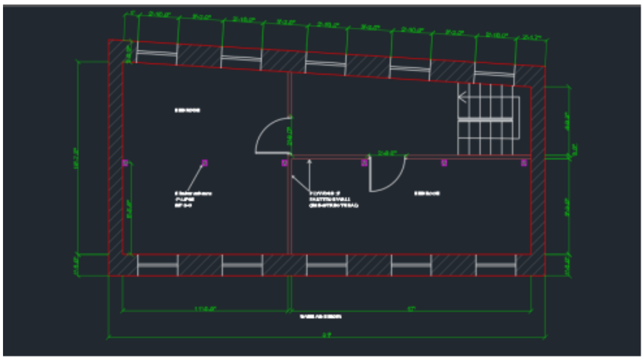

Figure 3: 2F plan

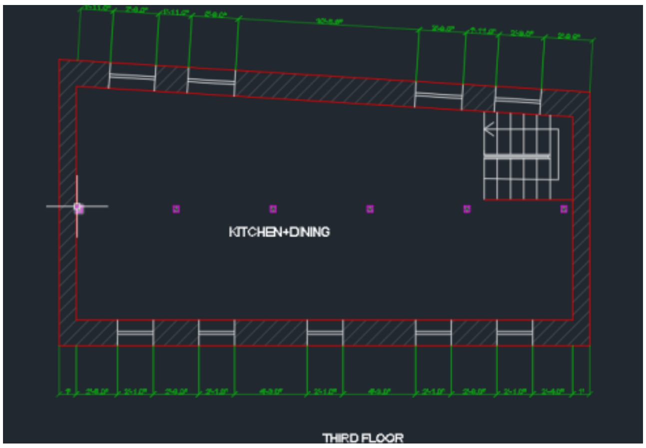

Figure 4: 3F plan

3. Structural Analysis

Finite element software DIANA version 10.5 was used to develop the model. For modelling, a three dimensional macro-modelling approach is adopted. The wall components are modelled as thick shell area elements whereas thin shell area element is used to model the slab floors. The floor made up of RCC slab is designated as rigid diaphragm whereas the timber floor on third storey is assigned as flexible diaphragm. Timber members are modelled as frame elements, and connections of rafters and joists is taken as pinned. All properties of building materials were obtained from literatures as the actual field data was missing. The foundation is assumed to be fixed at ground level. Soil structure interaction is not considered. Figure 5 represents the 3D modelling of the building in DIANA.

DIANA element library has different types of elements for modelling. Walls and floors of the house were modelled by shell elements as they represent both in-plane and out-of-plane deformations accurately. The elements are used in combination with the engineering masonry material model. 8-node curved shell element (CQ40S) having a quadratic shape function and a reduced 2×2 Gauss integration scheme is used. Full restraint condition was applied in the base. As there might be chance of shear locking, triangular curved shell elements are avoided as they would make the results erroneous. For meshing, a mesh size of 200 mm is used. The mesh size is chosen in proportion with the dimensions of available brick masonry. Table1 shows the material parameters used for numerical modeling.

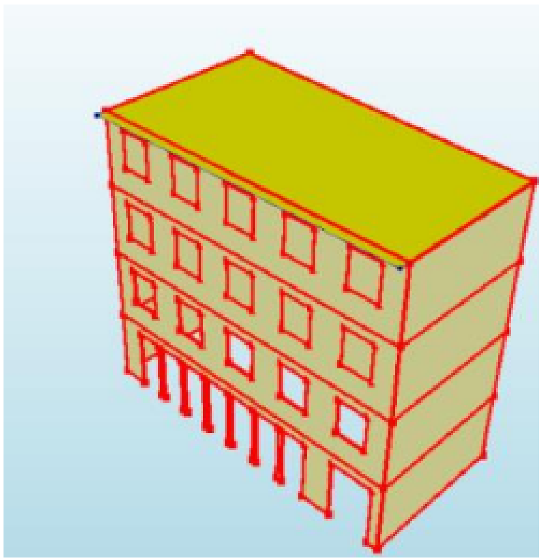

Figure 5: 3D Numerical modelling of building in Diana FEA

Table 1: Material Parameters use for Numerical Modelling

Parameters	Properties	COV
Young's Modulus, E (MPa)	150 MPa	90
Shear Modulus	90 MPa	N/A
Compressive Strength	1.21	N/A
Cohesion	0.05 MPa	59
Flexural Tensile Strength	0.05 MPa	N/A
Friction coefficient	0.6	N/A
Unit weight	168 kg/m3	N/A

4. Incremental Dynamic Analysis

IDA basically involves a series of nonlinear dynamic analyses under a wide range of multiple scaled ground motion records. It is used for determining seismic performance of structural system. NBC 105:2020 stipulates that maximum values of the response quantities obtained from the ground motion should be used if the number of ground motions used are less than seven. In case of the motions used more than seven, the average values should be used for evaluation [8]. Table2 depicts the motions chosen for analysis.

Table 2: List of earthquake ground motions

SN	Earthquake	Magnitude
1	Irpinia Italy	6.90
2	Northridge	6.69
3	Gorkha	7.8
4	India-Burma border	7.20
5	Friuli	6.50
6	Hollister	5.6
7	Livermore	5.8

The selected ground motion records taken from data centers should be scaled so as to match certain target response spectrum of specified location to meet the specified level of seismic hazard as per site location. For this study the target spectrum provided in NBC: 105: 2020 is used. Seismomatch software is used for scaling purpose of above ground motion data.The limit states for IP and OOP component are derived from FEMA specifications [9].

5. Results and Discussion

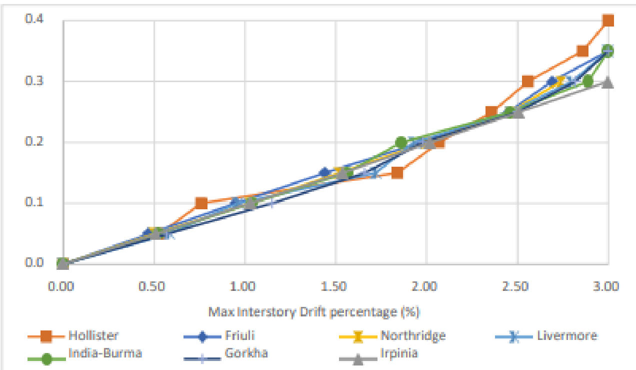

Figure 6: IDA curve for IP element

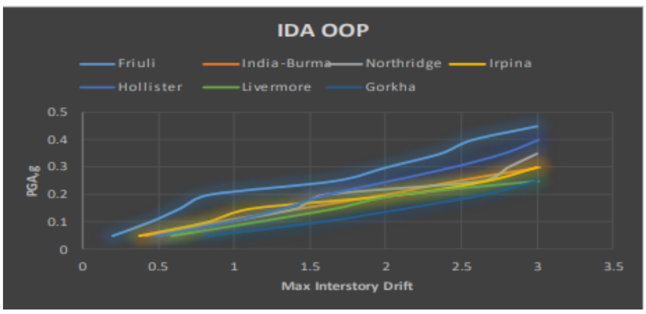

Figure 7: IDA curve for OOP element

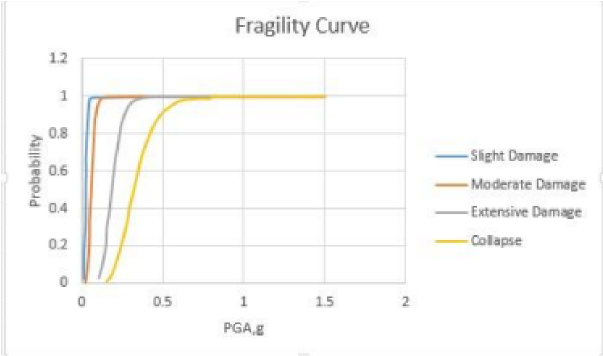

Figure 8: Fragility curve for IP element

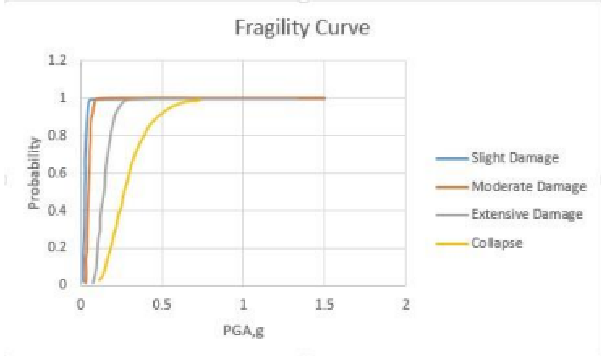

Figure 9: Fragility curve for OOP element

Maximum inter-storey drift ratio (IDR) is selected as the Engineering demand parameter(EDP) for this study. This is used to develop IDA curves leading to fragility curves. The IDA curves are developed through non- linear time history analysis under the selected seven ground motions. IDA curves are plotted between PGA on the y-axis and maximum inter-storey drift ratios (IDR) on x-axis for each IP and OOP element. Figure 6 and Figure 7 represents the IDA curves for IP and OOP element respectively.

Fragility functions are developed for the IP walls and the OOP walls, respectively, using the respective capacity curves and damage states indicated in FEMA. As seen in Figure 8 and Figure 9 OOP systems are more vulnerable than IP systems. For the given building, when the PGA is 0.2g, the slight and moderate damage level has probability of 100% for IP walls whereas it is 60% for collapse level . Whereas when PGA is 0.3 g the slight, moderate and extensive level has probability of 100% for OOP walls.

6. Conclusion

On the basis of the study, the following conclusion has been drawn.

- The walls in IP and OOP direction behave in different manner, i.e. OOP walls have lower seismic capacity than IP walls. They reach failure stage at lower PGA level.
- Through incremental dynamic analysis method, capacity curves and fragility curves for IP and OOP walls can be developed. Hence, incremental dynamic analysis is an apt method for analysis of unreinforced masonry buildings.

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