Impact of Soft Storey on Seismic Performance of RC Structures

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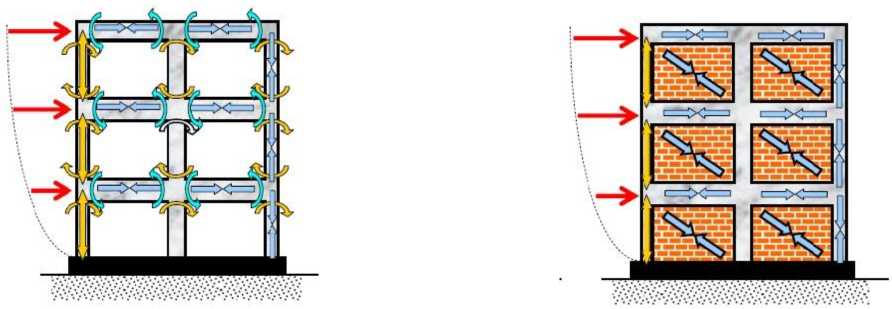
Abstract - *Main objective of present study is to study the relative performance of analysis of bare frames, stilt frames and infill frames with given loading conditions. Along with the lateral stiffness and lateral strength of the infill walls, the more realistic seismic assessment of the stilt building requires amount ductility required. The Present study deals with different kinds of aspects related to the performance of stilt framed buildings. In this study, two frames i.e. frame-A and frame-B are considered. Both frames are designed as bare frame, stilt frame and infill frame. All the frames are designed as per IS:456-2000 and IS-13920-1993. Moreover, these frames are further analyzed for different loading cases based upon IS:1893-2002. First of all the frames are designed and analyzed for gravity loading with design case as GRAV. Further, these frames are designed for earthquake zone III, IV and V namely, EQ3, EQ4, EQ5 respectively. In addition to this, the stilt frames of frame-A and frame-B are further designed for EQ3 and analyzed with the provisions that the ground storey columns have been designed for 2.5 times the bending moment, shear force, and axial force values coming from bare frame analysis i.e. design case as EQC3. Moreover, the stilt frames of frame-A and frame-B are further designed for EQ3 and analyzed with the provisions that the ground storey columns and beams have been designed for 2.5 times the bending moment, shear force, and axial force values coming from bare frame analysis i.e. design case as EQCB3. It was observed that Strength and stiffness deficit in ground storey caused by absence of infills is more prominent if ground storey height is more. Deformation capacity in most of the seismic design cases due to ductile detailing is considerably increased. Moreover, in frame-A, strength and stiffness deficit is compensated if ground storey columns are designed for 2.5 times forces; while in frame-B, strength and stiffness deficit is compensated if ground storey columns and beams, both are designed for 2.5 times forces.*

Key Words: Soft Storey, Dynamic Analysis, Stiffness, Stilt Frame

1. INTRODUCTION

The reinforced concrete (RC) moment resisting frames are becoming progressively common as compared to structural steel frames in developing countries like India due to low cost of material and labours. In order to divide the inside space according to the functional requirements, the vertical spaces formed by adjoining RC beams and columns are filled by masonry walls. Moreover, these masonry walls are used to protect the inside of structure from rain, wind, snow, etc. Generally, in India burnt clay bricks with cement mortar are used as unreinforced masonry work. Usually, the thickness of infill wall varies from 230 mm to 250 mm. To divide the interior space of the building in Urban India, use of half brick thick (~115 mm) walls is quite common. Due to which, their stiffness and strengths are neglected in the design and analysis of structures. However, their mass is taken into account for calculations of load. Moreover, it is also considered that the Infills alter the building behavior from predominant frame action [Fig. 1 (a)] to predominant truss action [Fig. 1 (b)].



(a) Bare Frame: Predominant Frame Action (b) Infilled Frame: Predominant Truss Action

Fig. 1: Structural Behavior of Bare Frame and Infilled Frame (Murty et al., 2002)

1.1 Stilt Buildings

Due to the increase in population especially in the developing countries like India, need of space plays a very vital role in day-to-day life. This need of space leads to the small size of plots and high cost of land. To remove these limitations, the ground floor area may be used in the form of parking in the various high-rise structures. The upper floor in these types of structures contains the infill walls but the area of ground floor does not contain any partition wall arrangement. Such kind of structures are mainly referred as "stilt buildings" / "buildings on stilts" / "open ground storey buildings (OGSB)" / "soft storey buildings" [Fig. 2].

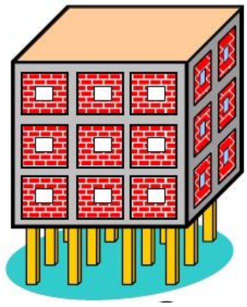


Fig. 2: Soft Storey Building [Murty (2004)]

2. RESEARCH OBJECTIVES

Eventually, the present study is an attempt to identify the strength and stiffness of the numerous RC buildings and explore the suitability of the stilt frames under seismic behavior, when designed for different loading conditions. In addition to this, this study covers the following aspects:

- To determine the most significant frame out of the considered frames like 'bare frames', 'infill frames' and 'stilt frames'.
- To evaluate the impact on strength, lateral stiffness and the capacity of deformation due to infills present.
- To evaluate the effect on stilts when ground storey columns are designed for 2.5 times bending moment, shear forces and axial forces.
- To evaluate the effect on stilts when ground storey columns and beams are designed for 2.5 times bending moment, shear forces and axial forces.
- To study the influence on the various properties of structures due to the slight variation of concrete grades during designing.

3. METHODOLOGY

3.1 DETAILS OF THE CONSIDERED FRAMES

In this study, two frames are considered in the form of typical high-rise structure having named as Frame-A an Frame-B. The frame-A consists of 3m high 4 storeys with panel dimensions of 4 m X 4 m [Fig. 3 (a)]. While, the frame-B consists of 6 storeys with panel dimensions of 3.5 m X 3.5 m. The height of the bottom storey is taken as 4.0 m while the upper storeys are 3.0 m high [Fig. 3 (b)].

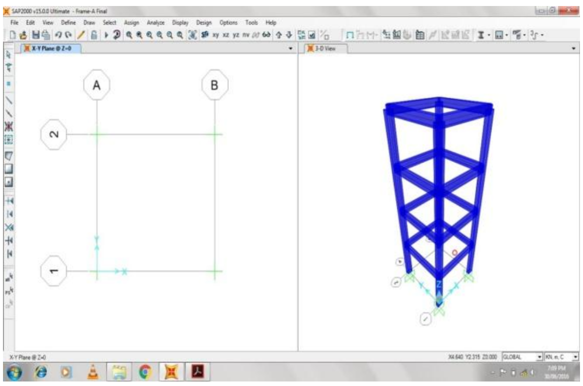


Fig. 3 (a): Frame-A

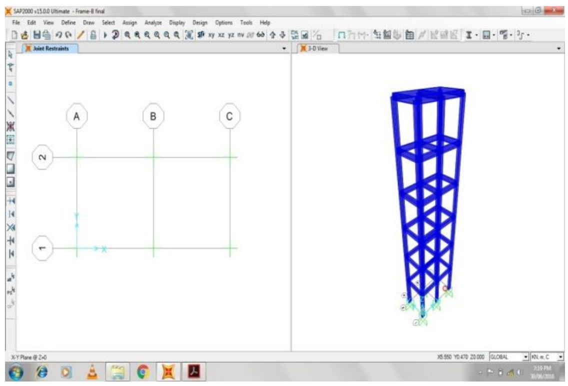


Fig. 3 (b): Frame-B

The infill wall has 230 mm thickness along both the considered frames. Dead load of infills is considered to be in the form of udl over the beams over which these walls rest.. Self-weight of columns and beams are calculated from unit weight of concrete and their cross-sections areas. The vertical distribution of design value of base shear is considered on the basis of IS:1893-2002 and their values are given in Table 1 and 2.

Table 1: Value of Base Shear along Height of Frame-A

Floor	Earthquake Force (kN)		
	Zone III	Zone IV	Zone V
Fourth	30.5	45.8	68.7
Third	19.84	29.76	44.64
Second	8.83	13.24	19.85
First	2.22	3.33	5
V_B	**61.39**	**92.13**	**138.19**

Table 2: Value of Base Shear along Height of Frame-B

Floor	Earthquake Force (kN)		
	Zone III	Zone IV	Zone V
Sixth	46.41	92.81	141.53
Fifth	30.64	61.28	93.45
Fourth	19.61	39.25	59.81
Third	11.03	20.06	36.64
Second	4.91	9.81	14.96
First	1.23	2.46	3.74
V_B	**113.83**	**225.67**	**350.13**

3.2 Design Cases

The design of both the frames is done as per IS:456-2000 limit state procedures. The design of both the frames is considered against gravity loadings on the basis of IS: 456 – 2000. However, the structural detailing is based on IS: 13920 - 1993 against seismic loading considered.

GRAV: In this case, frames have been designed for only gravity loads (DL and IL), and no earthquake load has been considered. Therefore, it is analyzed for only one combination, i.e., 1.5(DL+IL) and detailed as per IS:456-2000.

EQ3: In this case, the frames have been designed forDL, IL, and EL for zone III. The design base shear is 61.39 kN and 113.83 kN for both the considered frames.

EQ4: In this case, the frames have been designed for DL, IL, and EL for zone IV. The design base shear is 92.13 kN and 225.67 kN for frame-A and frame-B, respectively.

EQ5: the frames have been designed forDL, IL, and EL for zone V. The design base shear is 138.19 kN and 350.13 kN for frame-A and frame-B, respectively.

EQC3: These frames are designed for zone III. Further, the ground storey columns of stilt frame have been designed for 2.5 times the bending moment, shear force, and axial force values coming from bare frame analysis.

EQCB3: These frames are designed for zone III. Following the IS:1893-2002 provisions for stilt buildings, the ground storey columns and first floor beams are designed for 2.5 times the bending moment, shear force, and axial force values coming from bare frame analysis. Detailing is done as per IS:13920-1993.

4. RESULT AND DISCUSSION

The behavior of 4-storey frame-A and 6-storey frame-B are generally different in all the design cases. The ground storey height of frame-B is 4.0 m whereas height of all upper storeys is 3.0 m. Therefore, ground storey of frame-B is flexible compare to the upper stories, as column size is same in all stories while for frame-A, each storey is 3.0m high. On analyzing the frame-A and frame-B, the values of lateral strength, roof displacement / storey drift, initial lateral stiffness and ductility for both the frames are calculated in terms of percentage of their seismic weight and height and tabulated in the tables. Column over-strength factor (COF) is defined as the ratio of flexible strength of column and minimum (out of sagging and hogging) flexural strength of beam. Column over-strength factor of both frames are given in Table 7, where M_{yc} and M_{yb} are yield moments of column and beam respectively. Over-strength factor is calculated as ratio of maximum strength to design base shear (when designed for earthquake load also), and values are tabulated in Table 8. In addition, the lateral stiffness of ground storey for both frames is also calculated and is given in table 9.

Table 3: Lateral Strength of Both the Considered Frames

Design Case	Frame-A			Frame-B		
	Bare	Stilt	Infill	Bare	Stilt	Infill
GRAV	6.9	15.2	21.3	9.1	14.9	49
EQ3	10.7	19	24.3	14	18.4	51.9
EQ4	15.3	22.7	27.9	16.9	18.7	53.2
EQ5	36.1	37.5	42.7	35.2	35.5	68.7
EQC3	-	34.1	-	-	40.9	-
EQCB3	-	37.4	-	-	51.9	-

Table 4: Roof Displacement / Storey Drift of Both the Considered Frames

Design Case	Frame-A			Frame-B		
	Bare	Stilt	Infill	Bare	Stilt	Infill
GRAV	1.73	0.95	1.05	1.16	0.64	0.67
EQ3	3.38	2.09	2.1	1.96	1.47	1.12
EQ4	2.88	1.99	1.99	1.33	1.45	1.11
EQ5	2.79	2.07	2.07	1.36	1.05	1.25
EQC3	-	2.45	-	-	1.03	-
EQCB3	-	2.24	-	-	0.96	-

Table 5: Initial Lateral Stiffness of Both the Considered Frames

Design Case	Frame-A			Frame-B		
	Bare	Stilt	Infill	Bare	Stilt	Infill
GRAV	5.2	21.5	41.6	3.5	9.6	27.2
EQ3	8.1	28.5	45	4.8	12.3	30.9
EQ4	11.1	30.6	47.6	6.7	14.5	32.5
EQ5	19.1	41.7	54.8	13.2	23.9	40.2
EQC3	-	49.9	-	-	22.8	-
EQCB3	-	55.6	-	-	22.9	-

Table 6: Ductility of Both the Considered Frames

Design Case	Frame-A			Frame-B		
	Bare	Stilt	Infill	Bare	Stilt	Infill
GRAV	4.9	5.1	7.9	4.8	4.4	4
EQ3	9.7	11.7	14.6	8.8	10.6	7.3
EQ4	9	15.7	19.8	5.7	12.1	7.3
EQ5	5.5	8.6	10	5.5	7.6	7.9
EQC3	-	13.2	-	-	6.2	-
EQCB3	-	12.5	-	-	4.6	-

Table 7: Column Over-strength Factor of Both the Considered Frames

Design Case	Frame-A			Frame-B		
	Bare	Stilt	Infill	Bare	Stilt	Infill
GRAV	211	60	3	96	41	2.3
EQ3	269	104	2.7	102	79	1.3
EQ4	354	167	2.1	111	91	1.2
EQ5	594	511	1.2	231	275	0.8

Table 8: Over-strength Factor of Both the Considered Frames

Design Case	Frame-A			Frame-B		
	Bare	Stilt	Infill	Bare	Stilt	Infill
GRAV	-	-	-	-	-	-
EQ3	4.3	7.6	9.7	5.6	7.4	20.8
EQ4	3.8	9.7	7	4.2	4.7	13.3
EQ5	4	5.6	4.7	3.9	3.9	7.6

Table 9: Lateral Stiffness of Ground Storey of Both the Considered Frames

Design Case	Frame-A			Frame-B		
	Bare	Stilt	Infill	Bare	Stilt	Infill
GRAV	32	39	149	13	14	139
EQ3	53	65	172	18	19	147
EQ4	66	77	182	23	24	152
EQ5	106	119	222	46	48	178

OVERALL OBSERVATIONS AND CONCLUSION

Following salient points have been observed after studying all the frames:

1. The strength increment due to infills in stilt frames-A is about 8%W in all design cases except in EQ5, in which it is 1.5%W.
2. The strength increment due to infills in infill frames-A is about 14%W in all design cases except in EQ5, in which it is 6.6%W.
3. Strength increment in stilt and infill frames as compared to bare frames are up to 120% and 440% respectively.

4. Strength of stilt frame is 1.0-2.2 times the corresponding bare frames. Whereas strength of infill frames is 1.2 - 5.4 times the respective bare frames.
5. Contribution of infill frames in total strength of frames decreases in frames designed for higher seismic zones.
6. Strength reduction due to absence of infills in ground storey in stilt frame is 12-70%.
7. Strength of stilt frames-B is nearly equal to corresponding bare frames strength. However, strength increment in stilt frames-A as compared to bare frame is significant.
8. Overstrength factor of both the bare frames in all seismic design cases is found to be about four. Whereas it is 3.9-7.6 for stilt frames and 4.7-20.8 for infill frames.
9. Deformation capacity increases up to 100% owing to the ductile detailing.
10. Deformation capacity deceases considerably in most of the frames due to infill and reduction is up to 45%.
11. Yielding initiates in the ground storey columns of stilt frames at a very low deformation level as compared to bare and infill frames.
12. Both the stilt frames in all design cases collapse due to failure of ground storey columns.
13. In stilt frames, the ground storey displacement at collapse is more than 40% of the roof displacement in frame-A. However, it is more than 80% in frame-B.
14. Stiffness of stilt frames is 1.8-4.1 times the relative bare frames. Whereas stiffness of infill frames is 2.9-7.9 times the relative bare frames.
15. Ductility is increased in most of the frames due to infills. However, decrease was noted in few frames.
16. Seismic performance of stilt frames significantly improved in terms of strength and stiffness if bottom storey components are designed for higher forces.
17. With the decrease in characteristic strength, the lateral strength of the both the frames decreases and vice-versa.
18. The variation of lateral strength for the frame- A when designed for case EQ5 and EQCB3 is found to be almost equal while in case of frame-B, variation in lateral strength is found to be equal when designed for case EQ3 and EQ4.

REFERENCES

[1] Adalier, K., and Aydingun, O., (2001), "Structural Engineering Aspects of June27, 1998 (Adan-Ceyhan (Turkey) Earthquake", Engineering Structures, Vol. 23, pp 343-355.

[2] Al-Ali, A.A.K. and Krawinker, H., (1997), "Effects of vertical irregularities on seismic behavior of building structures", Rep. No. 130, John A. Blume Earthquake Engineering Centre, Stanford Univ., Stanford, California, 98.

[3] Al-Chaar, G., Issa, (2002), "Evaluating strength and stiffness of Unreinforced Masonry Structures", US Army Corps of Engineers, Engineer research and Development Centre, Vicksburg.

[4] AIJ, 1995, "Preliminary Reconnaissance Report of the 1995 Hyogoken-Nanbu Earthquake, Architectural Institute of Japan, Tokyo, Japan.

[5] ATC 40, (1996), "Seismic Evaluation and Retrofit of Concrete Buildings", Applied Technology Council, California.

[6] Balendra, T., Tan, K. H., and Kong, S.K., (1999), "Vulnerability of Reinforced of Concrete Frames in Low Seismic Regions When Designed according to BS 8110", Earthquake Engineering and Structural Dynamics, Vol. 109, No. 6, pp 1337-1361.

[7] Das, D., (2000), "Beneficial Effects of Brick Masonry Infills in Seismic Design of RC Frame Buildings", M.Tech Thesis, Department of Civil Engineering, IITK.

[8] Dasgupta, P., (2000), "Effects of Confinement on strength and Ductility of Large RC Hollow Sections", M.Tech Thesis, Department of Civil Engineering, IITK.

[9] Dande, P. S., Kodag P. B., (2013), "Influence of Provision of Soft Storey in RC Frame Building for Earthquake Resistance Design", International Journal of Engineering Research and Applications, Vol. 3, No. 2, pp 461-468.

[10] Dayaratnam, P., (1987), "Brick and Reinforced Brick Structures", Oxford and IBH Publishing Corporation Private Limited, India.

[11] Drysdale, R.G., Hamid, A. A., and Baker, A. L., (1993), "Masonry Structures-Behavior and Design", Prentice Hall Incorporation, New Jersey.

[12] IS:456-2000, (2000), "Indian Standard Code of Practice for Plain and Reinforced Concrete", Bureau of Indian Standards, New Delhi.

[13] IS:1893-2002 (Part-I), (2002), "Indian Standard Criteria for Earthquake Resistant Design of Structures", Bureau of Indian Standards, New Delhi.

[14] IS:13920-1993, (1993), "Indian Standard Code of Practice for Ductile Detailing of Reinforced Structures Subjected to Seismic Forces", Bureau of Indian Standards, New Delhi.

[15] IS:1905-1987, (1987), "Indian Standard Code of Practice for Structural Use of Unreinforced Masonry", Bureau of Indian

Standards, New Delhi.

[16] Jain, S.K., and Murty C.V.R., (2004), "Proposed Draft Provisions and Commentary on Indian Seismic Code IS 1893 (Part 1)", Department of Civil Engineering, Indian Institute of Technology, Kanpur.

[17] Kanitkar, R., and Kanitkar, V., (2004), "Seismic Performance of Conventional Multistorey Buildings with Open Ground Floors for Vehicular Parking", The Indian Concrete Journal, Vol. 78, No. 2, pp 99-104.

[18] Kumar, S., (2002), "A study on Modeling of Unreinforced Masonry Infilled RC frames for Seismic Reponse", M.Tech Thesis, Department of Civil Engineering, Indian Institute of Technology, Kanpur.

[19] Lee, H.S., and Woo, S.W., (2002), "Effects of Masonry Infill on Seismic Performance of a 3-Storey R/C Frame with Non-Seismic Detailing", Earthquake Engineering and Structural Dynamics, Vol. 31, pp 353-357.

[20] Lu, Y., (2002), "Comparative Study of Seismic Behaviour of Multistory Reinforced Concrete Framed Structures", Journal of Structural Engineering, ASCE, Vol. 128, No. 2, pp 168-178.

[21] Jain S.K., Lettis, V.C., Murty, C.V.R., and Bardet, J.P., (2002) "Earthquake Spectra Supplement A to volume 18", Oakland, CA: Earthquake Engineering Research institute, July 2002, pp. 149-185.

[22] Mondal, G., (2003), "Lateral Stiffness of Unreinforced Brick Infilled RC Frame with Central Opening", M.tech Thesis, Department of Civil Engineering, Indian Institute of Technology, Kanpur.

[23] Munde, P. K., Magarpatil H.R., (2012), "Seismic Response of RC Framed Masonry Infilled Buildings with Soft First Storey", International Journal of Engineering Research & Technology, Vol. 1, No. 9, pp 01-07.

[24] Murty C.V.R., (2004), "IITK-BMTPC Earthquake Tip 21" Department of Civil Engineering, IITK.

[25] Murty C.V.R., Goel, R.K., and Goyal, A., (2002), "Reinforced Concrete Structures", In 2001 Bhuj, India Earthquake Reconnaissance Report, ed.

[26] Nagare, K. P., Bhakskar, G., and Nair, V. (2015), "Seismic Response of RC Frame Building with First Soft Storey", International Research Journal of Engineering and Technology, Vol. 2, No. 04, pp 1762-1779.

[27] Ono, T., Zhao, Y.G., and Ito, T., (2000), "Probabilistic Evaluation of Column overdesign Factors for Frames", Journal of Structural Engineering, ASCE, Vol. 126, No. 5, pp 605-610.

[28] Rai D.C., (2004), "Proposed Draft for Structural Use of Masonry IS 1905", Department of Civil Engineering, Indian Institute of Technology, Kanpur.

[29] Razvi, S., and Saatcioglu, M., (1999), "Confinement Model for High Strength Concrete", Journal of Structural Engineering, ASCE, Vol. 125, No. 3, pp 281-289.