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STUDY ON THE EFFECT OF SOFT STORY ON INFILL RC FRAMES UNDER SEISMIC EFFECT

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ABSTRACT
Construction practice of reinforced concrete (RC) frames infilled with unreinforced masonry is quite common now-days in urban cities in Nepal and elsewhere. Previous study shows the lateral load transfer mechanism is different than that of bare frames in infill buildings. Because of the unavoidable circumstances like elimination of central columns, elimination of infill wall in basement for parking purpose and reducing the size of frame members etc. may cause the particular story to be soft.

In this study the infill RC frames with stiffness irregularity has been analysed with linear time history method using Gorkha-2015 earthquake as ground motion using structural analysis and design software (ETABS 2000 V.16). In total 8-numbers of 6-story RC infilled frames were analysed introducing the soft story in each story level respectively from basement to top. Regular frame was designed as per IS 1893:2002 load combination considering torsional effect. After analyse of bare frame, regular frame and irregular frames the global and story level seismic demand parameters were studied comparatively. Base/Story shear, Story displacement, inter-story drift and fundamental time period were the parameters compared taking regular frame as reference case.

Results showed that, there is significant effect of location of irregularity on the seismic demand. The global and story level seismic demand is higher when the irregularity is introduced in bottom part of the buildings and further it showed that the lateral strength of RC frames get highly enhanced due to introductions of infill in analytical models.

Keywords: Gorkha Earthquake, Masonry Infill, Stiffness Irregularity, Soft Story, RC Frames

INTRODUCTION
The story is said to be soft 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 threes story above (IS 1893:2002). Particularly for the purpose of the basement parking, storing heavy mechanical equipment, reducing the story height in upper story, elimination the columns in any story, eliminating the masonry in particular story, irregular distribution of the masonry in plan of the buildings etc. causes the story to be weak or soft.

The damage due to Bhuj earthquake was mainly because of the stiffening effect of the infilled frame that changes the behaviour of the building during earthquake and creates new failure mechanism [1].

One of the major causes of the building failure mainly for RC building was Soft story in Gorkha-2015, earthquake [2].

Seismic design code has quantified the magnitude of the irregularity in vertical position but not specified about the effect of the location of irregularity. Number of researches had concluded that the location of the irregularity in the structure is also of importance regarding the damage during earthquake excitation [3].

Masonry enhances in the stiffness and strength of the frames in global aspect before the cracking of it, but it may also harm the structure by altering the stiffness and strength if not properly distributed along the buildings. After the visual observation during Jabalpur earthquake (1997), the performance of RC buildings with brick infill having no abrupt change in stiffness has been very satisfactory i.e. unreinforced masonry contributed positively, but RC frames with open ground story has shown poor performance [4].

Figure 1. Soft Story Shear failure Gorkha earthquake (a) & (b) apartment in Nepal without infill in ground story [2]

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It has been found that the brick infills actually contribute in enhancing the strength of the structure by resisting the lateral deflection of frames applied to horizontal forces. The contribution has been felt primarily during the earthquake events, where, most of the infilled framed structures remain less damaged as compared to the frames which are left bare [5].

As the design code of many countries do not include the location of stiffness irregularity so far, so this study is intended to compare the global and story level seismic demand in infilled masonry RC structure with location of soft story in each story. The comparison of basic seismic parameters like base shear, story displacement, inter-story drift and fundamental time period has been considered in this study.

MATERIALS AND METHODOLOGY

Material and Geometrical properties

For the analysis steel grade of 415 MPa (Mega Pascal) and concrete grade of 25 MPa having Poisson's ratio of 0.2 for both concrete and masonry is used. Beam size of 550 mm depth and 300 mm width and column of 450 mm both width and depth, size of slab is 150 mm, specific weight of RCC and masonry used are 25 kN/m^3 and 20 kN/m^3 respectively.

Table 1. Material and geometric properties used in modelling

Parameters	Data	Unit	Remarks
Strength of Concrete (f_{ck})	25	MPa	
Modulus of Concrete, E_c	25000	MPa	$E_c=5000\sqrt{f_{ck}}$ (IS 456:2000)
Infill wall thickness (t)	230	mm	Figure(4)(a)
Infill wall height (h_{inf}),Length (L_{inf})	2950, 4550	mm	
Area of the infill (A_p)	13422500	mm^2	
Strength of the infill wall (f_m)	9.6536	MPa	IS 1893:2002 (6th Revision)
Modulus of masonry wall (E_m)	5309.4	MPa	FEMA 356:2000, $E_m=550f_m$
Strut angle with horizontal (θ)	32.95	Degrees	
Infill diagonal length (d_{inf})	5422.6	mm	
Height of the Column (h_c)	3500	mm	
Opening reduction factor (R_f)	0.574	-	Equation (3), 30% Opening
Equivalent Coefficient (λ_1)	0.001025	-	Equation (2)
Equivalent Strut width (w)	569.1787	mm	Equation (1)
Final Strut width (w')	326.7	mm	Equation (4)

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Software modelling and analysis

Extended Three dimensional Analysis of Buildings System (ETABS 2000 V.16) programme is used for the finite 3-D modelling and analysis of the building system. Beam and column are modelled as frame element while slab is modelled as shell element. Equivalent single diagonal masonry strut is modelled as pin jointed frame element. Material properties are defined in ETABS and the 3-D finite modelling is done. Dead load is calculated as per IS 875 part-I and imposed load as per IS 875-II. Regular model having regular distribution of stiffness is initially designed as per IS 1893:2002, from equivalent static method and Response Spectrum Method with torsional consideration. Total 25 combination of load are checked for design pass. After the design check, the regular model is made irregular by replacing masonry strut in each story level. Time history linear dynamic analysis was done with Gorkha-2015 earthquake as ground motion. The time history data is scaled in time domain by response spectral matching with target spectrum of (IS 1893:2002) specified design response spectrum for seismic zone-V, with zone factor of Z= 0.36.

Live load of 4kN/m^2 is used for the entire floor and 1.5 kN/m^2 is used for roof plan. Medium soil and importance factor was taken as 1 for the analysis. and building analysed are considered as special moment resisting frame (SMRF) having response reduction factor (R) as 5, damping ratio of 5%, modal analysis with Eigen Vector and linear time history analyse have been done. Only external wall is considered in the analysis considering 30% of central opening in infill panel.

Infill modelling

Infill is modelled as single equivalent masonry strut purposed by [6], which is recommended by FEMA 356:2000. The strut width of masonry is calculated as per equation (1).

$$w = 0.175\, d_{inf}(h_c\lambda_1)^{-0.4} \qquad (1)$$

where,

$$\lambda_1 = \left[\frac{E_m t_{inf} sin2\theta}{4E_c I_c h_{inf}}\right]^{0.25} \qquad (2)$$

where, E_m, E_c and I_c are Young's modulus of masonry, Young's modulus of concrete and Moment of inertia of column respectively. d_{inf}, t_{inf}, h_{inf} and h_c are the diagonal length of infill, thickness of infill, height of infill and height of column respectively, The angle of strut with horizontal is θ and w is the strut width without opening consideration.

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External wall opening is considered using the reduction factor [7], as

$$R_f = 0.6\left[\frac{A_o}{A_p}\right]^2 + 1.6\left[\frac{A_o}{A_p}\right] + 1 \tag{3}$$

where, R_f, A_o and A_p are reduction factor, open area and infill panel area respectively.

$$w' = R_f w \tag{4}$$

Final strut width (w') is calculated as per equation (4). Masonry infill mechanical properties are calculated as per IS 1893:2000, 6th revision, the compressive strength of masonry prism can be given as

$$f_m = 0.433 f_b^{\ 0.64} f_{mo}^{\ 0.36} \tag{5}$$

where, f_b and f_{mo} are compressive strength of brick and mortar in MPa. From IS 1077-1992, compressive strength of common burnt clay brick with grade 35 is 35 MPa and as per IS 1905-1987, minimum strength of mortar at 28 days with grade of H1 is 10 MPa. Equation (5) gives the masonry strength and modulus of masonry is then calculated as $E_m=550f_m$, that yield 5309.4 MPa.

Model descriptions

The building models considered in this analytical study are of 3 bays having bay width of 5m each in both X and Y directions with all story height of 3.5m.

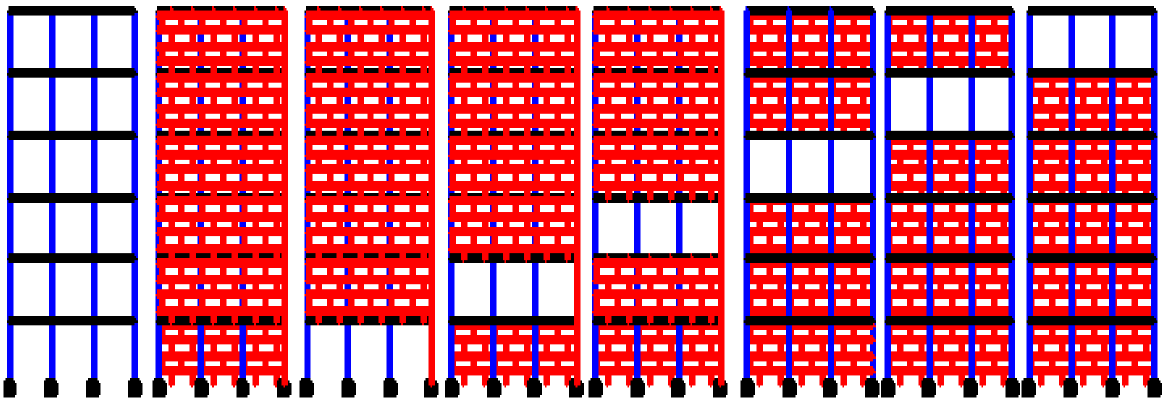

Figure 2. Elevation detail of six-story RC bare, regular and infill frames

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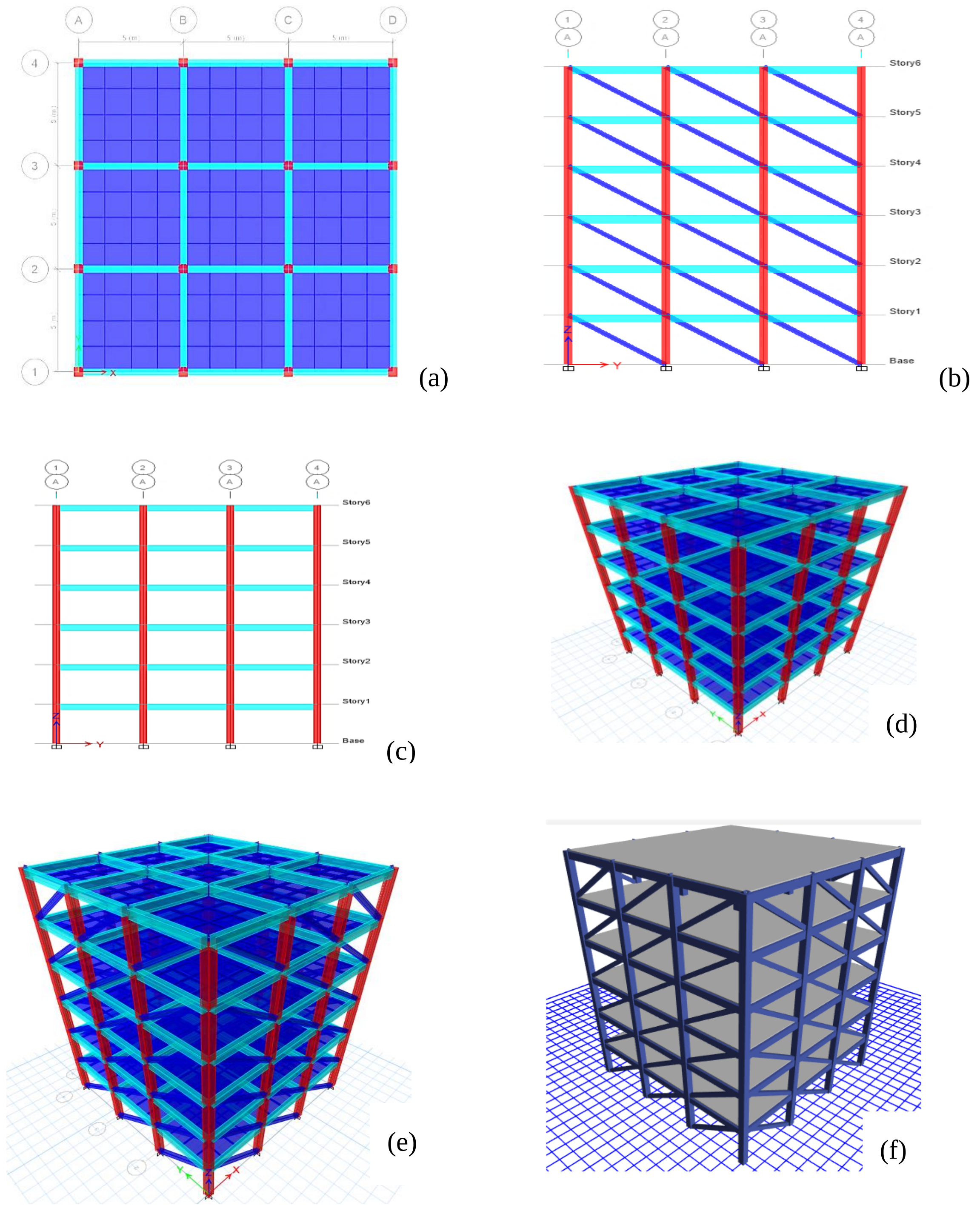

Figure 3. (a) Typical plan, (b) Elevation of regular frame, (c) Bare frame elevation, (d) 3-D bare frame, (e) Regular 3D model and (f) Rendered view 3D regular frame

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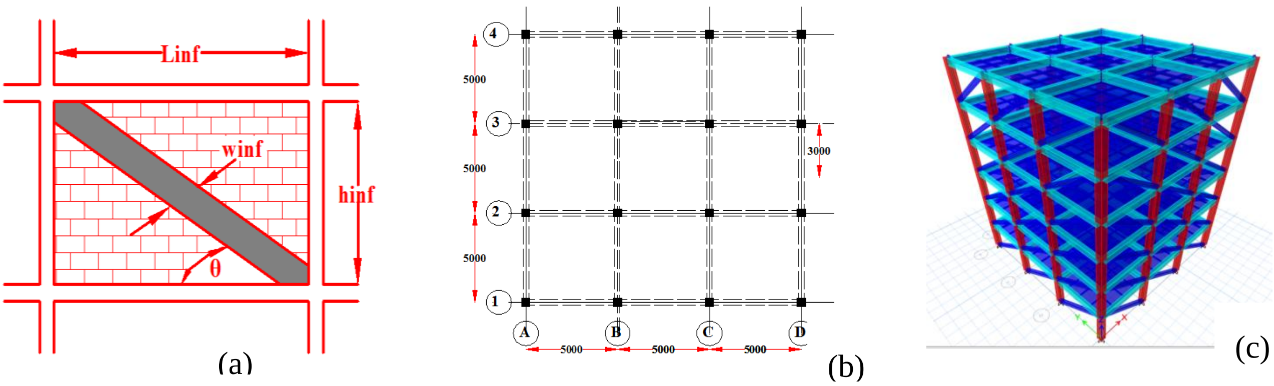

Figure 4. (a) Typical infill modelling, (b) Plan of the building and (c) ETABS 3D Model

Ground motion detail

Gorkha earthquake-2015, recorded in Institute of Engineering, Pulchowk Campus, Lalitpur Patan station [8] is used for the analysis.

Table 2. Detail of Ground motion used

Name of Earthquake	Date	Magnitude	D_e (kM)	PGA
Gorkha/Patan	25/04/2015	M_W=7.8	8.2	0.156g

Where, Mw is moment magnitude, D_e is Depth of hypocentre and PGA is peak ground acceleration of the ground motion.

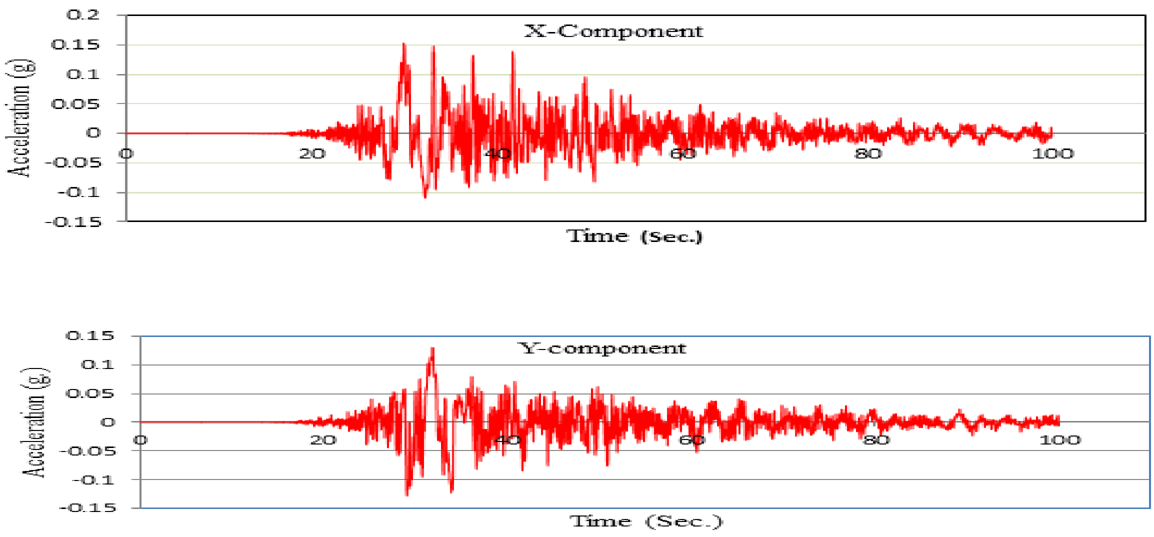

Figure 5. Time history record of Gorkha earthquake-2015 [8]

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RESULTS AND DISCUSSIONS

Basic seismic parameters base/story shear, story displacement, inter-story drift and fundamental time period of each irregular frame is compared with regular frame and bare frame. 6-irregular model having same story height, same bay width and regular distribution of mass with stiffness ratio of 0.55, one regular frame (having infill in all the story level) and one bare frame (without any infill wall in it) are modelled and results obtained are as follows:

Base/Story shear comparison

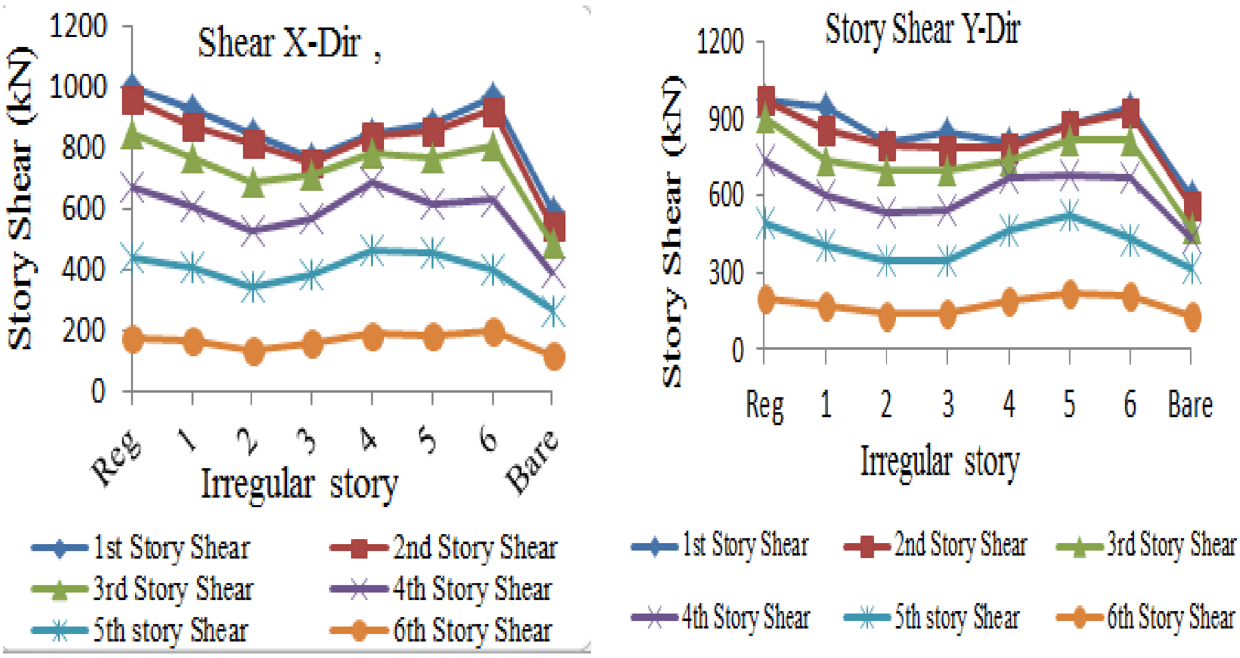

Figure 6. Base and Story shear distribution of all case

In X-direction, base shear is highest in regular frame 997 kN and least in the bare frame 595 kN. In all irregular case base shear is most when top story is soft and then in decreasing order with soft story 1^{st}, 5^{th}, 4^{th}, 2^{nd}, and 3^{rd} respectively. Irregularity changes significantly the story shear of 1^{st}, 2^{nd} and 3^{rd} story but has less significant change in other story shear wherever location of irregularity is.

And in Y-direction, the similar pattern of story shear is obtained, highest in regular frame 977 kN, followed by soft top story 601 kN. Irregularity in bottom one third story decreases the base shear and irregularity in top one third story slightly increase the base shear.

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Story displacements comparison

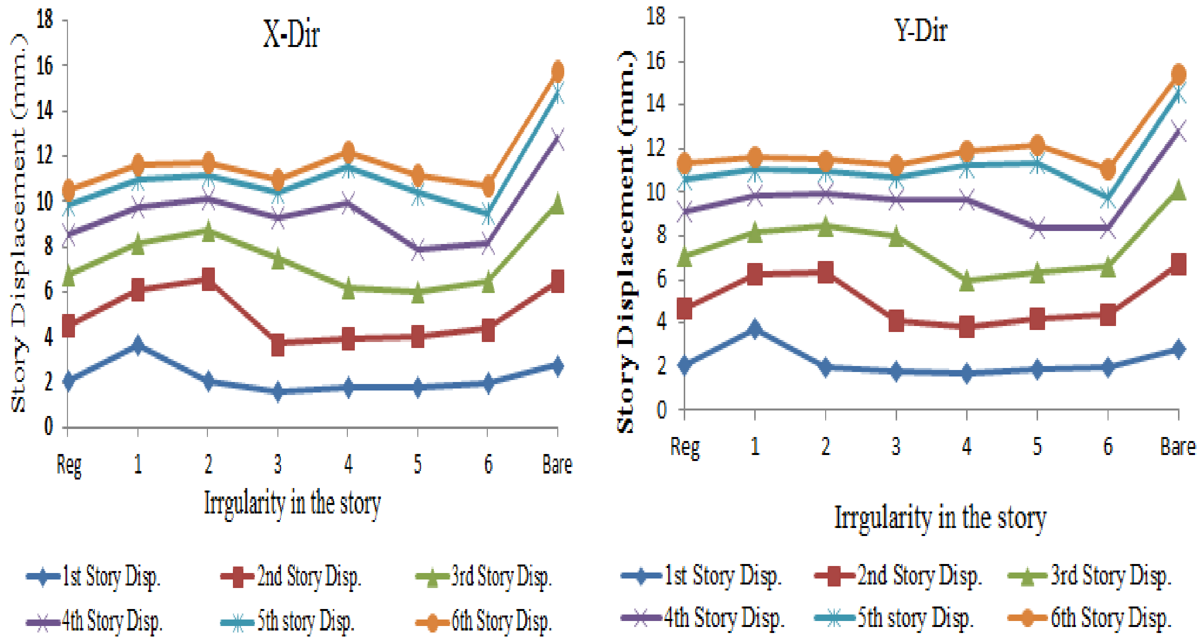

Figure 7. Story displacements comparison of all the cases

In both directions highest top displacement is in bare frame and least in regular frame building model. 50% and 36% are the higher displacement value in bare frame than regular frame in both X and Y-directions respectively. Irregularity when in ground story and in 1st story the top displacement significantly increased than when irregular top part story. When irregularity is in particular story in bottom one third i.e. when irregular 1st story the particular 1st story displacement is highly increased than that of regular one. That shows the story level demand of the building is highly influenced by the soft story under seismic excitation.

Inter-Story Drift comparison

IS 1893(2002-I), specifies the story drift in any story due to the minimum specified lateral force, with partial load factor of 1.0, shall not exceed 0.004 times the story height.

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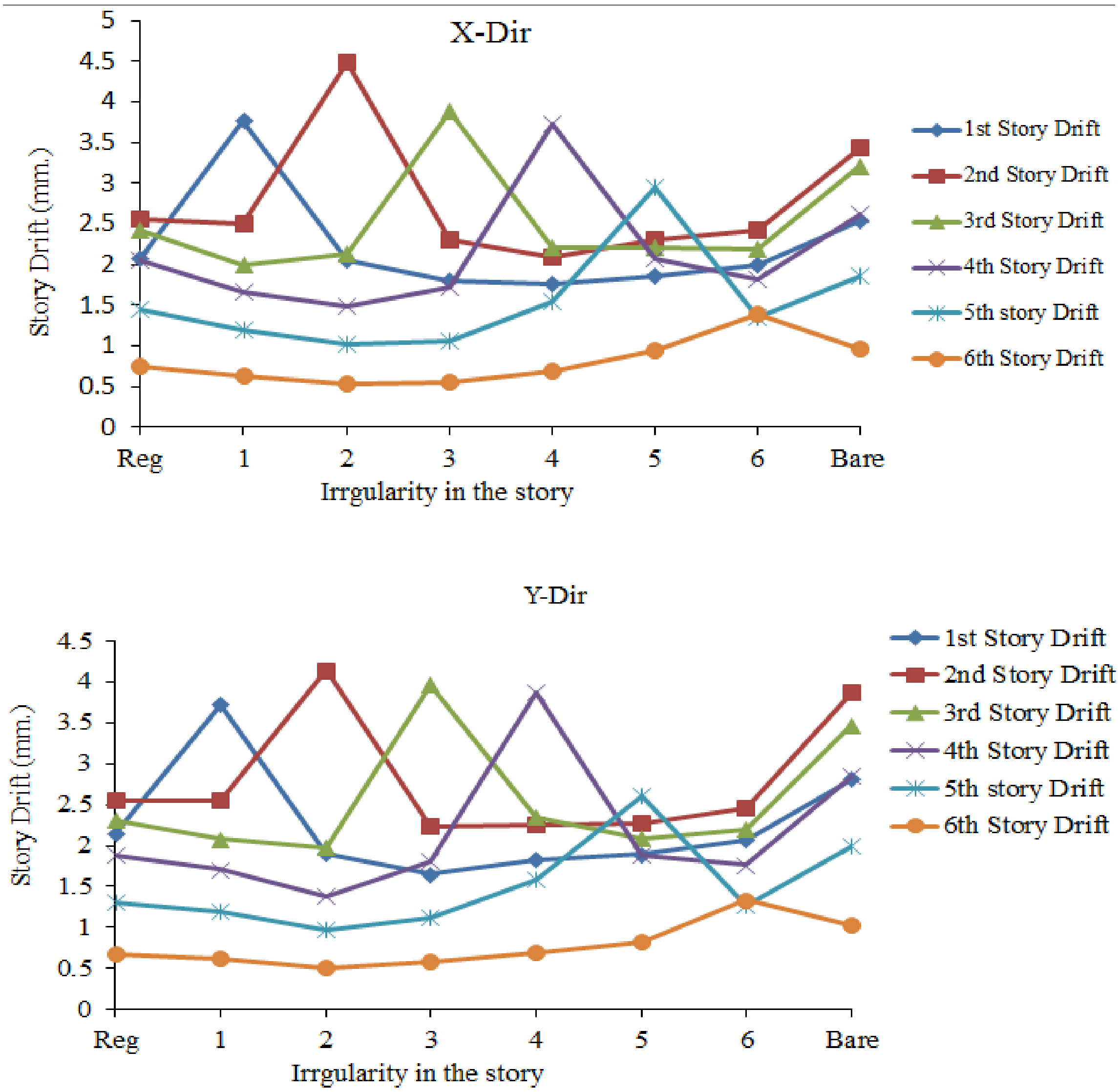

Figure 8. Inter-Story Drift Comparison of all the cases

In both regular and bare frame 2nd story drift is highest followed by 3rd story drift and least story drift of 6th story in both regular and bare frame in both directions. It is seen that the location of irregularity has major contribution on the abrupt increase in the story drift of that particular story. When irregularity is in 1st, 2nd, 3rd, 4th, 5th and 6th story than increase in the percentage of the inter-story drift in 1st, 2nd, 3rd, 4th, 5th and 6th story with respect to the regular frame is 82%, 75%,60.5%,82%,104% and 86% in X-direction and 74%, 62%, 71%, 106%, 98% and 96% in Y-direction respectively. From the result it is found that the irregularity in 2nd story yields highest inter-story drift in both directions of that particular story. When ith story is irregular, the inter-story drift of that particular ith story is abruptly increases then that of regular frame.

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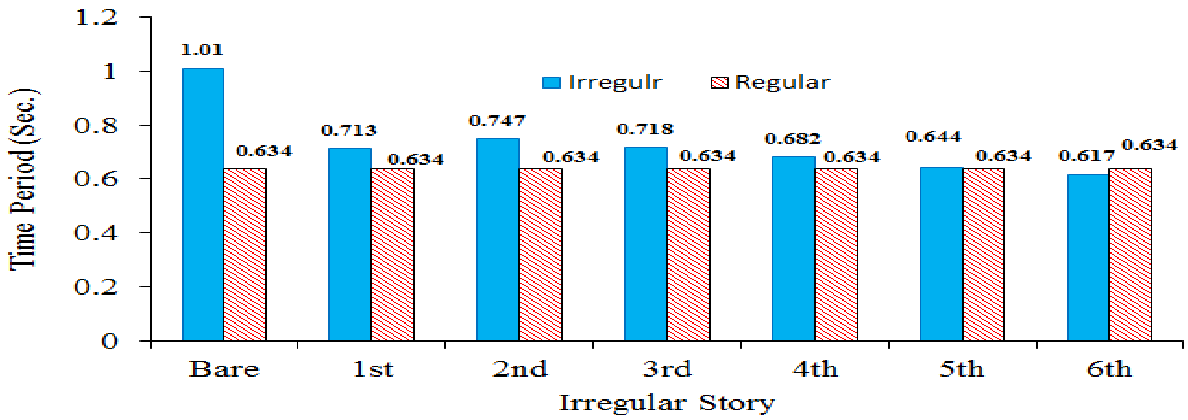
Time period comparison



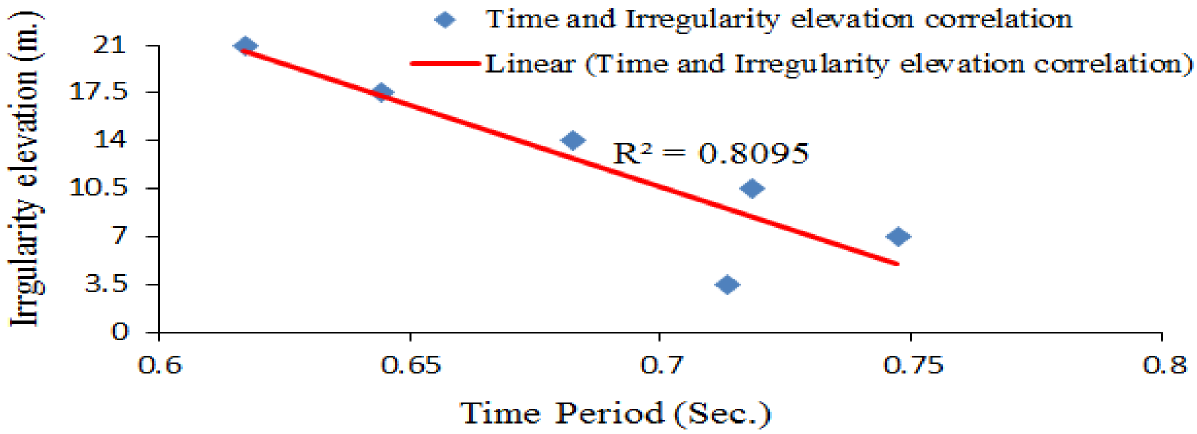


Figure 9. Fundamental time period comparison and time to irregularity elevation correlation

Number of the span, stiffness of the masonry panel, opening ratio of the infill panel, position of the soft story, span of the bay, length of bay etc. has influence on the fundamental time period of the building system [9]. Furthermore properties of the frame member also contribute to the variation of the fundamental time period of the building system. In this study time period of bare frame is found highest while least in case of regular frame. It is seen that the global stiffness enhancement of the infill frame that causes the decrease in time period of the regular building. Time period of bare frame is 60% higher than that of regular frame. In irregular cases when irregular 2nd story the time period is highest 0.713 sec. among all other irregular cases. It is observed that the negative linear correlation with correlation coefficient of 0.899 between the elevation of irregularity and fundamental time period, i.e. time is decreased when irregularity is introduced in higher elevation and time period increased when irregularity introduced in lower story.

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CONCLUSIONS

Regular (having regular infill wall in all story) frame, bare (no infill in any story) and irregular frames (having one specific story soft story) were analysed using linear time history method for comparison of the basic seismic parameters to conclude the effect of infill and soft story in special moment resisting RC frames.

The following conclusions were made from this current study

- ✓ Presence of brick infill wall in the RC frames enhances the lateral stiffness of the building which reduces the top displacement, but the lateral force on the structure increased heavily when infill is present. 67.4% is higher shear in regular frame than bare frame in this particular case.
- ✓ Irregularity in bottom portion of the building especially in ground and first story increased top story displacement significantly, while soft story in upper story has less impact on the top displacement of the building. Top displacement is highest in bare frame than the entire irregular and regular frame.
- ✓ In story level seismic demand of the building in irregular case especially when the irregularity is in 1st and 2st story the demand of the story is abruptly increased. So it is concluded that the location of the stiffness irregularity i.e. soft bottom story is critical towards the seismic excitation. So special considerations should be given while dealing with the soft story in bottom part of the RC frames, especially in ground story.
- ✓ Code specified fundamental time periods of the infill buildings are somehow near to the time period of regular frames, but for irregular case the time periods of code are not similar. And the time period also depend upon the elevation of the irregularity in the structure, furthermore it is seen that the reverse relation between time period and the elevation of the irregularity. Negative linear correlation between the time period and elevation of soft story.
- ✓ Finally in the light of above, it is concluded that the enhancement of infill should be considered in the analysis of RC infill frames, and the critical location of the stiffness irregularity is bottom story than upper story, so the special consideration should be given while treating the effect of irregular RC frames.

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