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Effect of Plan Configurations on the Seismic Performance of the Masonry Structure

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Abstract

The behavior of the masonry buildings is influenced by the plan configuration. The irregular configuration makes the building more vulnerable during earthquakes. Therefore, it is important to analyze the performance of the buildings against seismic action for both new and existing one. The paper aims to investigate the seismic performance of the different plan configurations unreinforced masonry buildings. Four two-storey building models with different plan configurations are selected and linear dynamic analysis using finite element software is performed to obtain the response of the buildings. The performance of the buildings was studied in terms of natural time periods, base shear and seismic response. Nonlinear analysis is also performed and the capacities of the building models are compared. From the study it has been observed that symetrical and regular building plan should be adopted to reduce the seismic vulnerability of the masonry structure.

Keywords

Masonry buildings, Irregular configuration, Linear dynamic analysis, Nonlinear static analysis

1. Introduction

Masonry is one of the most commonly used construction materials in Nepal. Due to easy availability of construction materials, masonry structures are more popular in rural areas of Nepal. Masonry is a complex material because it is defined as a composition of bricks and mortar. The possibility of combining these elements with different qualities and geometries give masonry a wide range of alternatives of mechanical behaviour and structural performance. It is well known that masonry has a good performance when resisting and transmitting compressive loads and poor performance to resist tensile demands makes it more vulnerable towards seismic action.

The behavior of a building during earthquakes depends critically on its overall shape, size and geometry. In recent Gorkha Earthquake 2015, the many unreinforced masonry buildings got extensive damaged and collapsed due to lack of structural integrity, stress concentration in corners and openings and a lack of construction detailing and construction practices that improve structural behavior of such buildings when subjected to ground shaking [1]. The re-entrant corners form due to plan irregularities causes stress concentration and result in the early failure of the building. But to fulfill the present need and site constraint, planning of irregular configurations is inevitable. Therefore, it is necessary to study the effect of building configuration on seismic vulnerability of masonry building. Many research has been made to study the effect of irregular configurations on the seismic vulnerability of RC buildings [2, 3] using dynamic analysis. So, static dynamic analysis is used to evaluate the vulnerability of the different unsymmetrical buildings. As the nonlinear method are better than the linear method in interpreting the effects of the structural irregularities nonlinear analysis is also performed [4].

2. Objective

Recent devastating Gorkha Earthquake 2015 has shown that the majority of the damage is due to the geometrical configuration of the masonry buildings. Therefore, this study aims to analyze the effect of building plan configuration on the seismic performance of the masonry structure. The main objective of the study is to obtain the seismic performance of the different plan configuration masonry structures in terms of natural time period and the seismic response.

3. Methodology

Four building models are used to study the different type of plan configurations. The seismic analysis of the building models was carried out using Finite Element Method (FEM) based software.The performance of the buildings was studied in terms of natural time period, base shear and storey displacements in response spectrum analysis using a code – IS 1893 (Part 1):2002[5]. The pushover analysis is performed to simulate the response of the structure when subjected to an incremental horizontal load using FEM.

4. Building Description

Four building typologies with different plan configurations are considered as shown in figure-1. The building model R1 has square plan selected to represent the symmetrical and regular buildings. The building model L1 has L shaped and selected to represent the L shaped eccentric plan.The building model LB1 is long rectangular building with length about four times the width of the building. This model is selected to represent the long slender building. The building model T1 has T shaped plan which is selected to represent the T shaped building. All the rooms of the buildings are 3mx3m so that all the walls are 3m apart from each other. All the building models used in this study are two storied unreinforced masonry structures. Brick with cement sand mortar wall is considered as load bearing wall. The thickness of masonry wall and reinforced concrete slab are taken as 350mm and 125mm respectively. The sizes of door and window are 900mmx2100mm and 1000mm x 1350mm and 1750mm x 1350 respectively. The total height of the building is 5.4 m with storey height of 2.7m. Rigid floor diaphragm is considered. Other data adopted during analysis are tabulated as below.

Table 1: Building Dimensions

R1	7.05mX7.05m
L1	7.05mX7.05m
LB1	13.75mX3.70m
T1	10.40mX7.05m

Table 2: Dead and live load on the building

Floor finish load	1	KN/m2
Roof live load	1.5	KN/M2
Floor live load	3	KN/m2l

Table 3: General data

Seismic Zone		V
Seismic Zone factor	Z	0.36
Building Type		Residential
Importance factor	I	1
Lateral load resisting system		Unreinforced masonry wall system
Response reduction factor	R	1.5
Height of the Building	H	5.4 m
Soil Type		II (Medium)

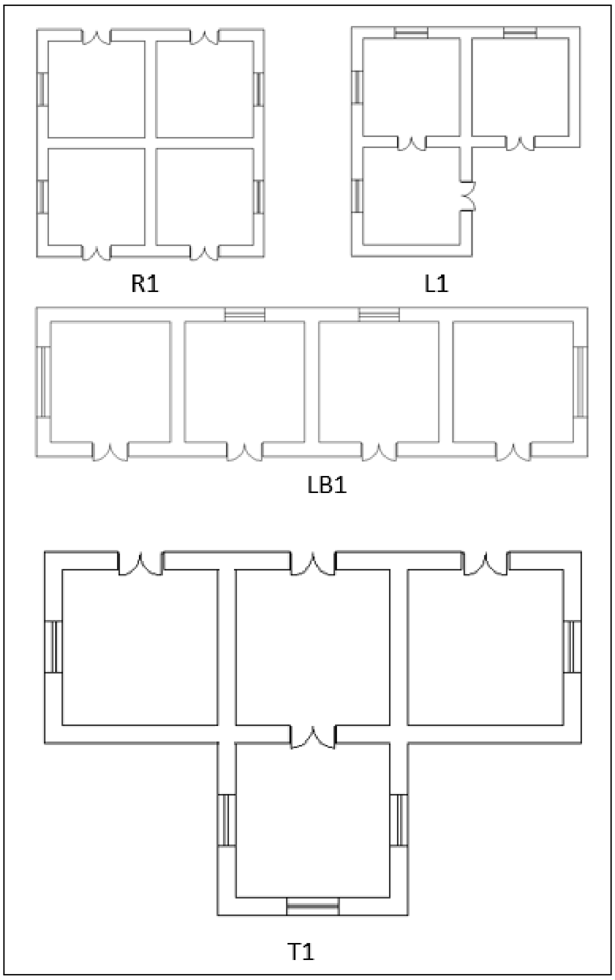

Figure 1: Building Models

Table 4: Mechanical Properties of Brick Cement Masonry

S.N.	Description	Mean Value
1	Modulus of Elasticity	880.00 MPa
2	Shear Modulus	382.60 MPa
3	Specific Weight of Masonry	19 KN/m3

5. Analysis and Result

The masonry wall is modeled as the two-dimensional finite elements (shell) of four nodes in Finite Element Analysis Software[6]. The materials of structural components are assumed homogeneous, isotropic and linearly elastic. Linear static and linear dynamic analysis using response spectrum using code – IS 1893 (Part 1):2002 [5] was performed. For the nonlinear analysis, the concepts of homogenized material and smeared crack modeling is used. Solid65 element which has capabilities to undergo crushing on compression and cracking on tension is used for the discretization of the masonry wall of the buildings[7]. For the modeling of cracking and crushing Willam-Warnke (WW) failure criterion [8] is used. Constitutive parameters of the masonries adopted to define the WW failure surface is presented in table 4.The stress-strain curve is also used to obtain the accuracy on the result as presented in table 6.

Table 5: Constitutive parameters for WW failure surface

S.N.	Property	Data
1	Compressive strength (MPa)	2.40
2	Tensile Strength (MPa)	0.05
3	Crack shear transfer coefficient	0.25
4	Crack compression transfer coefficient	0.75

Table 6: Stress strain data for Masonry[9]

S.N.	Stress (MPa)	Strain (mm/mm)
1	0.792	0.0009
2	1.800	0.0021
3	2.160	0.0029
4	2.400	0.0036

Table 7: Eccentricity and openings along the x-direction

Model	Eccentricity (%)	Opening (%)
R1-X	0.00	13.00
L1-X	5.24	13.24
LB1-X	0.00	13.57
T1-X	0.00	13.22

Table 8: Eccentricity and openings along the y-direction

Model	Eccentricity (%)	Opening (%)
R1-Y	0.00	9.28
L1-Y	4.47	9.38
LB1-Y	1.70	9.29
T1-Y	11.80	9.13

The building models have zero eccentricity except L shaped one which has 5.24% along the x-direction which are presented in table 7 and the eccentricities on different building models along y direction are presented in table 8. All the building models have almost same percentage of openings.

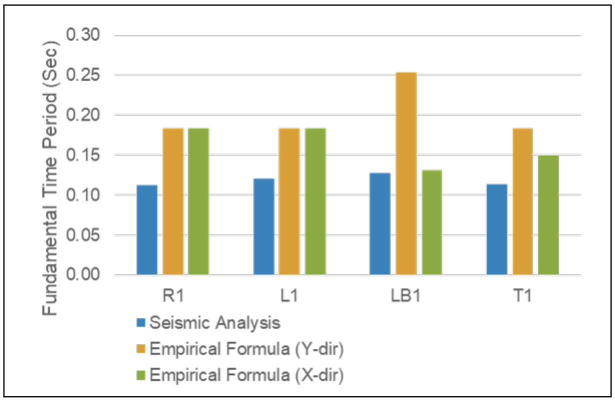

Figure 2: Fundamental time periods of the buildings

The fundamental time period of the building is one of the important parameter for the perormance evaluation. The aproximate fundamental natural time period of vibration of the building is calculated by using empirical formula from code – IS 1893 (Part 1):2002as presented in equation (1).

$$T = \frac{0.09h}{\sqrt{d}} \tag{1}$$

Where, h= height of the building, in m
d=base dimension of the building in the direction of earthquake considered, in m

The time period obtained from the empirical formula using equation (1) and from the seismic analysis of the building is shown in figure 2. The time period from empirical formula only depends on the height and the base dimension of the building. As model R1 and model L1 have same height and base dimensions they have same time period. In building model LB1 and T1 they have higher time period at shorter direction. The time period obtained from the seismic analysis is in increasing order for building model R1, T1, L1 and LB1. As the time period is function of the stiffness of the lateral load resisting system and the building mass, the change in time period is due to the change in stiffness and mass due to change in plan configuration.

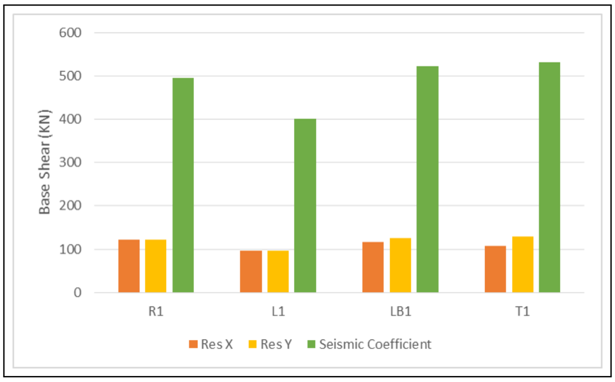

Figure 3: Base shear

Base shear obtained from seismic coeficient method and from response spectrum analysis is shown in figure 3. As the building models have different plan area normalize base shear i.e ratio of base shear to building weight is used to compare the base shear. The normalize base shear decreases by 7.76%, 11.73% and 20.86% while changing the plan configuration from building model R1 to L1, LB1 and T1 respectively along x direction.The normalize base shear decreases by 7.65%, 5.07% and 4.92% while changing the plan configuration from building model R1 to L1, LB1 and T1 respectively along y direction.

Table 9: Top storey displacement due to Res-x

Model	Top Displacement		% Increase in displacement along X-Dir
	X-Dir (mm)	Y-Dir (mm)	
R1-X	1.54	0.023	
L1-X	1.84	0.265	19.48
LB1-X	1.609	1.19	4.48
T1-X	1.294	1.055	-15.97

Table 10: Top storey displacement due to Res-y

Model	Top Displacement		% Increase in displacement along Y-Dir
	X-Dir (mm)	Y-Dir (mm)	
R1-Y	0.016	1.375	
L1-Y	0.275	1.573	14.40
LB1-Y	0.017	1.58	14.91
T1-Y	0.028	2.074	50.84

Top storey displacement of the building is also an important parameter because the movement can affect the structural and non structural element as well as adjacent building. From the table 9 it is seen that the building models L1 and T1 have 19.48% and 4.48% more displacement than square shape building where as LB1 has 15.97% less displacement than square shape R1 model along x-direction due to seismic force along x direction. From the table 10 it is seen that there is 14.40%, 14.91% and 50.84% increase in top storey displacement due to change in configuration from square shape R1 to L shape L1, T shape T1 and slender rectangular shape LB1 respectively along y direction due to seismic force along y direction. Story lateral response that is produced in the perpendicular direction to earthquake force along one direction is due to the torsional effect produced due to the asymmetric plan configuration.

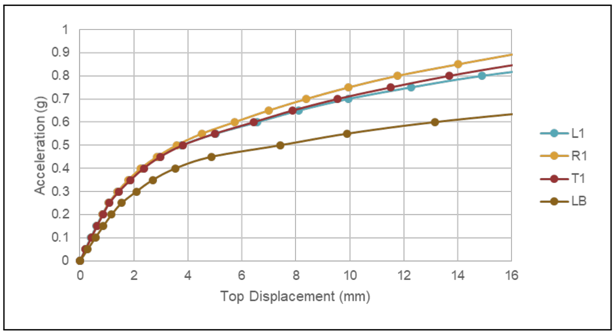

Figure 4: Pushover Curve

From the figure 4 it can be seen that the load carrying capacity of the building is in decreasing order from model R1, T1, L1 and LB1 which shows that the change in plan configuration from square shape to irregular and slender shape reduces the load carrying capacity of the buildings.

6. Conclusions

Based on the analysis the following conclusions are drawn,

1. By comparing the fundamental time period of the buildings, T shaped building has more time period than regular square shaped building, L shaped building has more time period than T shaped building and Long slender building has highest time period among four.
2. By comparing the normalize base shear of the buildings, base shear decreases while changing the plan configuration from square to long slender building, T shape building and L shape building respectively.
3. By comparing the storey displacement , T shaped building displaced more than regular square shaped building, L shaped building displaced more than T shaped building and Long slender building displaced most among four.
4. By comparing the seismic capacity, T shaped building has lower seismic capacity than regular square shaped building, L shaped building has lower seismic capacity than T shaped building and Long slender building has least seismic capacity among four. The irregular shaped buildings are more popular, but they are more vulnerable during earthquakes. Therefore, such buildings should be designed properly taking care of their seismic performance.

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