Research Inventy: International Journal of Engineering And Science
Vol.11, Issue 9 (September 2021), PP 24-32
Issn (e): 2278-4721, Issn (p):2319-6483, www.researchinventy.com

Seismic Performance Evaluation of RC Framed Building with Soft Storey

[1]Samundra Pokhrel,
Msc Student, Infrastructure Engineering and Management, Paschimanchal Campus, Institute of Engineering, Tribhuvan University, Pokhara, Nepal

[2] Sailesh Adhikari
Head of Department, Department of Civil Engineering, Paschimanchal Campus, Institute of Engineering, Tribhuvan University, Pokhara, Nepal

Abstract:*Construction practice of RC framed buildings with unreinforced infill walls is quite common nowadays in urban areas. Because of the absence of an infill wall in the ground storey for the purpose of parking, elimination of central columns for the purpose of the hall and reducing the size of columns may introduce a soft storey effect in that particular storey. Buildings having a soft storey effect are vulnerable to collapse due to earthquake load. This paper attempts to evaluate the seismic performance of RC framed buildings with the soft storey. In this study seismic response is carried out of a building with soft storey at different levels which is then compared to the structure having infill wall at all floor levels. Studies of structural parameters such as storey displacement, storey drift, and storey stiffness have been carried out using equivalent static analysis to investigate the influence of these structural parameters on the seismic behavior of buildings with soft storey.*

Keywords:*Soft Storey; Seismic Performance; Structural Parameters; ETABS; Infill Modelling.*

Date of Submission: 20-08-2021 Date of Acceptance: 04-09-2021

I. INTRODUCTION

Nepal is located in a high seismic region due to its geographical position along the tectonic boundary of the Indian and Eurasian plates. The high seismicity in these regions is attributed to the subduction of the Indian plate beneath the Eurasian plate, which seems to move at an average of 23 millimeters per year (Bilham, 2001). This movement causes elastic deformation of the plates instead of inelastic deformation and thus strain energy has been accumulating for several years which could end in disastrous earthquakes of greater magnitude in the future. In the last three decades, the country experienced one major and several moderate size earthquakes. After the 1980s RC construction in Nepal has been mushrooming and surpassed any other construction types. However, in rural Nepal stone masonry, adobe and wooden framed structures are still being dominant construction types. The construction technology, construction materials, binding materials are not significantly changing in rural settlements of Nepal. In contrast, the urban housing stocks are nowadays constructed either following by-laws, mandatory rule of thumb as suggested by Nepal Building Code or well-designed structures with analysis and ductile detailing frameworks.

During the sector study performed immediately after the 2015 Gorkha earthquake, it's observed that soft storey failure in RC buildings is one among the foremost common causes of collapse, along with another type of structural deficiencies. The ground floor in many RC buildings is used for commercial purposes and provided with Shutters, however, the upper stories of such buildings are provided with infill brick masonry walls. Similarly, just in the case of high-rise constructions, the bottom floor is left open for parking or sometimes basement parking is provided without infill walls. Such practices have led to the soft storey failure during the 2015 earthquake in most of the damaged RC buildings. In addition to the present, it had been observed that the majority of the buildings in the residential level were found to be practicing “weak column-strong beam” as depicted by the larger beams and smaller columns during field reconnaissance. Due to the lack of infill wall on the ground floor, the increased flexibility has significantly triggered the increased displacement within the ground floor thus the bulk of the cracks or minor to severe damages were found to be concentrated therein during field survey.

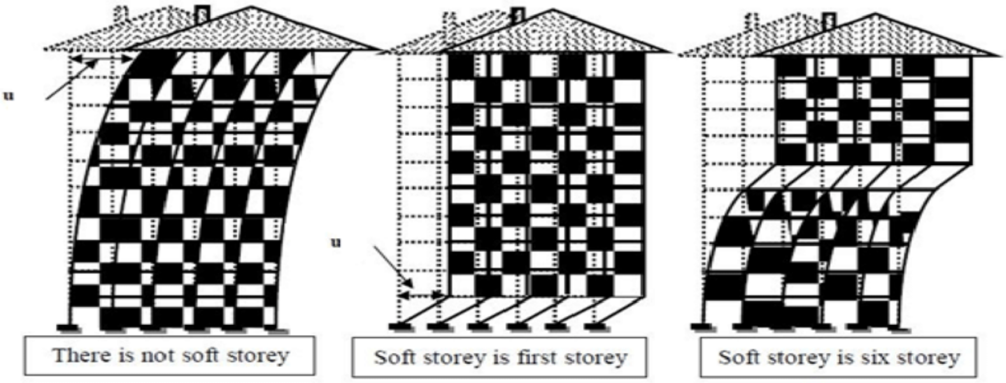


Fig.1: Behavior of soft storey in Earthquake. (Ref. Shailendra Singh, 2015)

II. AIM AND SCOPE

The main aim of this research is to analyze the effect of soft storey in different floor levels of RC framed building. However, specific objectives of this research are listed below;

a) To study the seismic behavior of RC framed building with soft storey effect at different floor levels.
b) To analyze structural parameters influenced by the effect of soft storey.
c) To analyze the structural parameters after the application of retrofitting measures in soft storey building.

Scope of the study

High-rise apartment building construction in Nepal started mainly after 2000 and most of such constructions are constructed within main city areas. (Malla, S., et al. 2019) Medium to high rise buildings in Nepal are special moment resisting frame (SMRF) constructions designed per Indian Standard Code. Number of researches concluded that one of the major causes of the building failure mainly for RC building was Soft story in Gorkha earthquake. To mitigate the effect of soft storey, it is essential to analyze the seismic behavior of RC building with soft storey.

III. LITERATURE REVIEW

A soft storey is a structural anomaly attributed to the discontinuity of stiffness along the height of a structure. Severe structural damages suffered by several modern buildings during recent earthquakes illustrate the importance of avoiding sudden changes in vertical stiffness and strength. According to IS1893:2016 “A soft storey is one in which the lateral stiffness is less than that in the storey above. The storey lateral stiffness is the total stiffness of all seismic force resisting elements resisting lateral earthquake shaking effects in considered direction.”

Open ground storey (also known as a soft storey) buildings are commonly used in the urban areas nowadays since they provide open space for parking areas which is most required. The building having soft storey shows comparatively more tendency to collapse during earthquake excitation due to the stiffness irregularity. If the stiffness of the upper storey is greater than the stiffness of the lower storey, the upper storeys move almost together as a single block, and most of the horizontal displacement of the building occurs in the lower storey itself. Thus, such buildings swing back-and-forth like inverted pendulums during earthquake shaking and therefore the columns within the lower storey are severely stressed. If the columns do not have the required strength to resist these high stresses or if they do not have adequate ductility, they may be severely damaged which may even lead to the collapse of the building.

Review of Past Study:

Hirde and Tepugade (2014) considered the multi-storey building with soft storey at different level for the analytical study. They observed the hinge formation pattern and concluded that, due to high shear forces at ground level soft storey, the hinges are formed in columns of ground soft storey, they carried out retrofitting measures with shear wall and it was observed that no hinges are formed in columns of ground soft storey when retrofitted with shear wall.

Khan and Vyawahare (2013) carried out the non-linear response of RC frame high rise building with soft storey at different levels in addition to one at ground floor. Their objective was to see the variation of load-displacement graph and check the maximum base shear and displacement of the frame with soft stories at different levels. After obtaining pushover curve the concluded that as the soft storey is shifted to higher level intensity of hinge formation becomes lower and lower and at the same time displacement increases and base shear also increases.

Hejazi (2011) discussed the effect of soft storey on structural response of high rise buildings. The paper highlights the occurring of soft storey at the lower level of high rise buildings subjected to earthquake has been studied. Also has been tried to investigate on adding of bracing in various arrangements to structure in order to reduce soft story effect on seismic response of building.

Dr. Saraswati Setia (2012) discussed dynamic ductility demand during probable earthquake. The stilt floor used in severely damaged or collapsed RC buildings introduced irregularity of sudden change of stiffness between ground storey and upper stories. In the upper stories brick infill walls were used due to which it increases the lateral stiffness of the frame by a factor of 3 to 4 times. For such buildings the dynamic ductility demand during probable earthquake gets only concentrated in the soft storey and the upper stories tends to elastic. In such buildings, the stiffness of the lateral load resisting systems at those stories was quite less than the stories above or below. Parametric studies on displacement, inter storey drift and storey shear have been carried out using equivalent static analysis to investigate the influence of these parameter on the behavior of buildings with soft storey.

Furtade and Anibal (2014) investigated the global structural safety of an existing building with a potential soft-storey mechanism and observed that a correct assessment of the building safety can be achieved by considering the presence of infill masonry walls. The absence of the infills on the ground floor introduced a soft-storey mechanism on the structure when submitted to seismic actions. Four different strengthening techniques were proposed and it is observed that the most efficient way for reducing the maximum drift was the addition of steel braces. This technique was the only one which succeeded in removing the soft-storey mechanism.

IV. METHODOLOGY AND MODELLING

Initially, an architectural plan is considered that contains locations of columns which is modeled using ETABS software considering structural plan of the building with assumed or appropriate dimensions, Loads are put on the structure as per IS code, factors like zone factor, importance factor, response reduction factor play a major role to determine the value of Base Shear of the structure, Design check is performed on the structure for the given value of structural member dimensions, For varying load combinations as per IS codes once the design check passes all the members of the structure, equivalent static analysis is performed resulting in output parameters like storey drift, storey displacement, storey shear etc.

Equivalent Static Analysis

The equivalent static analysis method is a simplified technique to switch the effect of various dynamic loading of an expected earthquake by a static force distributed laterally on the structure for design purposes. ESM is predicated on the elemental natural period of vibration of the structure. The total applied seismic force 'V' is typically analyzed in two horizontal directions parallel to the axes of the building (Fig 2). The equivalent static analysis method assumes that the building responds to the earthquake load in its fundamental lateral mode. In ESM analysis, story force is generated as per the height at which the story is located from the seismic base. Higher the story up within the building, more loads are going to be generated by that story. The structure must be ready to resist effects caused by seismic forces in either direction, but not in both directions simultaneously.

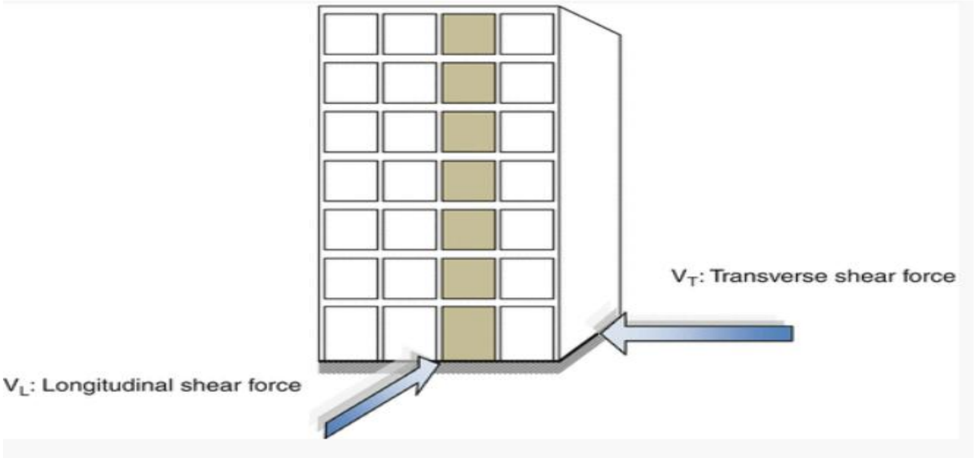


Fig 2: Total seismic force ‘V’ applied parallel to the main axes of the building. (Ref. Nouredine Bourahla, 2014)

MODELLING OF THE BUILDING

This contains the modeling of the building which has G+9 storeys having soft storey at different levels, the equivalent static analysis is carried out by using ETABS2016.

Following are the models considered for the analysis;

Case 1: Bare frame

Case 2: Regular frame (infill wall in all storeys)

Case 3: Model with soft storey at different floor levels

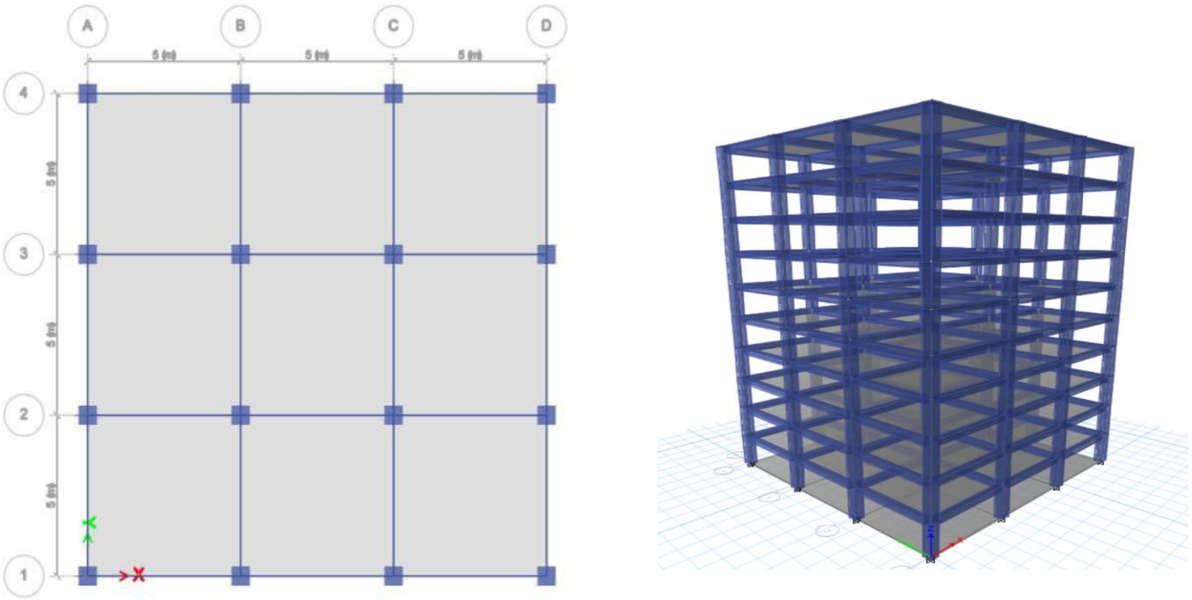
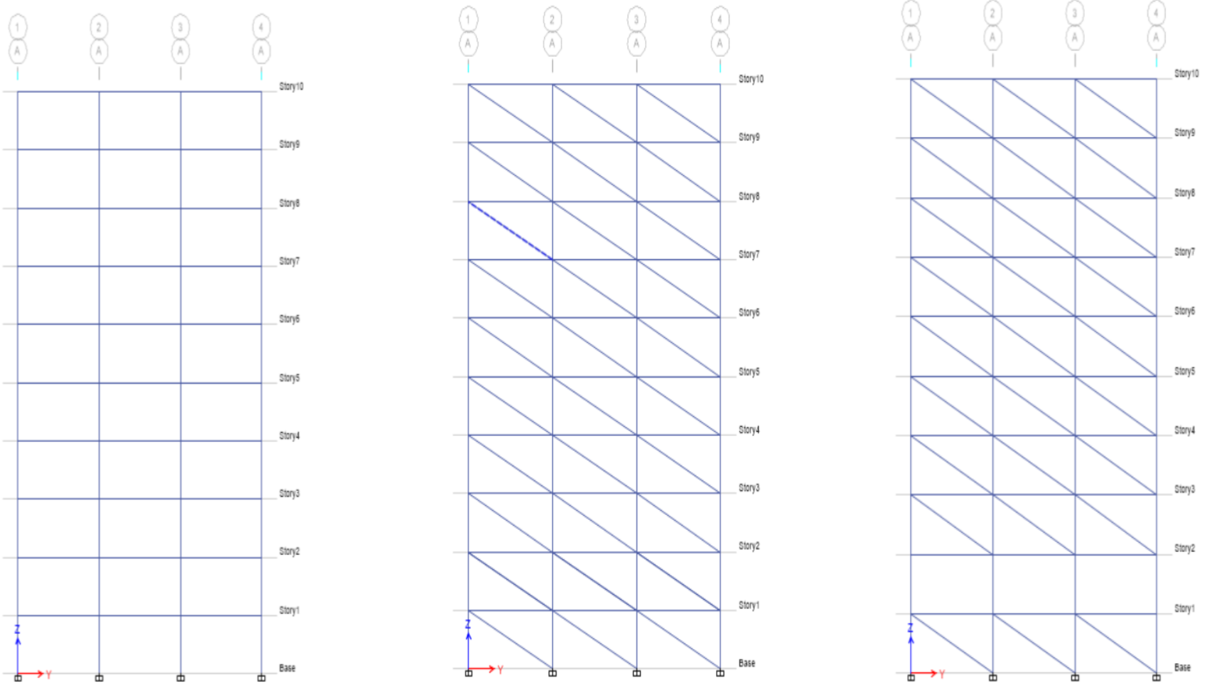
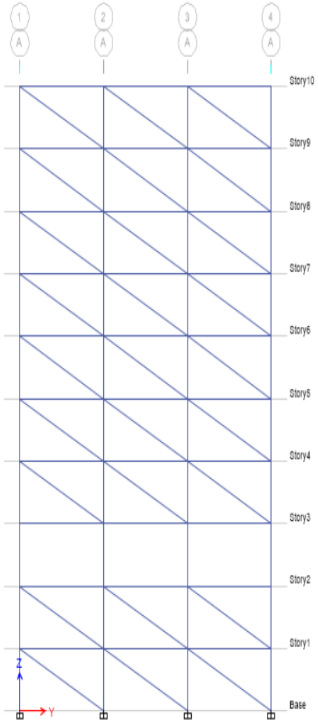


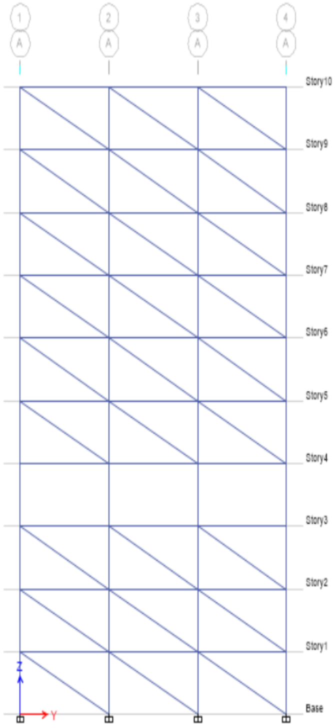
Fig 3. Plan and 3D view of Building Model



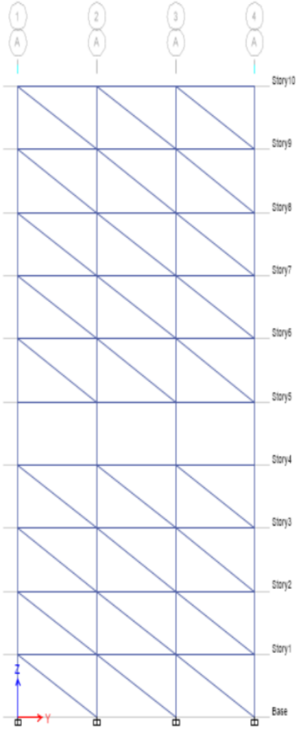
(a) (b) (c)


1
2
3
4
A
Story10
Story9
Story8
Story7
Story6
Story5
Story4
Story3
Story2
Story1
Base
Z
Y

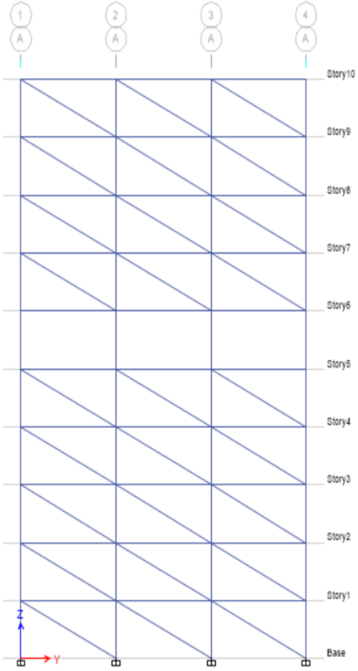
(d)


1
2
3
4
A
Story10
Story9
Story8
Story7
Story6
Story5
Story4
Story3
Story2
Story1
Base
Z
Y

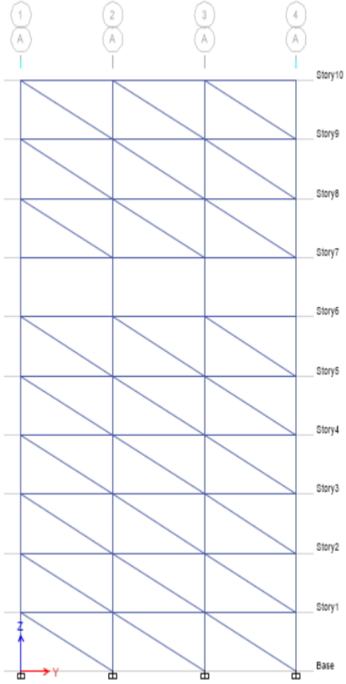
(e)


1
2
3
4
A
Story10
Story9
Story8
Story7
Story6
Story5
Story4
Story3
Story2
Story1
Base
Z
Y

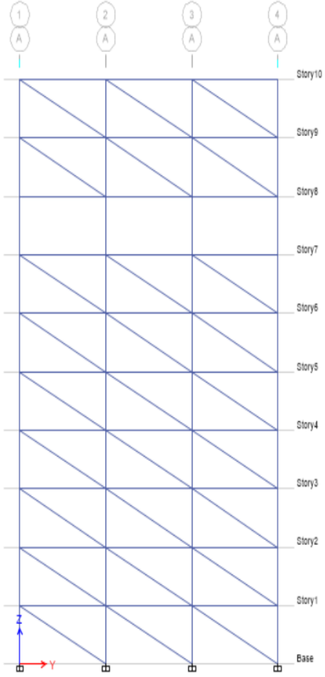
(f)


1
2
3
4
A
Story10
Story9
Story8
Story7
Story6
Story5
Story4
Story3
Story2
Story1
Base
Z
Y

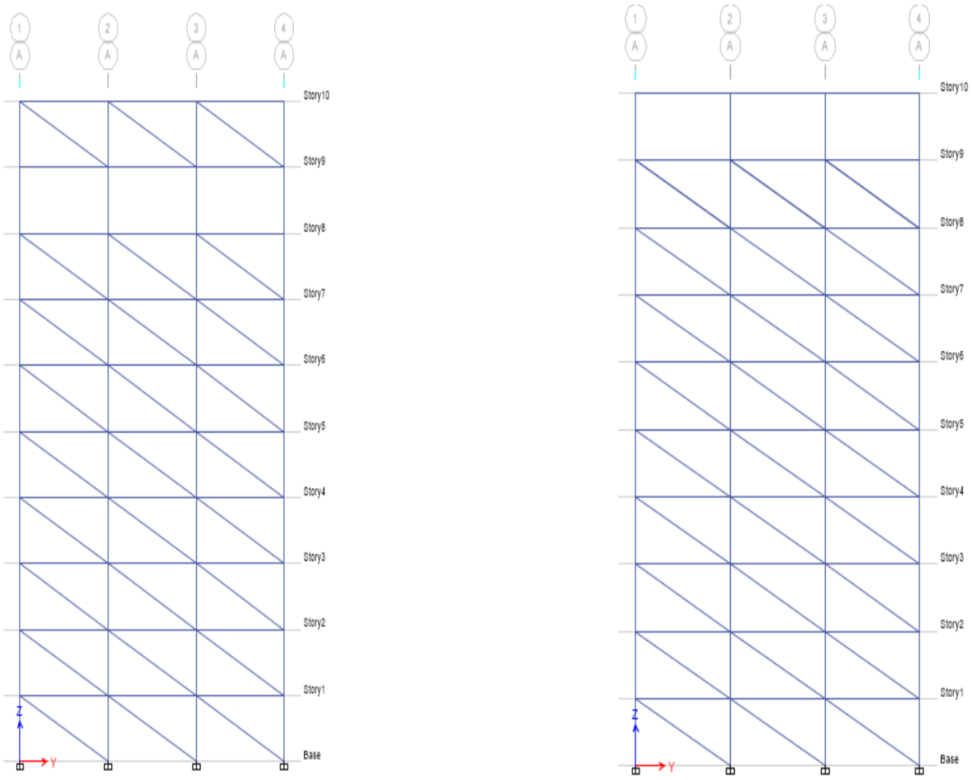
(g)


1
2
3
4
A
Story10
Story9
Story8
Story7
Story6
Story5
Story4
Story3
Story2
Story1
Base
Z
Y

(h)


1
2
3
4
A
Story10
Story9
Story8
Story7
Story6
Story5
Story4
Story3
Story2
Story1
Base
Z
Y

(i)



(j) (k)

Fig. 4: Elevation view for soft storey at different floor level

Table 1: Material Properties

Name	Type	Modulus of Elasticity (E), MPa	Unit Weight (KN/m^3)
M20	Concrete	22360.68	24.9926
M25	Concrete	25000	24.9926
Fe500	Rebar	200000	76.9729

Table 2: Section Properties

Members	Dimensions
Column	600×600 mm
Beam (Width × Height)	400×500 mm
Slab	Thickness=150mm

Table 3: Building Description

Storey	G+9
Typical Storey Height	3m
Bottom Storey Height	3m
Plan Dimension	18m×18m
Infill Wall Size	230mm
Grade of Concrete	M25
Grade of Steel	Fe500
Live Load	3KN/m^2(Typical Shell Load) 1.5KN/m^2(Terrace Shell Load)
Earthquake Data	Seismic Zone: V Response Reduction Factor: 5 Importance factor: 1 Soil: Type II

Calculation for Width of Equivalent Diagonal Strut for Infill Modelling:

The equivalent diagonal strut approach is used for the analysis and design of infilled frames subjected to in-plane forces. Currently, the single strut model suggested by IS1893:2016, is used in the equivalent static analysis of infilled RC frames.

Table 4: Calculation of Equivalent Diagonal Strut's width

S.N.	Parameters	Value
1	Thickness of Infill	230mm
2	Depth of Beam	500mm
3	Width of Beam	400mm
4	Depth of Column	600mm
5	Width of Column	600mm
6	Height of Infill	2500mm
7	Length of Infill	4400mm
8	Compressive Strength of Brick	5.5N/mm^2
9	Compressive Strength of Mortar	7.5N/mm^2
10	Modulus of Elasticity of RC Frame	25000N/mm^2
11	Width of Equivalent Diagonal Strut	660mm

V. RESULTS AND DISCUSSIONS

The behavior of masonry infill frames with varying soft storey level under lateral forces using macro model method is studied. Significance and effect of various parameters are studied. Seismic analysis is carried as per IS 1893 (Part 1):2016 guidelines. Basic seismic parameters story displacement, inter-story drift and storey stiffness of each irregular frame is compared with regular frame and bare frame. Nine different irregular model having open storey from ground floor to eighth floor having same story height, same bay width and regular distribution of mass, one regular frame (infill wall in all story level) and one bare frame (without infill wall) are modelled in ETABS and results obtained are as follows:

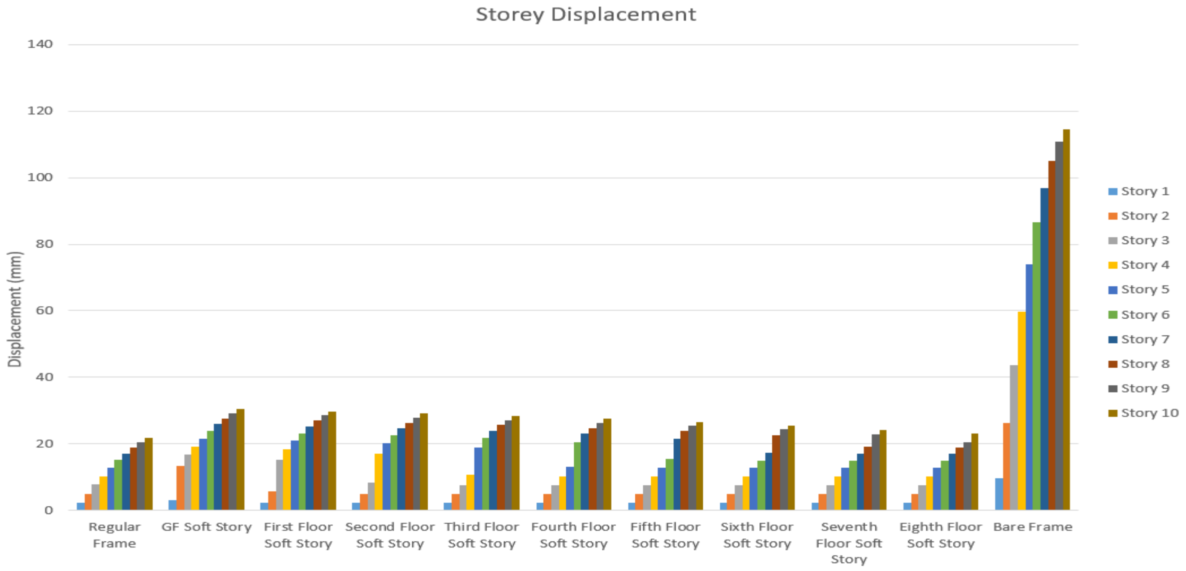


Fig. 5: Storey Displacement Comparison

1) Storey Displacement:

In this analysis, as shown in figure 5. Overall storey displacement is highest in bare frame building model and least in regular frame. After bare frame model displacement is high when irregularity in ground story. The overall displacement significantly decreases when the irregularity moves upward. The maximum lateral displacement of the building when the irregularity in Ground floor, first floor, second floor, third floor, fourth-floor, fifth-floor, sixth-floor, seventh-floor and Eighth-floor are increased by 39.92%, 37.3%, 34.14%, 30.6%, 26.72%, 22.37%, 17.46%, 11.95% and 6.88% respectively. While in bare frame model overall storey displacement is increased by 427.88% with reference to the displacement of regular frame building. That shows the building's story level demand is highly influenced by the soft story under seismic excitation.

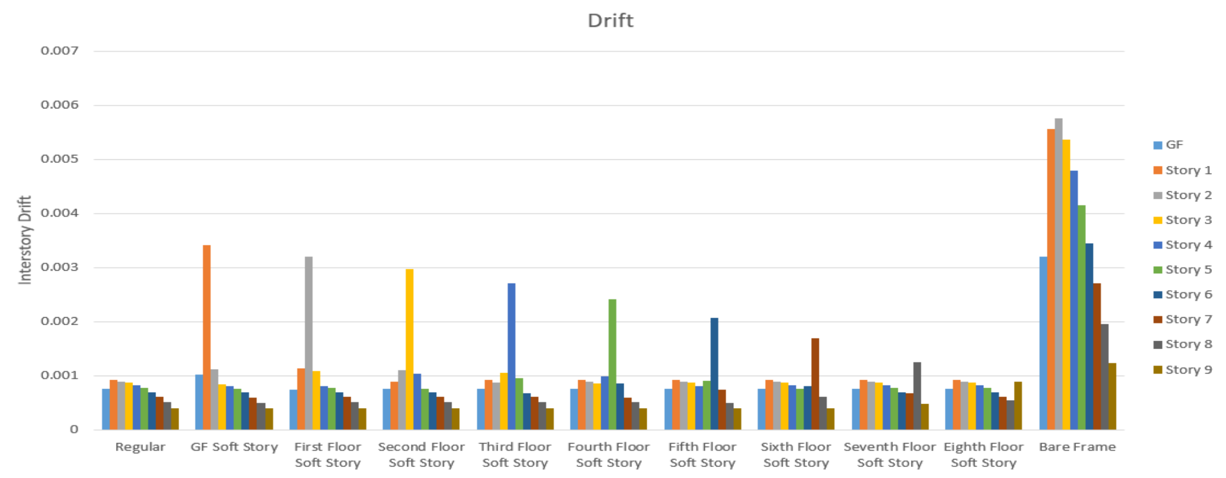


Fig. 6: Storey Drift Comparison

2) Storey Drift

The storey drift in the structure due to the seismic effect for soft storey at different floor is decreasing floor wise. That means when irregularity is in Ground floor, drift is maximum and it decreases when the irregularity moves upward. As per Indian standard, Criteria for earthquake resistant design of structures, IS 1893(Part 1): 2016, the storey drift in any story shall not exceed 0.004 times storey height. In current analysis, all the storey drift satisfy the storey drift limitation as per IS code. It can be observed from the analysis that the location of irregularity has major contribution on the abrupt increase in the story drift of that particular story. From the result it is found that the irregularity in Ground floor yields highest inter-story drift of that particular storey. When ith story is irregular, the inter-story drift of that particular ith story is abruptly increases than that of regular frame.

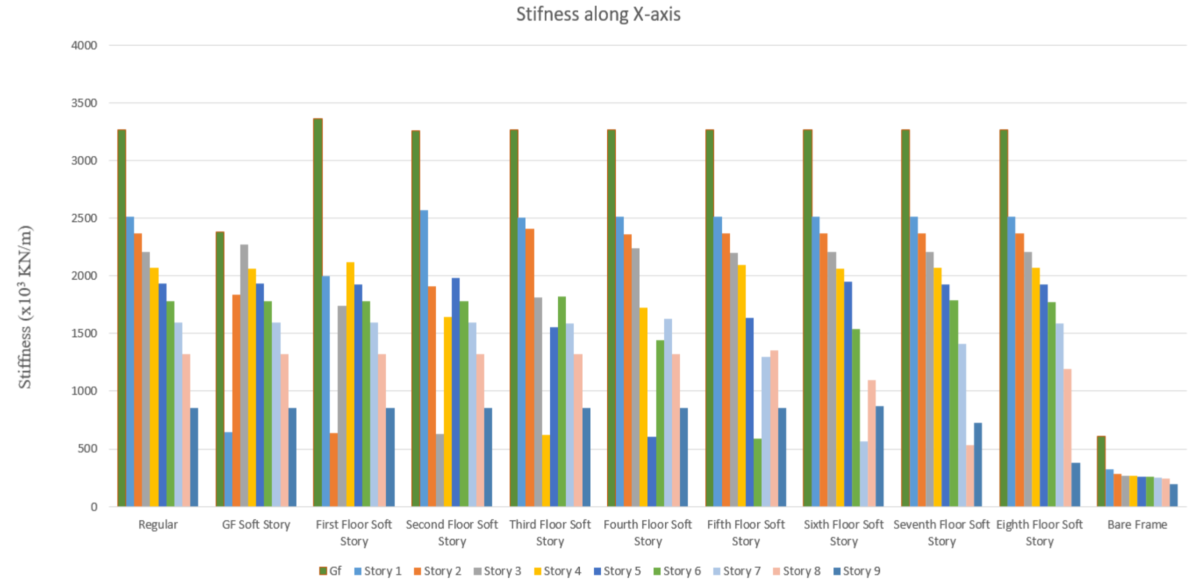


Fig. 7: Storey Stiffness Comparison

3) Storey Stiffness:

It is observed from the analysis result that the Storey Stiffness is gradually decreases with floor upward in regular frame. While irregularity in particular storey stiffness in that storey is abruptly decreases. Irregularity in particular floor also affects the stiffness of the floor above it. From the result it is found that the stiffness increases two storey above the irregular storey and starts decreasing gradually in above storeys.

VI. CONCLUSION

The conclusions made from this study are listed as follows;
a) Presence of infill wall in the RC frames increases the lateral stiffness of the building which reduces the overall storey displacement.
b) Irregularity in the bottom portion of the building particularly in the ground and initial story increased top storey displacement considerably, whereas the soft storey in the upper storey has less impact on the overall storey displacement of the building. In the bare frame model, overall storey displacement is highest as compared to the entire irregular and regular frame building model.
c) Storey level seismic demand of the building in the irregular case particularly once the irregularity is in Ground Floor and story the demand of the story is shortly increased. Thus it's terminated that the location of the stiffness irregularity i.e. soft bottom story is crucial towards the seismic excitation. Thus special issues ought to incline while dealing with the soft story in the bottom a part of the RC frames, particularly in a ground story.
d) From the analytical study, it is observed that the structural capacity decreases with introducing the soft storey effect at ground floor level which looks more vulnerable than the soft storey effect in the upper storey.
e) Finally in the light of the 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 a bottom story than upper story, so the special consideration should be taken while treating the effect of irregular RC frames.

Conflict of interest
There is no conflict to disclose.

REFERENCES

[1] Bourahla,N.,(2014) "Equivalent Static Analysis of Structures Subjected to Seismic Actions" Encyclopedia of Earthquake Engineering (pp.1-13)
[2] Bilham, R., et al. (2001) "Himalayan Seismic Hazard", Department of Geological Science and the cooperative Institute of Research in environmental Sciences, University of Colorado.
[3] Chandler, A., and Lam, N., (2001). "Performance-based design in earthquake engineering: a multi-disciplinary review." Engineering Structures 23: 1525-1543.
[4] Design Catalogue for Reconstruction of Earthquake Resistant Houses, Department of Urban Development and Building Construction.
[5] Furtado, A., et al. (2014). "Evaluation of different strengthening techniques' efficiency for a soft storey building." European Journal of Environmental and Civil Engineering, 21:4, 371-388.
[6] Ghobarah, A., and Said, A., (2002). "Shear strengthening of beam-column joints." Engineering Structures 24(7): 881-888.
[7] Hirde, S., and Tepugade, G. (2014). "Seismic Performance of Multistorey Building with Soft Storey at Different Level with RC Shear Wall." International Journal of Current Engineering and Technology, Vol.4, No.3, pp2019-2023.
[8] IS 1893 (Part I): 2016, 6th Revision, Criteria for Earthquake ResistantDesign of Structures; Bureau of Indian Standards, New Delhi, India
[9] Kanitkar, R., and Kanitkar, V., (2004), "Seismic performance of conventional multi- story building with open ground floors for vehicular parking". The Indian Concrete Journal, pp 99-1
[10] Khan, G., and Vyawahare, M., (2013), "Push Over Analysis of Tall Building with Soft Stories at Different Levels". International Journal of Engineering Research and Applications (IJERA), Vol. 3, Issue 4, pp.176-185.
[11] Lee, S., and Ko, D., (2007). "Seismic response characteristics of high-rise RC wall buildings having different irregularities in lower stories." Engineering Structures 29(11): 3149- 3167.
[12] Malla, S., et al. (2019) "Seismic Performance of High-Rise Condominium Building during the 2015 Gorkha Earthquake Sequence." Multidisciplinary Digital Publishing Institute, Vol. 9, Issue 2, pp 30-36.
[13] Repapis, C., et al. (2006). "Evaluation of the seismic performance of existing RC buildings: II. A case study for regular and irregular buildings." Journal of Earthquake Engineering 10(3): 429-452.
[14] Setia, S., and Sharma, V., (2012) "Seismic Response of R.C.C Building with Soft Storey." International Journal of Applied Engineering Research, ISSN 0973-4562 Vol.7 No.11
[15] Singh, S., and Babulal, V., (2015). "Seismic Response of Soft Storey on High Rise Building Frame." International Journal of Engineering Technology and Computer Research. 3. 41-48.

1Samundra Pokhrel. "Seismic Performance Evaluation of RC Framed Building with Soft Storey." *International Journal of Engineering and Science*, vol. 11, no. 9, 2021, pp. 24-32.