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Influence of Vertical Irregularity on Seismic Performance of Masonry Building

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Abstract

The behavior of masonry buildings during earthquake motion depends on the configuration of the building. Irregular configuration in plan or elevation can be a main cause of failure during earthquake. Vertical irregularity is recognized as the major deficiency and a cause of failure during earthquake. Hence, this study addresses the effect of vertical irregularity on seismic performance of masonry buildings. A four storey regular masonry building is taken and is modified to 4 different vertical geometrical irregular buildings and the mass irregularity is introduced in regular and one vertical geometry irregular building. The magnitude and location of mass irregularity is changed in the building. All the buildings are subjected to seismic loads and the response of the building is computed numerically. It is observed that the vertical irregularity considered affects the seismic response of the building. Also, the magnitude of mass irregularity increases the response of the masonry building. The seismic response is maximum when the mass irregularity is in the upper part of masonry building. The combination of irregularity i.e. mass irregularity and vertical geometry irregularity enhance the response of the masonry building.

Keywords

Masonry -Vertical Irregularity -Mass Irregularity

1. Introduction

Masonry construction is one of the oldest and most common building techniques in the world. Masonry is be defined as a structural assemblage of masonry units, such as stones, bricks and blocks, with a binding material known as mortar. Normally these are designed for vertical loads and since masonry has adequate compressive strength, the structure behaves well as long as the loads are vertical. Masonry buildings are being constructed in Nepal from early ages and are still in use in rural and semi-urban area[1]. Most of the masonry buildings are non-engineered and are vulnerable of earthquake.

Recent Gorkha Earthquake 2015 and past earthquake demonstrate that the masonry buildings are vulnerable to earthquake, major loses of life was due to collapse of masonry buildings. Damage in masonry buildings are mainly in load bearing wall, gable walls, near wall openings and wall corners. Tilting, collapse of walls at roof level, out- of -plane wall failure, in-plane diagonal cracking, diagonal cracking around door or window opening, delamination of wall and corner separation are the common failure pattern in these buildings. The major deficiency in masonry building are poor material properties, poor construction detailing, unconfined gable walls ,improper geometrical configuration , large openings and lack of proper maintenance [2]. These various deficiencies found in masonry buildings make them vulnerable to even a small earthquake among them one of the major deficiencies is vertical irregularity in masonry building. Vertical irregularities are characterized by vertical discontinuities in the distribution of mass, stiffness and strength. In set-back structures there is a sudden change in the vertical distribution of mass, stiffness, and in some cases, strength which may affect the seismic performance of the masonry buildings. The variability of mass distribution, in plan and in elevation, which shifts the center of mass away from the geometrical center of the floor plan, originates the accidental eccentricity which effect the torsional response of the building[3]. So, it is necessary to study the effect of vertical irregulates in masonry buildings. Seismic performance of the regular masonry building is better than plan irregular masonry building [4].

2. Objective and Methodology

The objective of the study is to analyze and compare th seismic perfomance of regular and irregular masonry buildings and to study the effect of mass irregularity in seismic performane of masonry buildings. In the present work, seismic responses of unreinforced brick masonry building having different vertical irregularities are obtained numerically using a finite element-based software, ETABS and are compared with the regular building. The major inputs are geometry of building, storey height, total mass on floor and modulus of elasticity and earthquake data. The modulus of elasticity for brick masonry is taken as 2703.2 MPa[5]. Response Spectrum analysis of total 23 different building model with different irregularities are done and the response of structure is in terms of fundamental natural period, storey displacement and base shear are compared.

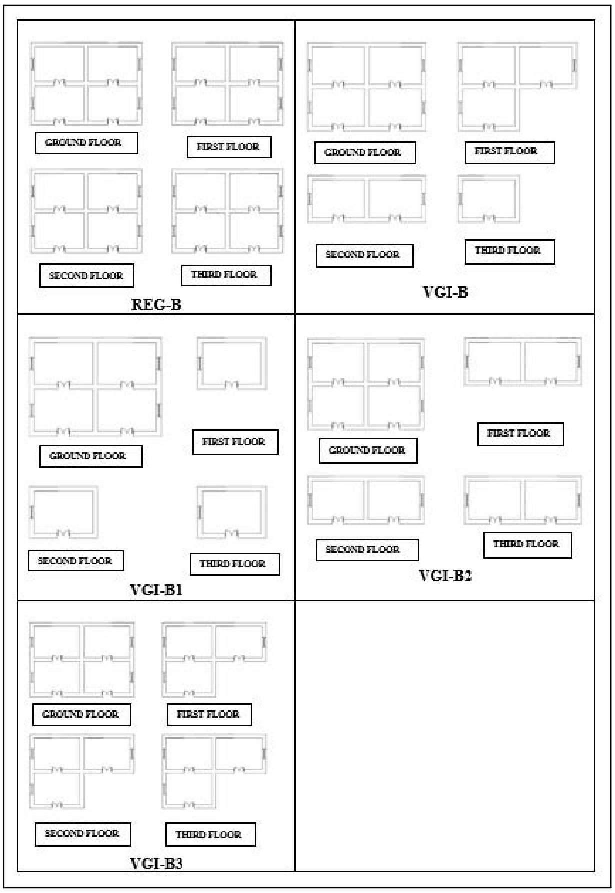

Figure 1: Plan of Study Building

3. Building Description

The unreinforced brick masonry building with different irregularity are taken as sample building in this study. The building models analyzed in this study represent the example of irregular buildings constructed in different part of Nepal. The building used in the study are four storied unreinforced brick masonry. Brick in cement sand mortar (1:4) is considered as the load bearing wall. Thickness of wall is 350mm and reinforce concrete slab is of thickness 125mm, all the room size is 3mx3m, storey height is 2.5m and rigid floor diaphragm is considered. The size of window is 900mm*1000mm and 1000mmx1200mmrespectively. REG-B is regular building whereas VGI-B, VGI-B1, VGI-B2, VGI-B3 and VGI-B4 are building model with vertical geometry irregulates.

4. Analysis of irregular masonry building

Different irregularities are defined by standards. A structure can be irregular, when the certain parameter exceeds the limit specified in that standard. IS 1893:2016(Part I)[6] has specified different irregulates which are shown in Table 1

Table 1: Irregularity limits prescribed by IS 1893:2016 (Part I) (i = storey number, a = adjacent storey number

Type of Irregularity	Limit
Mass(M)	M<1.5Ma
Vertical Geometry (VG)	VG<1.25VGa
Stiffness(S)	S<Si+1

Brick masonry building with storey height 2.5m is considered for the study. For incorporated irregularities the vertical configuration of the regular building is changed and for mass irregularity the magnitude and location of mass is changed in building. In total 23 cases are analyzed, 1 is regular case,13 cases are of single irregularity either mass irregularity or vertical geometrical irregularity and 9 case building possess combined irregularity both mass and vertical geometry irregularity. Linear dynamic i.e. response spectrum analysis is performed of all the building model as per IS 1893(Part I):2016. The loading for residential building was considered on basic of IS 875 (Part I)[7]. Live load of 3.0 KN/m^2 on floor and 1.5 KN/m^2 on roof were provided.

4.1 Configuration having Single Irregularity

Vertical irregularity includes mass, geometry and stiffness. In this study mass and vertical geometry irregularity are considered for analysis. The 13 building with single vertical irregularity. For all the case analyzed, room size and number of storey are kept constant. 4 vertical geometry irregularity was analyzed as shown in Figure 1 and 9 mass irregularity was analyzed as described below .

4.1.1 Mass Irregularity (MI)

Three different cases of mass irregularity 1.5M, 2M and 3M are used for analysis. M is mass of storey and 1.5M,2M and 3M indicates the 150 %,200% and 300% mass irregularity in that storey i.e. that storey has mass 1.5,2 and 3 times the mass of adjacent storey. Mass irregularity is introduced by increasing the mass of particular storey. The position of mass irregularity was shifted from 2nd, 3rd and 4th storey.

4.1.2 Vertical Geometry Irregularity (VGI)

4 case of vertical geometry irregularity VGI is considered for the analysis and compared with the regular one. Irregularity is introduced by varying vertical configuration along the height of the buildings as shown in Figure 1. Each room is reduced in every storey to make it vertical irregular in geometry.

4.2 Configuration having Combined Irregularities

Nine cases with combined irregularity are considered for analysis. The vertical geometry irregularity and mass irregularity is combined. in vertical geometry irregular building the mass irregularity is introduced. 1.5M, 2M and 3M are used for analysis. Mass irregularity is introduced by increasing the mass of particular storey. The position of mass irregularity was shifted from 2nd , 3rd and 4th storey in Vertical geometry irregular building.

5. Results and Discussion

Masonry buildings models with vertical irregularities were analyzed and the response were studied. The variations in dynamic response of the buildings due to mass and vertical geometry irregularities were evaluated and expressed in terms of fundamental natural period, base shear and roof storey displacement. The result obtained from the analysis of masonry buildings having single and combination of vertical irregularities 23 buildings were studied. The variation in response of irregular buildings is plotted and compared with the regular building.

5.1 Variation in natural period of buildings

Fundamental natural period of vibration is determined by carrying out the Eigen value analysis on the masonry buildings. Figure 2 represents the variations in natural periods of different vertical irregular building and compared with the regular buildings.

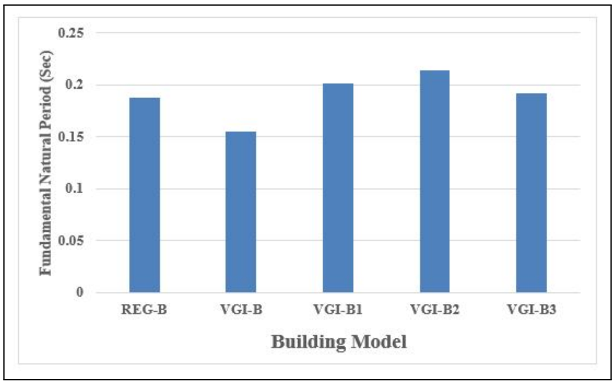

Figure 2: Variation of Fundamental natural Period of Vertical geometry Irregular Masonry building

Figure 2 shows that the fundamental natural period of building VGI-B3, VGI-B1 and VGI-B2 increased by 2.13 %, 6.91 %, 13.83 % with respect to REG-B building. whereas the fundamental natural period of building VGI-B decreased by 17.55 %. As the time period is function of the mass of building and the stiffness of lateral load resisting system the change in time period is due to the change in stiffness and mass due to change in vertical configuration.

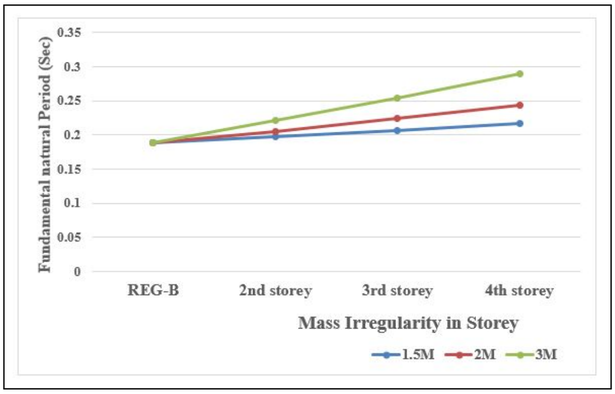

Figure 3: Fundamental natural period for REG-B building with different mass irregularity at different storey

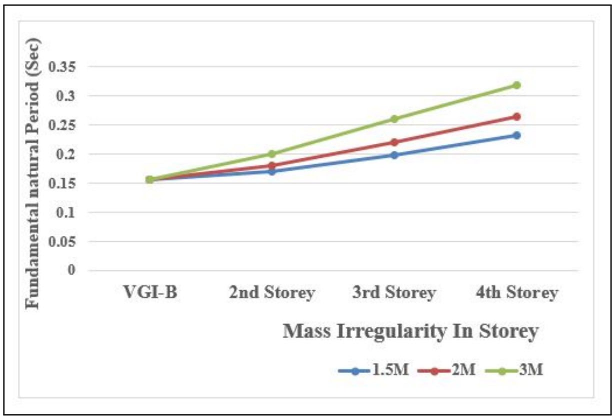

Figure 4: Fundamental natural period for VGI-B building with different mass irregularity at different storey

Figure 3 shows that variation in fundamental natural period for REG-B building obtained when the magnitude of mass irregularity is increased and shifted from lower storey to upper storey.The time period of the buildings increased by 4.78%, 10.10% and 15.42% when the 150% mass irregularity i.e. 1.5M is introduced in 2nd ,3rd and 4th storey of regular configuration building REG-B. Similarly, in 200% mass irregularity i.e. 2M also the time period increased by 9.4%, 19.14% and 29.78% when introduced in 2nd ,3rd and 4th storey of regular configuration building. The time period of the buildings increased by 17.55%, 35.10% and 54.25% when the 300% mass irregularity i.e. 3M is introduced in 2nd ,3rd and 4th storey of regular configuration building Figure 4 shows in vertical geometry irregular building i.e. VGI-B, the time period of the buildings increased by 9.03%, 27.09% and 49.03% when the 150% mass irregularity i.e. 1.5M is introduced in 2nd ,3rd and 4th storey. Similarly, in 200% mass irregularity i.e. 2M also the time period increased by 15.48%, 69.67% and 73.68% when introduced in 2nd ,3rd and 4th storey of VGI-B building. The time period of the buildings increased by 29.03%, 67.09% and 105.16 % when the 300% mass irregularity i.e. 3M is introduced in 2nd ,3rd and 4th storey of VGI-B building. The combination of vertical irregularity and mass irregularity increase the fundamental natural period of building. It shows that the when the seismic mass increase the fundamental natural period increases. It can be seen that with inclusion of heavy masses on the floor of masonry building the natural period increase and is maximum when placed on the roof floor. When a building with irregular distribution of mass along its height than the different mass vibrates at different height from the base which changes the effective stiffness and finally natural period varies. The increase in natural period is amplified in the masonry building with the combination of mass and vertical geometry irregularity.

5.2 Variation in Base Shear

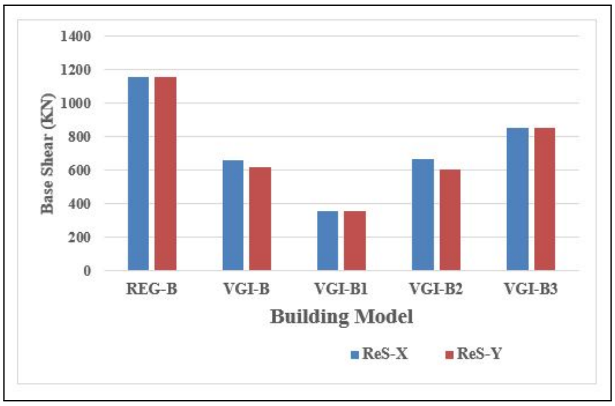

Figure 5: Comparison of Base Shear of Regular and Vertical Geometry Irregular Buildings

Base Shear of building with different vertical configuration are shown in Figure 5 the base shear for vertical irregular building decreased with respect to the regular building as base shear is function of mass and mass decreases in Vertical geometry irregular building. The minimum base shear is for VGI-B building as it has minimum seismic weight and base shear is maximum for REG-B building.

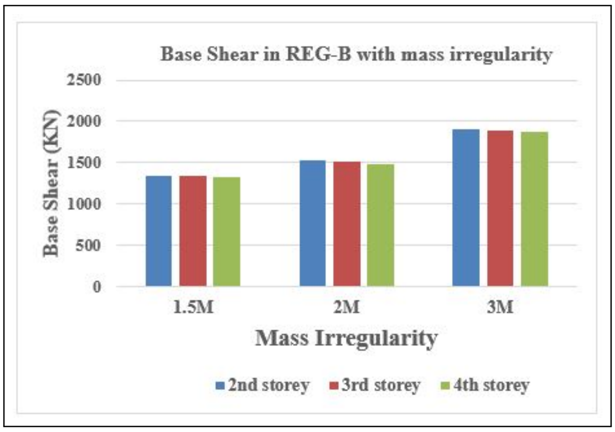

Figure 6: Base Shear Comparison for REG-B building with different mass irregularity at different storey

As in figure 6 it can be seen the base shear increase as the magnitude of mass irregularity increases. The base shear is maximum in both when 3M mass irregularity is introduced in REG-B building. It can be seen that the position of mass irregularity has no major effect of base shear of regular building.

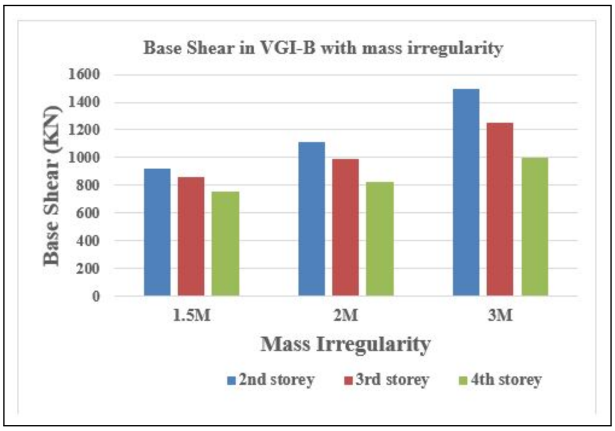

Figure 7: Base Shear Comparison for VGI-B building with different mass irregularity at different storey

As in figure 7 it can be seen the base shear increase as the magnitude of mass irregularity increases in vertical geometry irregular building VGI-B. The base shear is maximum when 3M mass irregularity is introduced in REG-B building. The decrease in base shear when same magnitude of mass irregularity is introduced in 2nd 3rd and 4th floor is due to decreasing order of mass applied in each storey as the mass varies in each storey in VGI-B building.

5.3 5.3 Variation of Roof Displacement

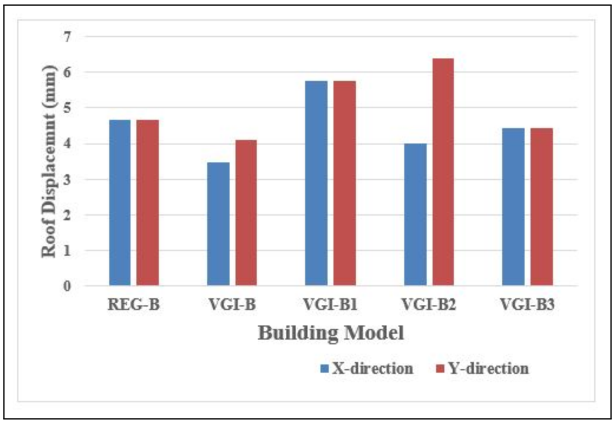

Figure 8: Comparison of roof displacement of Regular and Vertical Geometry Irregular Buildings

Roof storey displacement along X-direction decreased in VGI-B, VGI-B2 and VGI-B3 buildings with respect to REG-B building by 25.85%, 14.68% and 5.41% respectively. And the roof storey displacement along Y-direction decreased in VGI-B and VGI-B3 buildings with respect to REG-B building by 11.8%, and 5.15% respectively whereas for VGI-B2 building it increase by 37.21%. The roof displacement increases by 23.25% and 23.52% in X- direction and y-direction in buildings VGI-B1. The change on roof displacement is due to change in geometrical configuration in vertical direction.

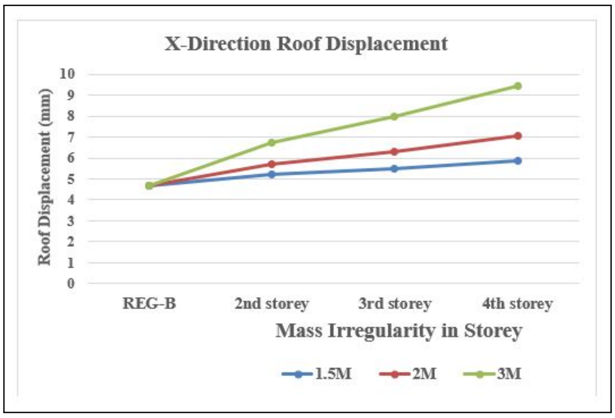

Figure 9: Roof displacement Comparison for REG-B building with different mass irregularity at different storey in X-direction

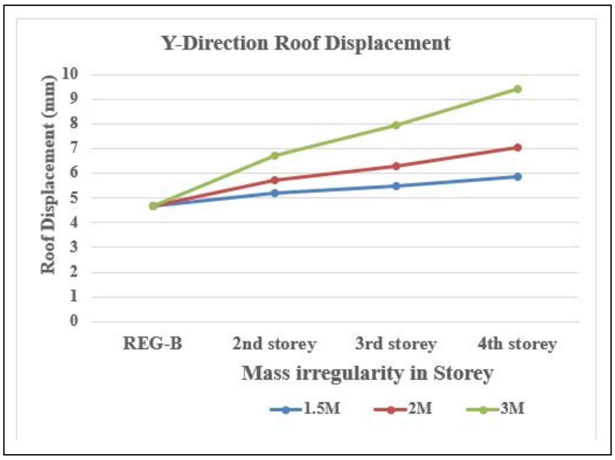

Figure 10: Roof displacement Comparison for REG-B building with different mass irregularity at different storey in Y-direction

Figure 9 and Figure 10 show the variation in roof displacement of REG-B building with different mass irregularity at different storey. Roof displacement in both X-direction and Y- direction increase when the magnitude of mass irregularity increase. The maximum increase in roof displacement is 101.7% when 3M mass irregularity is introduced at 4th storey. And the minimum increase is when 1.5M mass irregularity is placed on 2nd storey and is 11.25%. For each mass irregularity the roof displacement in both X and Y- direction increases when the mass irregularity sifts towards roof storey.

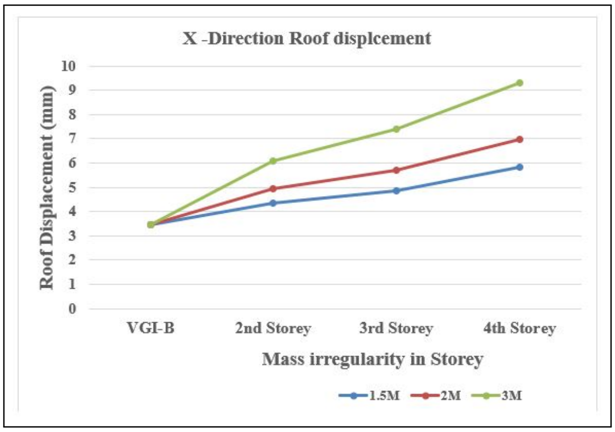

Figure 11: Roof displacement Comparison for VGI-B building with different mass irregularity at different storey in X-direction

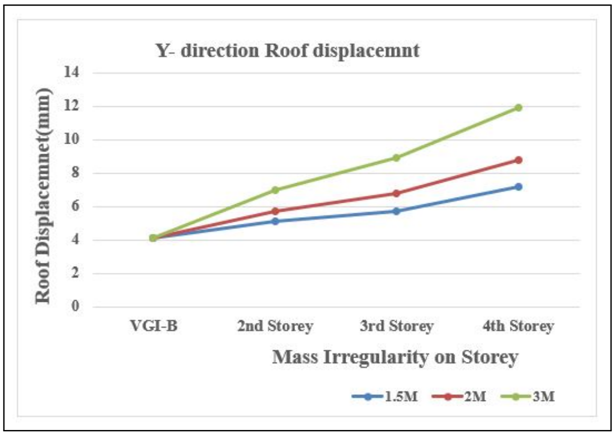

Figure 12: Roof displacement Comparison for VGI-B building with different mass irregularity at different storey in Y-direction

Figure 11 and Figure 12 show the variation in roof displacement of vertical geometry irregular building VGI-B with different mass irregularity at different storey. Roof displacement in both X-direction and Y-direction increase when the magnitude of mass irregularity increases in VGI-B building. The maximum increase in roof displacement is 187.1% when 3M mass irregularity is introduced at 4th storey. And the minimum increase is when 1.5M mass irregularity is placed on 2nd storey and is 23.89%. For each mass irregularity the roof displacement in both X and Y- direction increases when the mass irregularity sifts towards roof storey. Roof displacement of buildings is an important parameter because the movement of the building affects the structural and non-structural elements as well as adjacent buildings. From seismic analysis it is seen that the roof displacement increases when the magnitude of mass irregularity increases and is maximum when mass irregularity is in the top storey. For the combination of irregularity i.e. mass irregularity in VGB-B building the percentage increase in roof displacement is higher than in single irregularity i.e. mass irregularity in regular building. Roof displacement comprises the global deformation demand of building. Therefore, the change in magnitude and position cause variation in the storey drift demands and hence roof displacement is highest when highest mass irregularity is present at roof level.

6. Conclusion

Masonry buildings models with vertical irregularities were analyzed and the response were studied. The variations in dynamic response of the buildings due to mass and vertical geometry irregularities were evaluated and expressed in terms of fundamental natural period, base shear and roof storey displacement. The result obtained from the analysis of masonry buildings having single and combination of vertical irregularities 23 buildings were studied. The variation in response of irregular buildings is plotted and compared with the regular building.

1. Change in vertical geometry changes the fundamental time period of masonry building. Fundamental natural period of VGI-B decreases and VGB-B1, VGB-B2 and VGB-B3 increase as compared to REG-B building model. Different magnitude of mass irregularity i.e. 1.5M,2M and 3M in REG-B masonry building at top storey increase natural time period by 15.42-54.25% and by 4.78-9.03%when the mass irregularity is in second storey in comparison to that regular building. This effect is further amplified in Vertical geometry irregular building by maximum 105.16% with respect to VGI-B building when 3M i.e. 300% mass irregularity is present in top storey.

2. Base shear of VGI-B, VGI-B1, VGI-B2 and VGI-B3 building decrees with respect to REG-B masonry building. Base shear of masonry building increase as the magnitude of mass irregularity increase. Base shear is maximum when 3M i.e. 300% mass irregularity is present in REG-B and VGI-B

building.

3. In comparisons regular building REG-B. roof displacement in X-direction decrease in VGI-B, VGI-B2 and VGI-B3 building and increase in VGI-B1 building model whereas in Y direction roof displacement increase in VGI-B1 and VGI-B2 building model and decrease in VGI-B and VGI-B3.Roof displacement is more when the magnitude of mass irregularity increase at the top storey of REG-B masonry building by 25.58-101.7% and highest when the mass irregularity is in the roof storey. This effect is amplified in vertical geometry irregular building VGI-B by 187.1% ,when 3M mass irregularity is present in top storey.

4. The combination of irregularity i.e. mass irregularity and vertical geometry irregularity masonry building makes the masonry building more vulnerable to earthquake

5. Linear dynamic analysis was performed for different irregular masonry building, for better comparison of seismic perfoemance nonlinear analysis can be performed.

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