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Seismic Response of Soft Story RC Building

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Abstract
Nepal is one of the seismic prone country and many of city is growing haphazardly which have so many buildings are soft according to achieving their demand like basement parking, shoping complex etc. The main objective of this thesis is to briefly describe about analytical seismic performance evaluation for RCC frame building with masonry infill through non linear static pushover analysis. The building is designed by response spectrum analysis using IS1893:2016 and seismic behavior is evaluated using pushover analysis. For pushover analysis, defining hinges by ASCE 41 code with auto defined for beam and column and for equivalent strut hinges are defined manually. The performance point is obtained after analysis and it has been seen that the performance point is increasing upward when the location of softness is shifted upward in both Push X and Push Y loading case. The evaluation of Base shear, time period, displacement, story drift and hinges properties at the performance level of the building in different location of soft storey cases in both direction. The lateral stiffness and strength of the building is increasing with masonry infill which reduces the top displacement but lateral forces are heavily increased.

Keywords
Seismic evaluation, performance point, Pushover analysis, Equivalent strut, Soft stories, IS1893:2016

1. Introduction

According to IS1893:2016 or NBC105:2020 the story in which the lateral stiffness is less than 70 percent of that in the story above or less than 80 percent of the average lateral stiffness of the three story above is a soft story. While fulfill our demand like basement parking, basement storage, for shop, restaurant, banking, swimming pool inside building etc. then the story becomes soft. The soft stories cannot withstand the high earthquake shake and the building failure occurs[1]. One of the major failure of building in Gorkha earthquake is soft failure. Since the building can also becomes soft if the masonry infill is not properly provided. The masonry infill enhances the lateral stiffness and strength[2]. The architectural requirement like open floor design is not easy to eliminate the architectural design criteria and the floor becomes soft[3]. In this thesis the behavior of soft story building in seismic zone of V is discuss. The location of soft stories effects on the function of building in earthquake. The variation location of soft stories in building and its seismic behavior is discussed in this thesis. The nine stories building with different location of soft story and symmetric in plan is taken to observe the seismic parameter.

2. Objectives of the study

The main objective of this study is to identify the seismic response of soft storey reinforced concrete building with masonry infill. The seismic responses like base shear, time period, inter story drift, displacements etc. are evaluated in different location of soft story and the results are compared with the regular building. Also the specific objective is to evaluate performance level of soft story building comparison to regular building. The vulnerability with different location of soft story is evaluated.

3. Non-linear analysis

The non-linear static analysis also called pushover analysis is used to evaluate the performance point and seismic parameter. Pushover analysis is analysis of the structure step by step. In this analysis the failure of structure is individual component and the dynamic forces are transferred to another component. The simulation of the pushover analysis is the phenomenon by which the load applied until the weak link in the structure is found. Similarly, the second iteration starts after first weak link and loads are redistributed. This process is continuing until the whole structure is collapse. At each step of pushover analysis, all analytical results are saved. Thus, base shear, time period, story drift, displacement etc. seismic components data are saved at each step. The capacity curve is the pushover curve, i.e. base shear vs control node displacement. The base shear is in ordinate and control node displacement is in absiccica. For finding out the performance point in this research, Capacity spectrum method is used. The capacity spectrum method needs to convert the capacity curve into acceleration displacement response spectrum (ADRS) format. Also, the demand spectrum curve (spectral acceleration vs time) needs to convert into ADRS format for performance point calculation. Thus, both the capacity curve and demand curve are converted into ADRS format i.e. spectral acceleration vs spectral displacement curve [4].

The general procedure for converting the capacity curve into ADRS format is to first calculate the conversion factor like modal participation factor (MPF) and modal mass coefficient (α) using the following equation(1)and (2)[5].

$$MPF1 = \frac{\sum m_i \phi_{i1}}{\sum m_i \phi_{i1}^2} \tag{1}$$

$$\alpha = \frac{[\sum m_i \phi_i]^2}{[\sum_{i=1}^{N} m_i][\sum_{i=1}^{N} m_i \phi_{i1}^2]} \tag{2}$$

Where, m_i =mass assigned to level i, ϕ_{i1} =amplitude of mode 1 at level i, N= the number of stories in building .

The spectral acceleration (S_a) and spectral displacement (S_d) at each point on capacity curve is calculated by using the following equation.

$$S_a = \frac{V_b}{W} \cdot \frac{1}{\alpha} \cdot g \tag{3}$$

$$S_d = \frac{\triangle_{roof}}{MPF_1 \phi_{roof1}} \tag{4}$$

Where V_b= base shear, W=building total weight, $\triangle_{roof}$= roof displacement

The demand curve i.e. Spectral acceleration(S_a) vs Time (T) is converted into ADRS format by using the following equation (5).

$$S_d = \frac{T^2 S_a}{4\pi^2} \tag{5}$$

According to Stafford-Smith and Carter (1969) the relative flexural infill stiffness is calculated by using equation (6)[6]:

$$\lambda H = H[\frac{E_m t_{in} sin(2\theta)}{4E_c I_{col} h}]^{0.24} \tag{6}$$

Where, h= Height of infill panel, in mm, I_{col} = Moment of inertia of the adjacent column, in mm^4, t_{in}= Thickness of the infill wall, in mm, θ=Angle of the diagonal strut with the horizontal, E_m= Modulus of elasticity of infill panel, (MPa), H= Height of column ,in mm.

Mainstone (1971) uses the equation (6) and evaluate the equivalent strut width of infill masonry by the following equation.

$$a = 0.175 d_{in} (\lambda H)^{-0.4} \tag{7}$$

Where, d_{in}= Diagonal length of the infill , in mm.

The strut should be pin-connected to the column at a distance l_column from the face of the beam[7].

$$l_{column} = \frac{a}{cos\theta_{column}} \tag{8}$$

$$tan\theta_{column} = \frac{h - \frac{a}{cos\theta_{column}}}{l} \tag{9}$$

$$l_{beam} = \frac{a}{sin\theta_{beam}} \tag{10}$$

$$tan\theta_{beam} = \frac{h}{l - \frac{a}{sin\theta_{beam}}} \tag{11}$$

4. Model Description

The hypothetical building with nine story is taken to study and details of building is shown in table 1. Ten number of models with different position of soft stories and naming of different models are shown in table3.

Table 1: Building details

Type of building	SMRF	
No of story	9	
Story height	3.5	m
Bay in X and Y direction	5*4	
Plan dimension	25*20	m
C/C distance between the column	5	m
Beam Size	500*350	mm
Column size	600*600	mm
Slab deptha	150	mm

Table 2: Infill Details

Infill wall thickness(t_{inf})	230mm
Infill wall height (h_{inf})	2950 mm
Infill wall length(l_{inf})	4400mm
Area of the infill(A_p)	13275000 mm^2
Strength of Brick (f_b)	10MPa
Strength of Mortar(f_{mo})	15MPa
Strength of the infill wall (f_m)	9.6536MPa
Modulous of masonary wall (E_m)	2755.77 MPa
Strut angle with horizontal(θ)	33.26
Infill diagonal length (d_{inf})	5325.41mm
Height of column (H_c)	3500mm
Opening reduction factor (R_f)	0.574
Equivalent cofficient (λ)	0.001157
Equivalent strut width (a)	532.57mm
Final strut width (a')	306mm
Poissions ratio(μ)	0.2
Moment of Inertia (I_c)	1.08 *10^{10} mm ^{4}
Cross section of strut	230 *306 mm
Area of Cross section of strut	70380 mm^2
l_{column}	855 mm
l_{beam}	1127mm
Axial strength of strut (R_{cr})	352.64KN

Table 3: Modal details

Modal Name	Description
G1	First story soft
G2	Second story soft
G3	Third story soft
G4	Fourth story soft
G5	Fifth story soft
G6	Sixth story soft
G7	Seventh story soft
G8	Eight story soft
G9	Ninth story soft
Regular	Full infill

5. Research methodology

The Building is selected as the hypothetical building. For modeling and analysis, ETABS program software version 19 is used. The beam is modeled as a flexural member and column is compression member. Fe 500 Rebar and M25 grade concrete material is define on it. The slab is modeled as thin shell element. Only nine stories with different location of soft stories is modeled.

All the models which is selected for thesis is designed by using the Indian standard code IS 1893:2016[8]. The height of each story of all models is taken as 3.5m. The number of bay in X and Y direction is taken as 5 and 4 bays respectively. The ten models are selected as a moment resisting frame having soft story at different location. To avoid tension, symmetric in plan having length 25m and breath 20m is considered for the study. The details of model is shown in Table 1. Effective stiffness of structural component are according to IS 1893:2016[8]. The dead load is the self weight of structure and floor finish is taken as 1.75 KN/m^2. The superimposed load is taken as 2.5 KN/m^2 for all typical floor and for top floor is 1.5 KN/m^2. The load due to brick infill wall is found out by considering the specific weight of brick masonry 21.2 KN/m3 is 14.38 KN/m. The soil is taken as medium type, importance factor 1, response reduction factor 5 and zone factor is 0.36. The structure analysis software ETABS V19 is used for analysis using IS code. For the modeling of masonry infill in ETABS, the materials strain-stress curve of masonry is defined on it according to Kaushik et.all.(2007)[9] and equivalent strut width according to Stafford-Smith-Carter equation (6) and Mainstone equation(7). The strut is insert between two columns having pin jointed at both ends to prevent the external bending moment from structural member. The thickness of the equivalent strut is same as the thickness of masonry wall. The modulus of elasticity of infill masonry is according to IS 1893:2016. Under the seismic loading the behavior of strut is equivalent to the RC frame building. The width of strut given in empirical equation (7) depends upon the diagonal length of infill and column height in addition to the coefficient λ. The numerical coefficient λ which depends upon stiffness properties column, thickness of masonry and modulus of elasticity of masonry[10]. The infill detail is shown in Table 2.

The plastic hinges in the Reinforced concrete member are modeled as ASCE-41 code. The plastic hinges in the flecxural member like beam is modeled using ASCE41 table 10-7 and for compression member plastic hinges (P-M2-M3) intraction hinges are medeled as ASCE-41 , table 10-8. The plastic hinges for strut is defines as ASCE code table 11-7. Plastic hinges for strut are defines as axial (p-type) hinges .In beam plastic hinges are defines as shear hings. The location of the plastic hinges for colum l_{column} is calculated using equation 8 and eq.(9) . Also for location of plastic hinges l_{beam} for beam is calculated as per equation (10) and equation(11). These location distances are shown in table 2. The location of plastic hinges for strut is defined mid-point of hinges.

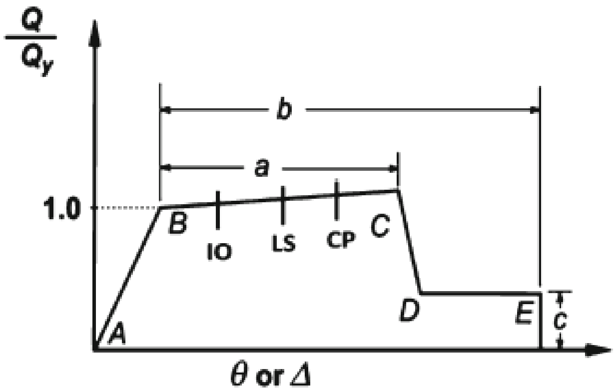

Figure 1: Force-deformation curve for defining hinges

The force deformation or moment rotation curve shows that five points A-B-C-D-E. The starting point of curve is origin. The structure has no deformation up to point B i.e. linear up to the point B. Thus, after the point B the structure starts deformation. While defining the back bone curve of non linear hinges the point B is just above A i.e. the coordinate of point B is (0,1). Since the deformation starts from point B, the acceptance criteria Immediate occupancy (IO),life safety(LS) and collapse prevention (CP) are in between BC. The BC line is 10% positive slope for defining the backbone curve. After the collapse prevention (CP), the point C in the figure1 is the ultimate capacity of the pushover analysis. Also, the positive slope from the C to D is defined on backbone curve for other purpose. The point E is total failure point i.e. hinge will drop load down.

The force-deformation curve or Moment rotation curve is used to model a structure. In the above fig1 a, b,and c are the modeling parameter and IO ,LS, CP are the acceptance criteria for structure. In this research the frame structure is model with American Society of Civil Engineering (ASCE 41) code .In beam the flexural and shear hinge like M2-M3 is used in this modeling. The modeling parameter and Numerical acceptance critera for Non linear procedure of flexural member is like beam is taken from ASCE 41 code of table no.10-7. The hinge distance taken from face of the column is l_{beam} defined by equation(10).In Column the interacting surface hinge like P-M2-M3 is used .The modeling parameter and Numerical acceptance critera for Non linear procedure ofor column is taken from ASCE 41 code of table no.10-8.The hinge distance in column is taken from the face of the beam is l_{column} defined by equatin (8).For infill between the column with masonary, in this research the equivalent strut model is used so only the axial hinge is used in model like P-type hinge. The modeling parameter and acceptance criteria of axial P-type hinge is defines by ASCE 41 code of table 11-9. The P-type hinge in strut is formed at mid span of strut[5].

6. Results and Discussions

In this research the analysis of building is conducted using well known software ETABS V19.The buildings models are designed by Response spectrum analysis method and after design the non linear static analysis (Pushover analysis) is done for discussing the seismic parameters. The modeling and analysis of this building is done using ETABS software and the seismic parameter like displacement, story drift, story shear, base shear, time period etc. are discuss below. The discussion of the results is based on Dynamic analysis of building. The different location of geometrical vertical irregularity of building is shown in table 3.

6.1 Performance Point

The point of intersection of capacity spectrum and demand response spectrum is taken as the performance point. The performance point in terms of spectral acceleration and spectral displacement is shown as

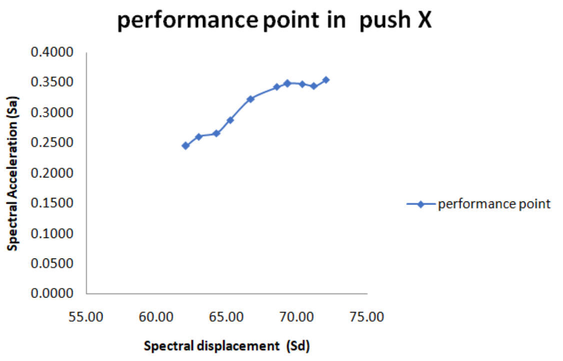

Figure 2: Performance point in different model in X-direction.

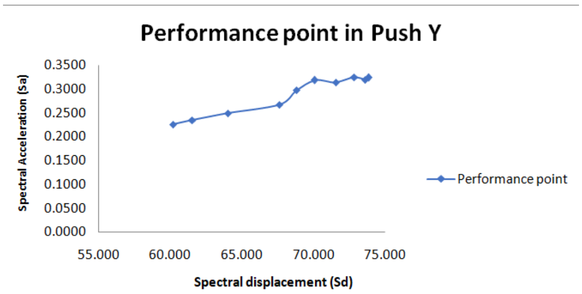

Figure 3: Performance point in diffferent model in Y-direction.

The performance point is found minimum when building is first story soft in both push X and push Y loading case. The spectral acceleration and spectral displacement found is 0.245g and 62.09mm. Similarly ,the maximum performance point found is in regular case having spectral acceleration value is 0.354g and spectral displacement is 72.03mm. The performance point is increasing when location of softness is shifted from first story to Ninth story in both case of Push X and push Y. In camparison, the regular building have more than 44.6% and 43.3% spectral acceleration than first story soft in both push X and push Y cases respectively.

Here the performance point of the building is increasing order from shifting the location of soft stories first story to ninth and regular. The regular building has maximum performance point in comparison to all models. As the performance point is increasing means that the intersection of capacity curve and demand curve has more value which leads to more stiffer and ductile than others

6.2 Base Shear

The base shear is maximum when the building is regular and is slightly greater than seventh and eighth floor soft building. The base shear in case of regular is19152 KN in X- direction and 18879 KN in Y-direction and is followed by 9th story soft which is 18701KN in X-direction and 18748 KN in Y-direction.

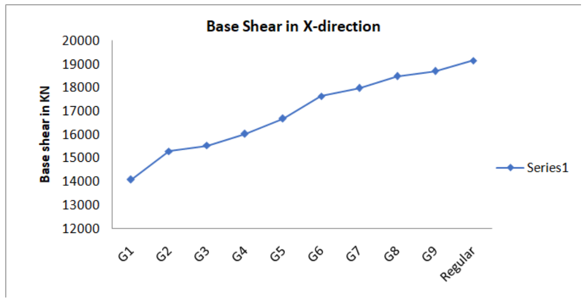

Figure 4: Base shear in X- direction.

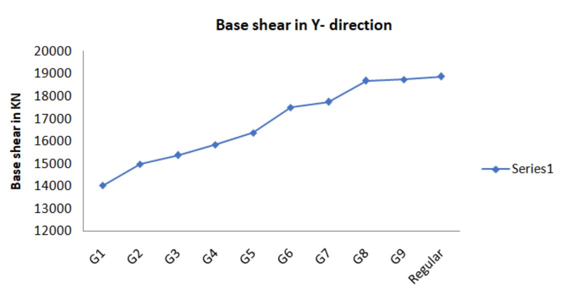

Figure 5: Base Shear in Y- direction.

Similarly the base shear in 1st story case is minimum and is 14081KN. All the base shear in camparision to the regular building which is increasing order as irregularity of the building is increasing from 1st, 2nd, 3rd, up to 9th story .When the irregularity increasing from 1st to the 9th story the base shear is increasing by 8.64%, 1.57%, 3.21%, 4.04%, 5.74%, 1.93%, 2.79%, 1.17% and 2.41% as softness increase from 1st to 2nd,2nd to 3rd, 3rd to 4th, 4th to 5th, 5th to 6th,6th to 7th, 7th to 8th , 8th to 9th and 9th to regular respectively in X-direction. Similary, irregularity increasing from 1st to the 9th story the base shear in increasing by 6.78%, 2.68%, 3.02%,3.36%, 6.88%, 1.37%, 5.34%, 0.33% and 0.7% as softness increase from 1st to 2nd, 2nd to 3rd, 3rd to 4th, 4th to 5th, 5th to 6th, 6th to 7th, 7th to 8th, 8th to 9th and 9th to regular respectively in Y-direction. While comparing the 1st story irregular building base shear in regular model the base shear is less than by 36% and 34.6% in X-direction and Y-direction respectively.

The analysis of the building is done by taking the constant mass. Thus, all the irregular building model have same seismic weight and the base shear is only depends on the seismic coefficient parameter as acceleration coefficient (Sa/g). Here, the zone factor, importance factor, response reduction factor of all model is taken as same value. The acceleration coefficient vs time curve, the value of spectral acceleration is decreasing if time period is increasing. When the mass of the building is constant the time period of the building is only depends on stiffness. As irregularity increasing from 1st story to 9th story the stiffness of the building is also increasing and time period is decreasing. Thus, the Base shear of the building is increasing when location of the softness of the building increasing from ground to top.

6.3 Time Period

After the non linear static analysis(Pushover Analysis) the performance point is find out by FEMA 440 equivalent linearization procedure . At the performance point the effective period of all model is as shown in figure below.

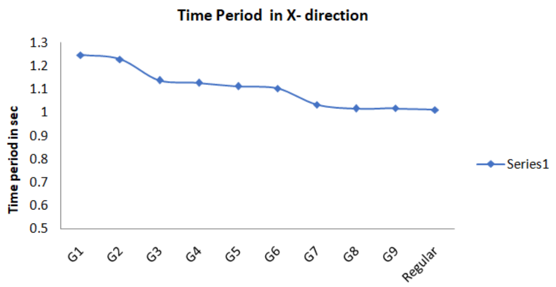

Figure 6: Time Period in X- direction.

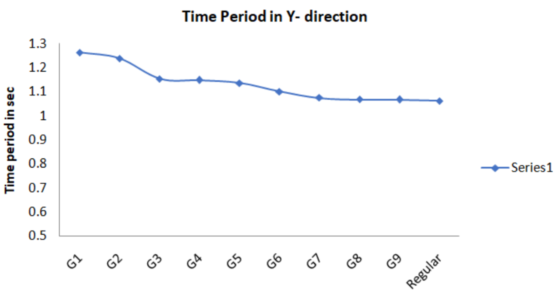

Figure 7: Time Period in Y- direction.

The maximum and minimum time period is found in 1st story soft and regular model. The maximum time period in comparison to all models of building is 1.247 sec and 1.263 sec in X-direction and Y-direction respectively. Similarly, the minimum time period in comparison to all model of building is 1.012 sec and 1.062 sec in X-direction and Y-direction respectively. Time Period is decreasing in order as location of the softness is increasing from ground to top. Thus,the time period when the irregularity in 1st story is 23.2% and 18.9 % more than the regular building. In conclusion, the time period is depends on mass and stiffness of the the structure. In our research study the mass of the structure is constant so only the stiffness effect on period. Thus, stiffness increases as the location of irregularity (soft story) increases from 1st story to 9th story and regular. As a result the time period is decreasing when location of softness increases

6.4 Story Shear

Story shear is another seismic parameter and in our research study, the story shear is find out after the pushover analysis. Since the performance point of the building is not exactly on fixed step so that all storey shear data tabulated below is extracted just below the performance point.

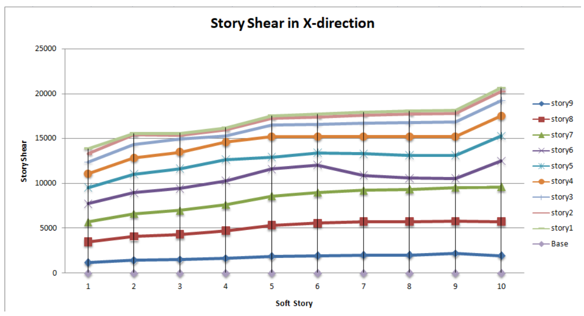

Figure 8: Story shear in X- direction

In this research study the story shear in case of regular model is 20635KN and 20686KN in X and Y direction respevtively. Also the storey shear in case of 1st storey soft is 13889KN and 13154KN in X and Y direction respectively. The maximum story shear is in case of regular and minimum in case of 1st story soft(G1) model. With the increasing the location of irregularity the storey shear in 1st storey is increasing order.

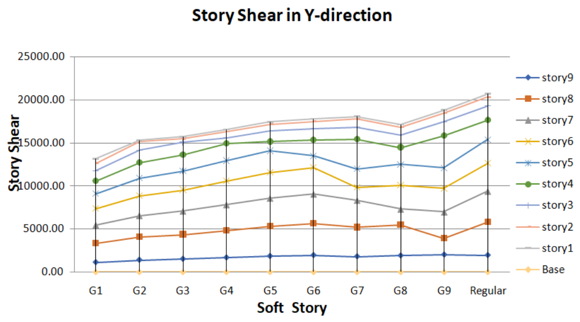

Figure 9: Story shear in Y- direction

The lateral force acting on each of story is story force. The sum of all the story forces is the base shear. The story forces is maximum in first story among all models. By comparing the story forces the maximum force is found in regular model and minimum is in first story soft. Shifting of location of softness in upward is increasing the story shear.

6.5 Displacement

The displacement is maximum in 1st story soft (G1 model) and is minimum in regular model. The maximum top story displacement is 114.27mm and 115.17 mm in X- and Y-direction respectively.

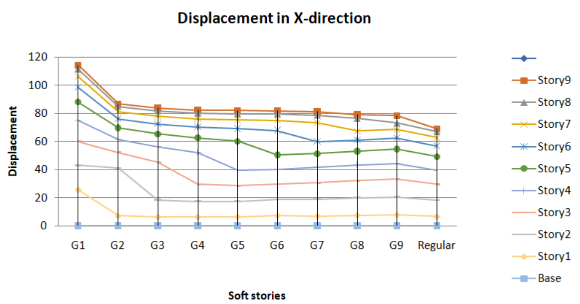

Figure 10: Displacement of different stories in X-direction

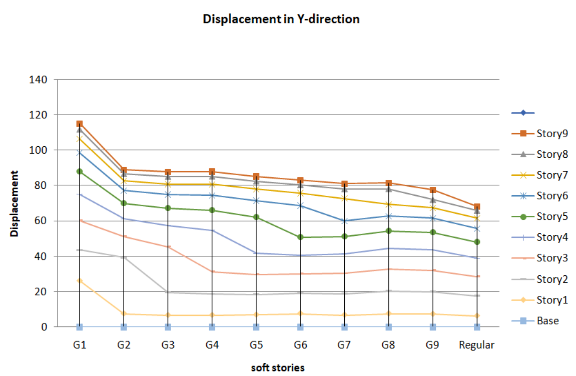

Figure 11: Displacement of different stories in Y-direction

Also the minimum top story displacement is 69.13mm and68.35mm in X and Y direction respectively. Top story displacement is decreasing when the location of irregularity (soft story) increasing from 1st to top. In this study the top story displacement demand in first three model like G1,G2,G3 is reasonably considering in seismic vulnerability in both X and Y direction. Also the top story displacement in G4,G5,G6,G7 and G8 is more or less equal in both direction. In comparison to the regular building, the displacement demand in first story soft (G1) model is more than 65.3% in X-direction and 68.5% in Y-direction.

The top displacement is depends on the lateral force and stiffness of structure. Top story displacement is maximum when building is first story soft since stiffness in coparison to regular one much less. In regular building stiffness is maximum so top displacement is very low.

6.6 Story Drift Ratio

Story drift ratio of irregular modes G1,G2,G3,G4,G5 and G6 have maximum value at particular story is soft and model G7, G8,G9 and regular have maximum value at the second storey.While in comparision to the regular model the irregular model G1,G2,G3,G4,G5 and G6 have 76.0%, 80.9%,62.1%,57.5%,52%,46.9% more drift ratio in X- direction and 66.3%,64.6%,67%,68.1%,46%,50.1% more drift ratio inY-direction respectively. Story drift is the relative displacement of particular story to its adjacent below. Story drift ratio is the ratio of story drift to height of story. The story drift is maximum when the particular story is soft and when location of softness is increasing upward the story drift is also shifted upward at that story up to story six. The location of softness above six story the story drift is not

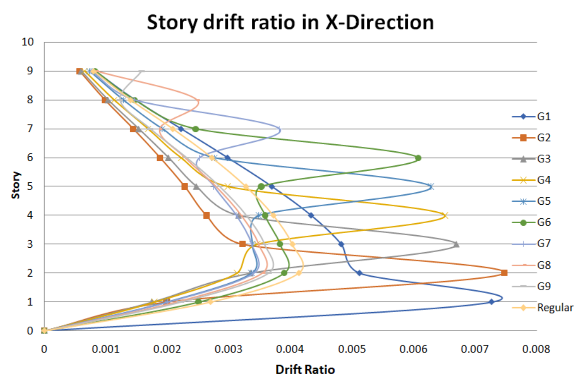

Figure 12: Story drift of different stories in X-direction

maximum at that story but is in story two.

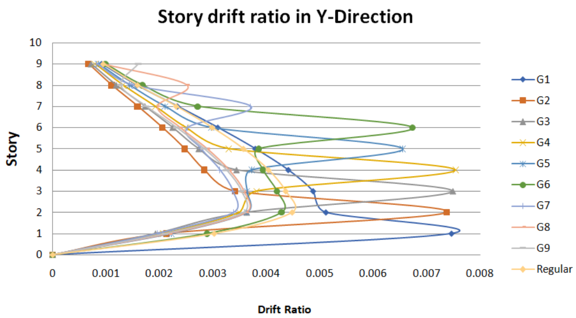

Figure 13: Story drift of different stories in Y-direction

7. Conclusions

The following conclusion has been made from the analytical study carried out in different location of soft stories.

- Base shear is minimum in first story soft model and maximum in regular model. Shifting the location of soft stories upward the base shear is more. While comparing the 1st story irregular building base shear in regular model, the base shear is less than by 36% and 34.6% in X-direction and Y-direction respectively.
- The fundamental time period of infill building, specified in a code is more or less equal to the regular frame building but its quite difference in vertical irregular building. The time period of irregular building depends upon location of irregularity and is decreasing when location of irregularity is shifted upward.
- The story drift is maximum at particular story level when that story is soft. Whether the location of soft stories above the half mid height the story drift is maximum in story two.
- By shifting the location of vertical irregularity upward, the top displacement is decreasing. Thus,building with masonry infill enhance the lateral stiffness and reduces the top displacement but lateral force on the structure is heavily increased.
- Structural performances are significantly affected by different location of soft storey. The improvement of performances increase with shifting of soft storey upward to the total height of building. The maximum performance level is in regular case among all the soft stories cases.

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