Inclusion of Stiffness of Masonry Infills in Seismic Analysis and Design of Pilotis Buildings: Comparison of Provisions in the Indian Code

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Abstract - *Pilotis buildings or Open Ground Storey buildings are known to be vulnerable to seismic loading due to early formation of collapse mechanism in the ground storey RC columns. The present Indian code of IS:1893-2002 prescribes two approaches for analysis and design of such structures: (1) Model the structure as bare frame, run the analysis and apply a magnification factor of 2.5 for beams and columns of ground storey (or soft storey), or(2) Include stiffness of the masonry infill in the model, run the analysis and design for the forces as obtained by analysis. The stiffness of the masonry infills are represented by diagonal struts in the model. This paper investigates and compares the design results obtained by approaches (1) and (2) and deduce which is more economical. For this study, the RC framed building with brick masonry infill are designed, in accordance with the provisions of the IS code.*

Key Words: *Masonry infill, RC frames, open ground storey, soft storey, diagonal strut, IS:1893-2002.*

1.INTRODUCTION

As the availability of land is not able to meet the demand of the growing population, the necessity of using the ground floor as parking space is very high. Hence there is a trend of utilising ground storey of the building itself for parking. These types of buildings with no infill masonry walls in ground storey, but infilled in all upper storeys, are called Pilotis buildings. They are also known as 'open ground storey building'(OGS), or 'stilted buildings'.

Functionally, it is advantageous but when considering the seismic response, such buildings have increased vulnerability. From the history of earthquakes it was evident that the major type of failure that occurred in Pilotis buildings included breaking of lateral ties, buckling of longitudinal reinforcement bars, crushing of core concrete etc of the open ground storey. The upper storeys are much stiffer than the open ground storey due to the stiffness of infill walls. Thus, the upper storeys move almost together as a single unit, and most of the lateral displacement of the building occurs in the open ground storey itself. This type of buildings sway back and forth like an inverted pendulum as seismic response, and thus the ground storey columns and beams are heavily stressed. Hence, the ground storey

columns must have sufficient strength and ductility than the upper storeys.

The open ground storey framed buildings behave differently when compared to a bare framed building or fully infilled framed buildings under lateral load. A bare frame is less stiff than a fully infilled frame. It resists the lateral load through frame action and shows plastic hinges at failure. Where as in a fully infilled frame the lateral loads are resisted by truss action. A fully infilled frame shows less inter-storey drift with higher base shear. In fully infilled frame, less force dissipates through the frame elements than through infill walls. In conventional design practice, the stiffness and strength of infill walls are ignored in the structural modelling. This approach will be conservative only in the case of fully infilled framed building. OGS building is stiffer than the bare framed building and has larger drift in the ground storey and fails by soft storey-mechanism at the ground floor. Hence, it may be unconservative to ignore stiffness and stiffness of infill wall while designing Pilotis buildings.

An accurate method of analysing OGS buildings is by including the strength and stiffness of infill walls in the model. Unfortunately, there are no guidelines given in IS 1893: 2002 (Part-1) [10] for modelling the effect of infill walls. Nowadays, as an alternative to this, a bare frame analysis is generally used which ignores the effect of the infill walls. For such cases Clause 7.10.3(a) states: "The beams and columns of soft storey are to be designed for 2.5 times the storey moments and shears calculated under earthquake loads of bare frames." This magnification factor (MF) is required to be the compensation for the vertical stiffness discontinuity of the OGS buldings. The conservative nature of this empirical recommendation of IS code 1893-2002 was first pointed out by Kanitkar (2001)[9], and then followed by Subramanian (2004) and Kaushik (2006)[10].

1.1 NEED FOR THE PRESENT STUDY

As experienced by the structural engineers at design offices, the magnification factor of 2.5 given by IS 1893:2002, is not realistic for all buildings, since this factor is independent on no:of storeys, no: of bays, etc. This led to check the

applicability of the code recommended multiplication factor (MF) requiring an accurate analysis of OGS buildings including infill stiffness and strength. The presence of masonry infill walls in upper storeys alone creates following issues:

- Increases the base shear
- Decreases the natural time period of vibration
- Increases the lateral stiffness of the building frame
- Increases the ground storey shear forces and bending moments

There is a clear necessity to assess the design provisions recommended by the IS code 1893:2002 based on accurate analysis.

2 ANALYTICAL MODELLING

The building selected for this study is an eight storeyed hospital building. The building has overall dimension of 24m X 12m.The buliding description of each element is shown in Table-1, properties of concrete and brick is shown in Table-2 and Table-3 respectively. A typical floor plan showing the arrangements of beams and columns are shown in Figure 1.The analysis and design was done in STAAD.Pro V8i.
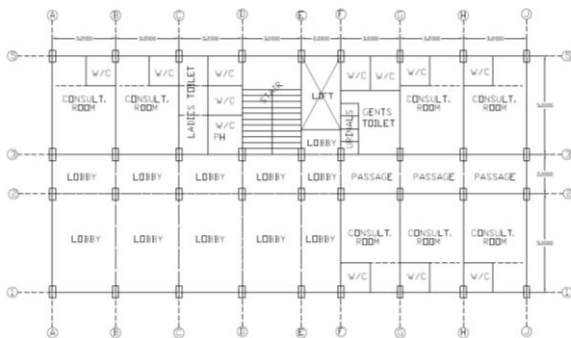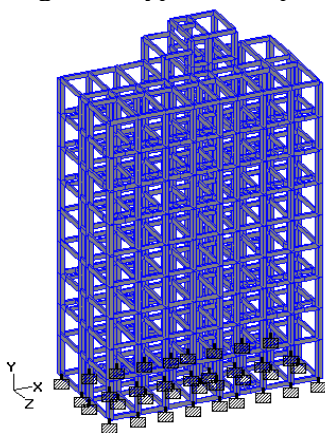

Figure 1: Typical floor plan

Figure 2: 3D view of the building with global directions

Table-1: Building Description

Elements	Dimensions
Slabs	100mm
Machine room slab	150mm
Beams along longitudinal direction	230mmX600mm
Beams along transverse direction	230mmX700mm
Secondary beams for W/C ,Toilets	230mmX400mm
Brick wall	230mm
Columns	800mm X 400 mm
Each Storey Height	3.6 m
Seismic Zone	III
Importance Factor	1.5
Structure Type	SMRF building
Soil Type	Medium

Table-2 : Properties of concrete

Property	Value
Grade of concrete	M25 (25N/mm^2)
Unit Weight of concrete	25kN/m^3
Young's Modulus	2.17185X10^7 kN/m^2
Poisson's ratio	0.17
Grade of Steel	Fe500D (500 N/mm^2)

Table-3 Properties of infill brick

Property	Value
Compressive strength	3.5 MPa
Density	20 kN/m^3
Young's Modulus	1.925X107kN/m^2
Poisson's ratio	0.17

2.1 OGS MODELS CONSIDERED FOR ANALYSIS

MODEL A
Case 1: (G+4) storey building with diagonal struts in upper floors but not ground floor,(Model A-1).
Case 2: (G+4) storey building with no diagonal struts (Bare framed Building),(Model A-2).

MODEL B
Case 1: (G+5) storey building with diagonal struts in upper floors but not ground floor,(Model B-1).
Case 2: (G+5) storey building with no diagonal struts (Bare framed Building),(Model B-2).
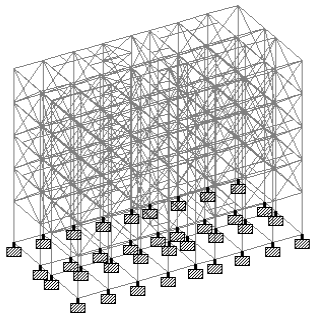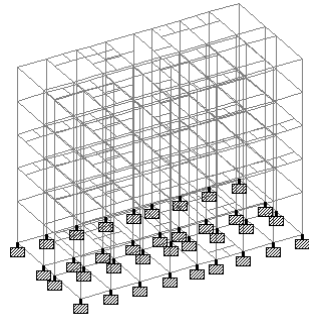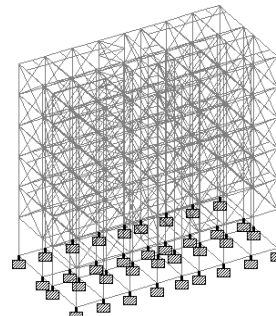
Figure 3: Model-A1

Figure 4: Model-A2

Figure 5: Model-B1
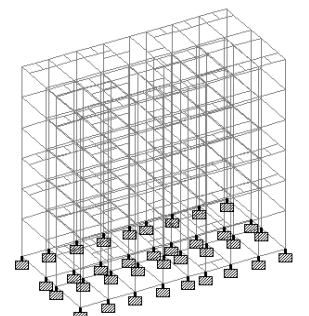
Figure 6: Model-B2
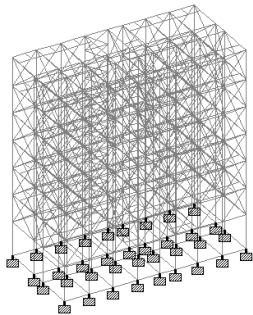
Figure 7: Model-C1
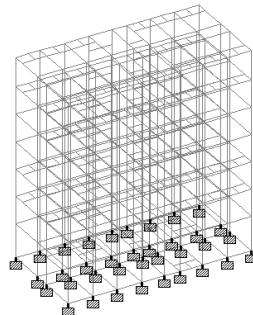
Figure 8: Model-C2
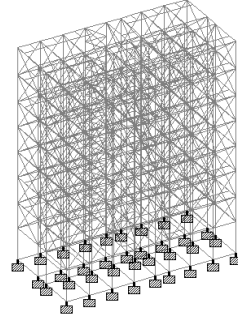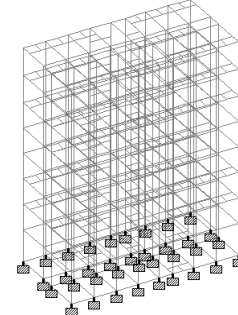

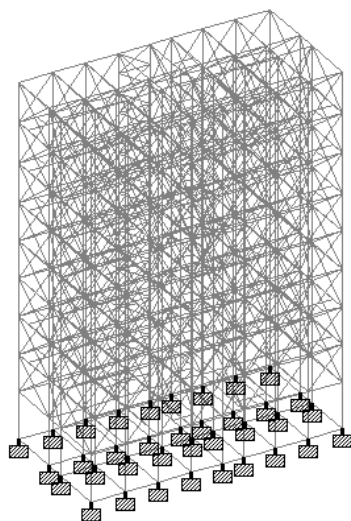**Figure 9:** Model-D1

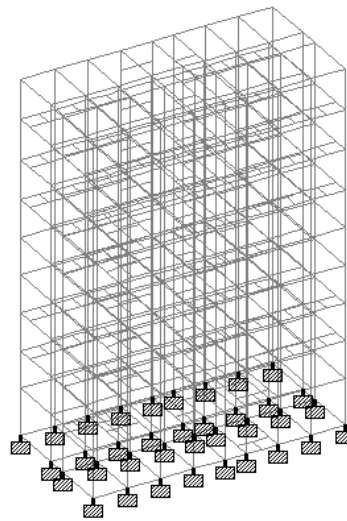**Figure 10:** Model-D2

Figure 11: Model-E1

Figure 12: Model-E2

MODEL C

Case 1: (G+6) storey building with diagonal struts in upper floors but not ground floor,(Model C-1).

Case 2: (G+6) storey building with no diagonal struts (Bare framed Building),(Model C-2).

MODEL D

Case 1: (G+7) storey building with diagonal struts in upper floors but not ground floor,(Model D1).

Case 2: (G+7) storey building with no diagonal struts (Bare framed Building),(Model D-2).

MODEL E

Case 1: (G+8) storey building with diagonal struts in upper floors but not ground floor,(Model E-1).

Case 2: (G+8) storey building with no diagonal struts (Bare framed Building),(Model E-2).

2.2 MODELING OF INFILL WALLS

Infill walls are modeled as truss elements. The thickness of the elements is taken same as that of the wall thickness from Clause 7.10.2.4 of [7]. The width of the element is taken as 1/3rd of its length from Clause 7.10.2.2 of [7], which is shown in Figure 13.
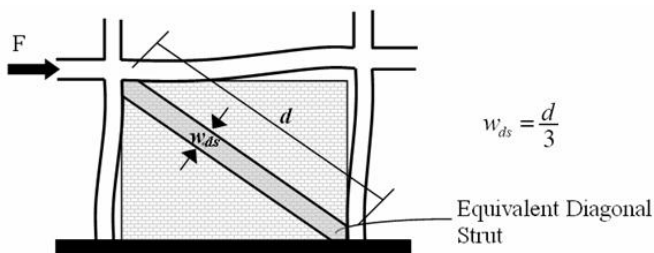

Figure 13 : Diagonal Strut Model

Table-4 : Diagonal Strut Dimensions

GROUND TO FIFTH FLOOR		
DIAGONAL LENGTH (m)	STRUT WIDTH(m)	STRUT THICKNESS(m)
4.82	1.61	0.23
3.5	1.17	0.23
4.12	1.37	0.23
4.69	1.56	0.23
6.16	2.05	0.23
SIXTH TO EIGHT FLOOR		
DIAGONAL LENGTH(m)	STRUT WIDTH(m)	STRUT THICKNESS(m)
5.01	1.67	0.23
3.56	1.19	0.23
4.34	1.45	0.23
4.88	1.63	0.23
6.31	2.1	0.23

Models with diagonal struts in both the diagonal directions, but with struts having half the required width (i e., with w_{ds} = d/6) are used for the modal analysis, to obtain the modal parameters, viz., modal frequencies and mode shapes. The storey wise lateral loads for each mode are calculated from these parameters and applied to a model with the diagonal struts (in both diagonal directions) having the full required width (ie., w_{ds}=d/3), but assigned compression only property.The lateral loads are manually calculated from modal parameters of the mentioned former model and applied in the latter model as concentrated loads at each floor diaphram centre. Lateral loads for each mode is applied as seperate load cases and SRSS combination of the lateral load cases is taken as the seismic case. The latter model is then used for the analysis,analysed first with all diagonal struts inactivated for the gravity load cases, and then activated for response spectrum lateral loads.

3 RESULTS AND DISCUSSIONS

3.1 Dynamic parameters of the building

The modal analysis is conducted on both the model with half-widthed diagonal struts in both directions and the bare frame model. The modal characteristics obtained are tabulated in Table 5. The mode shapes are also graphically shown in figure 14 and figure 15.
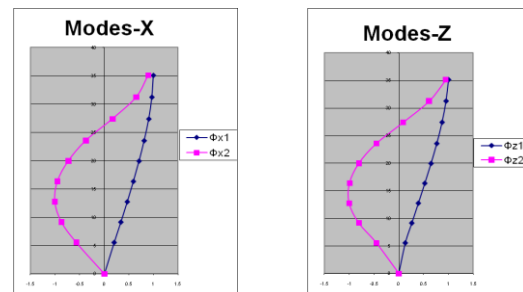

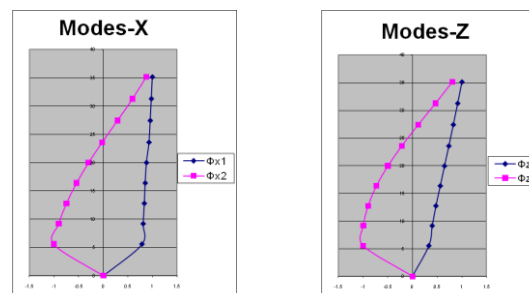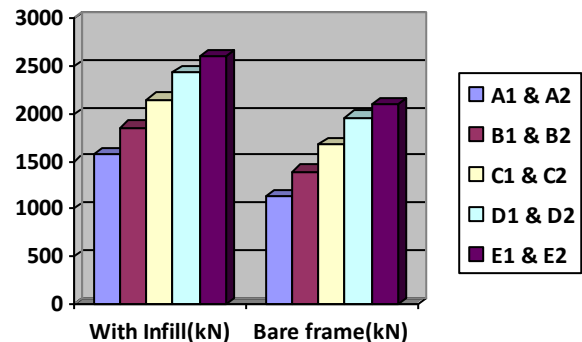**Figure 14 :** Modes shapes in X and Z directions (Without diagonal strut model)

Figure 15 : Modes shapes in X and Z directions (With diagonal strut model)

Table-5 : Modes of two models in X and Z-directions

		Modes in X-direction				Modes in Z-direction			
		Bareframe		Frame with diagonal		Bareframe		Frame with diagonal	
		Mode 1	Mode 2	Mode 1	Mode 2	Mode 1	Mode 2	Mode 1	Mode 2
Time Period		2.20686	0.65417	0.84824	0.17606	1.65875	0.47455	0.68743	0.20184
		Φ_{x1}	Φ_{x2}	Φ_{x1}	Φ_{x2}	Φ_{z1}	Φ_{z2}	Φ_{z1}	Φ_{z2}
Floorwise displacements at diaphragms	Roof	1	0.889484	1	0.8692149	1	0.944976	1	0.804051
	8th	0.970357	0.647974	0.97932	0.5919244	0.949611	0.609512	0.914649	0.463991
	7th	0.907589	0.168285	0.956385	0.2865163	0.870461	0.087651	0.8263	0.114027
	6th	0.81287	-0.3741	0.931482	-0.024385	0.763775	-0.45516	0.73651	-0.21916
	5th	0.708379	-0.72697	0.878592	-0.299293	0.648268	-0.806	0.64895	-0.50025
	4th	0.592248	-0.94778	0.853952	-0.542199	0.523483	-0.9934	0.563633	-0.73209
	3rd	0.467937	-1	0.836205	-0.747185	0.394683	-1	0.475674	-0.89968
	2nd	0.33751	-0.86706	0.812192	-0.902431	0.262957	-0.80542	0.401682	-0.99749
	1st	0.200711	-0.56787	0.787063	-1	0.132392	-0.45339	0.333444	-1
	Ground	0	0	0	0	0	0	0	0

From the figure 14 and 15, it is clear how the mode shapes of the model with diagonal struts shows max displacement at ground floor (soft storey) with the above floors displaced almost like a rigid body.

On design, it has been found that from among the load combination cases prescribed in the code[13] ,namely 1.2 (D.L+L.L+EQ), 1.5 (D.L ±EQ) and 0.9D.L ±1.5EQ, the 2nd combination case in the above list is found to be the critical case for design, in both the directions. Therefore the presentation of results in following sections deal with only that combination case. In this paper, only the case of seismic load in Z-direction is presented and correspondingly the moment of columns about its local Y-direction (M_y).

3.2 Comparison of Maximum Axial loads (P_u)

Axial loads in case of Response Spectrum Analysis (RSA) is compared between different Bare frame models and Infill models to see the difference between them and also to obtain the Magnification Ratio (M.R).

Table-6 : Maximum Axial Loads for different models

RSA Result for P_u				
Element	Model Name	With diagonal strut(kN)	Bare frame(kN)	M.R
Column	A1 & A2	1568.77	1137	1.379745
Column	B1 & B2	1857.66	1398	1.328798
Column	C1 & C2	2149.63	1675	1.283361
Column	D1 & D2	2439.89	1959.22	1.245337
Column	E1 & E2	2599.48	2100	1.237848

Chart-1 : Comparison of P_u

3.3 Comparison of Maximum Moment about local Y direction(M_y)

Moment about column local Y direction(M_y) in case of Response Spectrum Analysis (RSA) is compared between different Bare frame models and Infill models to see the difference between them and also to get the Magnification Ratio (M.R).The local direction of the column with respect to the global directions in STAAD.Pro V8i are shown in figure 16. X,Y,Z represents the global directions and x,y,z represents local directions of column.
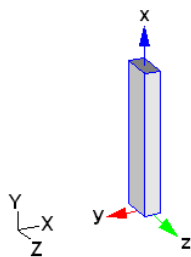
Figure 16 : Local direction of the column

Table-7: Maximum Moment along Y direction

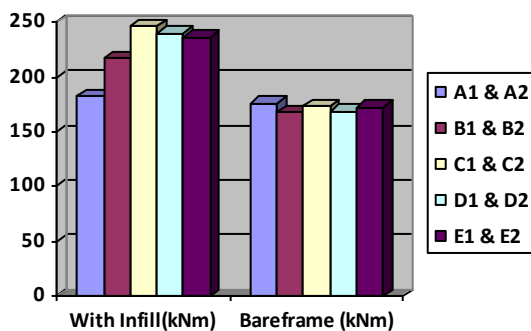| RSA Result for M_y				
Element	Model Name	With diagonal strut (kNm)	Bareframe (kNm)	M.R
Column	A1 & A2	182.83	176.23	1.037
Column	B1 & B2	217.87	167.83	1.298
Column	C1 & C2	246.71	173.91	1.418
Column	D1 & D2	240.13	169.14	1.419
Column	E1 & E2	236.6	172.84	1.368

Chart-2 : Comparison of M_y

3.4 Comparison of Area of Steel Required (A_{st})

Area of Steel Required (A_{st}) in case of Response Spectrum Analysis (RSA) is compared for the G+8 model between different Bare frame models and models with diagonal strut to see the difference between them.

Table-8: Maximum Area of Steel Required

RSA Result for A_{st}				
Element	Model Name	With diagonal strut (mm²)	Bareframe (mm²)	Ratio
Column	A1 & A2	6322.88	5768.66	1.096
Column	B1 & B2	7530.24	6258.22	1.203

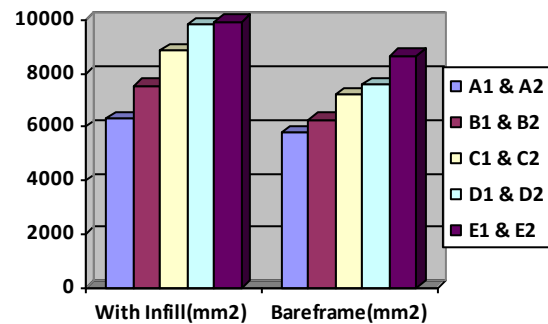| Column	C1 & C2	8866.06	7218.96	1.228
Column	D1 & D2	9821	7590.52	1.293
Column	E1 & E2	9953	8673.98	1.147

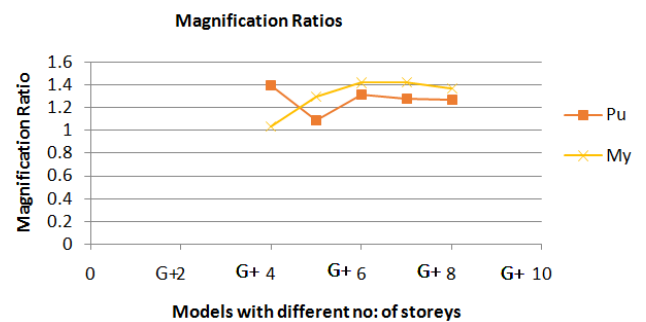**Chart-3:** Comparison of A_{st}

Chart-4 : Comparison of Magnification Ratios

From the above analysis it is concluded that M.R obtained for axial loads is in the range of (1.2 to 1.4) for column, which is nearly 44% less than, which is prescribed by IS code. i.e. 2.5. Similarly for moment about local y-direction, M.R is in range of (1 to 1.4) for column, which is 44% less than value of 2.5. And finally the ratio for area of steel required was obtained in the range of (1 to1.3) for column.

4 CONCLUSIONS

i) Indian Standard code gives a value of a multiplication factor of 2.5 to be multiplied to the ground storey design forces when a building has to be designed as open ground storey. The magnification ratio of several models were found out using RSA and the analyses supports that a factor of 2.5 is too high to be multiplied to the column forces of the ground storey. This is particularly true upto G+8 buildings.

ii) IS code provision , the constant M.F does not account for dependence on number of storeys, number of bays , type and number of infill walls

present. But the present study proves that magnification factor increases with number of storeys.

iii)   To find the precise design forces, one needs a non-linear analysis or time history analysis and it is a tedious work .This is already proved in the present study. Hence the necessity of a simple method/provision for the design of OGS buildings is very high.

iv)   M.R required for axial loads is in the range of (1.2 to 1.4), M.R required for moment about local y-direction in the range of (1 to 1.4) which is less than prescribed by IS code. i.e. 2.5. It is therefore recommended to use the method of inclusion of diagonal struts, since it is more realistic and was also found to be economical for the building investicated.

REFERENCES

[1]   Asokan, (2006) Modelling of Masonry Infill Walls for Nonlinear Static Analysis of Buildings under Seismic Loads. M. S. Thesis, Indian Institute of Technology Madras, Chennai.

[2]   Al-Chaar, G. (2002) Evaluating strength and stiffness of unreinforced masonry infill structures. *U.S. Army Corps of Engineers*. Technical Report NO. ERDC/CERL TR-02-1. Construction Engineering Research Laboratory. Campaign. USA

[3]   Arlekar, J.N.; S. K. Jain and C.V.R Murty (1997) Seismic response of RC frame buildings with soft first storeys. *Proceedings of CBRI golden jubilee conference on natural hazards in urban habitat.* New Delhi

[4]   Chug, R. (2004) Studies on RC Beams. Columns and Joints for Earthquake Resistant Design. M. Tech Project Report. Indian Institute of Technology Madras, Chennai. India

[5]   Das.S (2004) Seismic design of vertically irregular reinforced concrete structures. Ph.D. Thesis. North Carolina State University. Raleigh. NC

[6]   Dhansekar, M. and A.W. Page (1986) the influence of brick masonry infill properties on the behaviour of infilled frames. Proceedings of Institution of Civil Engineers. Part 2. 81. 593-605

[7]   Document No. IITK-GSDMA-EQ05-V4.0,"Proposed draft provisions and commentry on India Seismic code IS 1893, (Part-1)",National Information Centre on Earthquake Engineering,IIT Kanpur,India

[8]   Fardis, M.N. and T. B. Panagiotakos (1997) Seismic design and response of bare and masonry-infilled concrete buildings. Part II: Infilled structures. *Journal of Earthquake Engineering.* 1. 475-503

[9]   Holmes, M. (1961) Steel frames with brick and concrete infilling. *Proceedings of Institution of Civil Engineers*. 19. 473-478

[10] Kanitkar, R. and V. Kanitkar (2004) Seismic performance of conventional multi-storey buildings with open ground storey floors for vehicular parking. *The Indian Concrete Journal*. 78. 99-104

[11] Kaushik, H. B. (2006) Evaluation of strengthening options for masonry- infilled RC frames with open first storey. Ph.D. Thesis. Indian Institute of Technology Kanpur,

[12] STAAD.Pro V8i, Bentley Systems,United States

[13] IS 1893 Part 1 (2002) Indian Standard Criteria for Earthquake Resistant Design of Structures, *Bureau of Indian Standards*, New Delhi.

[14] T.Sruti Sai, Dr.T.Chandrasekhar Rao, B.Vasudev (2016) Seismic Response of RC Framed Structures Having Plan and Vertical Irregularities with and Without Masonry Infill Action, *International Research Journal of Engineering and Technology* (IRJET) e-ISSN: 2395 -0056 Volume: 03 Issue: 02 p-ISSN: 2395-007.