STUDY OF SEISMIC RESPONSE OF 12 STOREY RCC BUILDING CONSIDERING INFILL PANELS AS PER INDIAN STANDARDS

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ABSTRACT. Masonry infills in structures are normally considered as non-structural elements and their contribution in the stiffness of structure is generally ignored in practice, this assumption can lead to an unsafe design. The infill wall though constructed as secondary element of a structure behaves as a integral part of the structural system and also determines the behaviour and response of the structure, especially when the structure is subjected to lateral loads. This paper presents response spectrum analysis of 12 storey reinforced concrete office building considering bare frame, masonry wall infilled frame and frame with equivalent diagonal strut model of infill as specified in IS 1893 (part1):2016. The analysis was carried out in ETABS and a spreadsheet was developed to perform the manual calculation of response spectrum analysis to validate and compare the results obtained from ETABS. The results showed significant effect in the base shear and displacement of the structure. As the stiffness of the structure increased, it started attracting more force on to it thereby increasing the base shear value and reducing the maximum displacement of structure. The results obtained from manual calculations and software analysis were found to be comparable and within acceptable limits which indicates the suitability of the method provided in IS code for analysis. The paper also highlights some points, newly added in IS 1893 (part1):2016, which need some attention from authors.

Keywords: Masonry Walls, Equivalent Strut, Response Spectrum Analysis, ETABS

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INTRODUCTION

As far as structural response is concerned, the infill walls plays an important role in the structural response and its behaviour to lateral loads especially seismic loads. The infill walls have a wide variability in structural behaviour due to ground motion characteristics, mechanical properties of infills, overall geometry, presence of openings etc. The presence of infill can lead to improved performance of a building as well as increase in the overall mass of the structure which results in increased base shear values. A well-designed structure with proper implementation of infill can increase the strength of the structure, the lateral stiffness and resistance which reduces lateral deflection.

Various models of analysis of buildings with infill walls have been developed by researchers through rigorous research and experiments considering the infills as integral elements of structure and thereby taking part in lateral load resistance. The equivalent strut models put forward by authors are found to be effective in simulating the behaviour of the infill walls. Polyakov (1960) first conducted the experimental tests on masonry Infill walls and proposed that the walls behaved as bracings. Holmes (1961), Stafford-Smith (1962) and Mainstone (1971) put forward their theories and methods to calculate the equivalent width of diagonal struts for infill walls supported by their test results. Many revisions were later provided by researchers based on their works.

The paper focuses on the implementation of the method of calculating equivalent strut model as recommended in IS 1893 (part1):2016. In the present work the equivalent strut model is calculated and modelled in ETABS also similar models with infill walls and without infill walls are modelled to obtain a comparative data of response of structure for lateral seismic loads and response spectrum analysis.

DIFFERENT METHODS AVAILABLE FOR CALCULATING EQUIVALENT STRUT PARAMETERS

Various methods for determining the equivalent strut parameters for an infill wall are available which are widely used in various parts of world

Indian code IS 1893 (part1) :2016

- The equivalent strut width as adopted by IS 1893:2016 is a modification of the formula given by Mainstone in 1971 and is given by:

$$W_{ds} = 0.175\left(\lambda H_{inf}\right)^{-0.4} L_{ds},$$

Where, $$\lambda = \sqrt[4]{\frac{\mathrm{E_m t Sin2\theta}}{\mathrm{4E_f I_c H_{inf}}}}$$

- For URM walls with openings no reduction in width is required.
- Thickness of Equivalent diagonal strut shall be taken as thickness of original URM infill wall, provided $\frac{H_{inf}}{t} < 12$ and $\frac{l}{t} < 12$.(This is a major drawback)

Mainstone (1971)/FEMA 306/ ASCE/SEI 41-06/ ERDC/CERL

- Based on experimental observations, Mainstone gave formula for calculating width of equivalent diagonal strut which incorporates the relative stiffness of frame to infill as given by Stafford and carter. This formula is widely adopted by many other future publications such as FEMA306 & ERDC/CERL.

$$W_{ds} = 0.175(\lambda \mathrm{H})^{-0.4} L_{ds}$$

Where, $$\lambda = \sqrt[4]{\frac{\mathrm{E_m t Sin2\theta}}{\mathrm{4E_f I_c H_{inf}}}}$$

- If there are any openings present in the infill panel and/or there is existing infill damage, the reduced equivalent strut width must be reduced as follows;

$$W_{ds(red)} = W_{ds}(R_1)(R_2)$$

Where, R_1 = Reduction factor for in-plane evaluation due to presence of opening
R_2 = Reduction factor for in-plane evaluation due to existing infill damage.

HOLMES (1961)

Holmes based on his observation of steel frame and corresponding values of horizontal thrust and deflection the width of equivalent diagonal strut was given as:

$$W_{ds} = \frac{L_{ds}}{3}$$

Liauw and Kwan (1984)/Crowley and Pinho (2006)

- Non-integrated infilled frames are those in which the infill and the frame are not bonded together.
- Through experimental and analytical methods, they studied nonlinear behavior of non-integral infilled frames.
- Using their experimental results, the following formula was given:

$$W_{ds} = \frac{0.95 H_{inf} Cos\theta}{\sqrt{\lambda H_{inf}}}, \qquad \text{when friction is included}$$

and least of $W_{ds} = 0.45 H_{inf} Cos\theta$ and $\frac{0.86 H Cos\theta}{\sqrt{\lambda H_{inf}}}$, when friction is not included.

Turkish code, TEC (2007)

The Turkish code has specified the width of equivalent strut as given in the expression below

$$W_{ds} = 0.175(\lambda H)^{-0.4} L_{ds}$$

Where, $$\lambda = \sqrt[4]{\frac{E_m t \sin 2\theta}{4 E_f I_c H_{inf}}} \quad \text{and} \quad E_m = 200 f'_m$$

In all the above expressions,
I_c= Moment of inertia of the adjoining column
E_m & E_f = Modulus of elasticity of masonry wall and RC frame
t = Thickness of infill wall
θ = Inclination of strut with horizontal
h = Clear height of RC frame between top and bottom slab
L_{ds} = Length of equivalent strut (Fig. 1)

MECHANICS INVOLED IN INFILL PANEL

Figure below shows a frame ABCD with a wall infill subjected to a horizontal shear force, H, giving rise to complementary vertical shear forces of Htanα. The resultants of these shear forces are compressive forces $\frac{H}{\tan\alpha}$ acting at B and D along the diagonal BD. At failure the wall and frame will only be in contact near B and D, as shown in figure 1. The equivalent strut is also shown in the same figure, where the wall panel has been replaced by an equivalent strut BD and the shear forces carried by the frame alone are also shown:

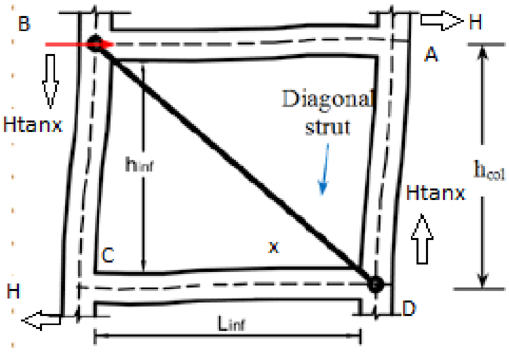


Figure 1 Application of horizontal shear force to frame

Hence from the above figure it is clear that the masonry infill panels behave as a diagonal strut during loading and finding the width of this diagonal strut has been given primary importance by many researchers as it influences the infill behaviour which in turn influences stiffness and strength properties of frame with infill.

MODELLING DETAILS

The details of the framed building model along with loading are provided in the Table 1.
All loadings such as dead loads, live loads and seismic load are calculated and applied on the structure as per Indian standard recommendations such as IS 875-Part-1(1987), IS 875-Part-2(1987), and IS 1893-Part-1(2016).

Table 1 Model and Loading details

NUMBER OF STORIES	G+11	
Plan Dimension	22.5m x 22.5m	
Spacing between frames	7.5m along both directions	
Floor Height	Ground Floor	5.2m
	Other floors	5m
Elevation from depth of fixity	60.2m	
Size of Beam	0.3m x 0.6m	
Size of column	0.5m x 0.5m	
Depth of slab	100mm	
Thickness of infill panel	0.23m	
Grade of concrete	M30	
Grade of steel	Fe415	
Unit weight of Concrete	25 kN/m^3	
Unit weight of steel	78.5 kN/m^3	
Unit weight of Infill	20 kN/m^3	
Poisson ratio	0.17	
Damping factor	0.05	
Location	Delhi	
Seismic zone	IV	
Importance factor	1	
Response reduction factor	5	
Soil type	Medium (type II)	
Live load on floor	Up to 11th storey	4 kN/m^2
	On roof	1.5 kN/m^2

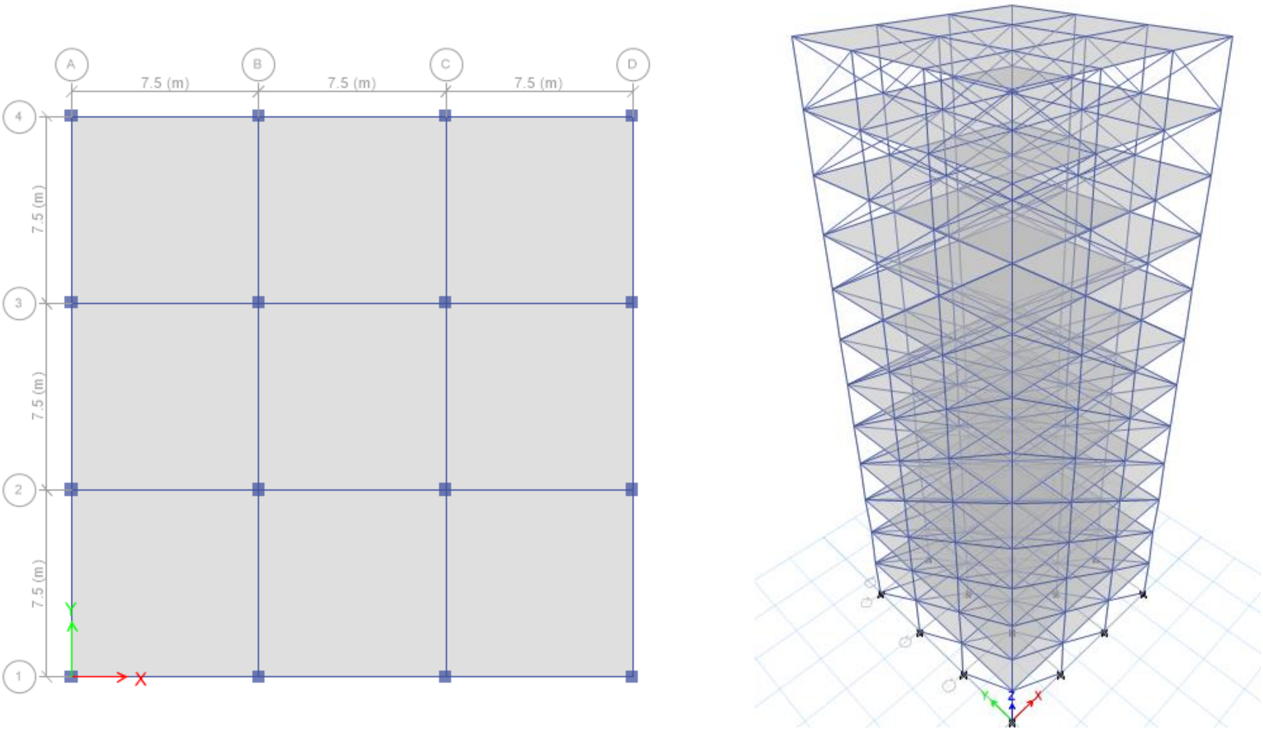


Figure 2 Plan and 3D view of 12 Storey building with equivalent diagonal strut

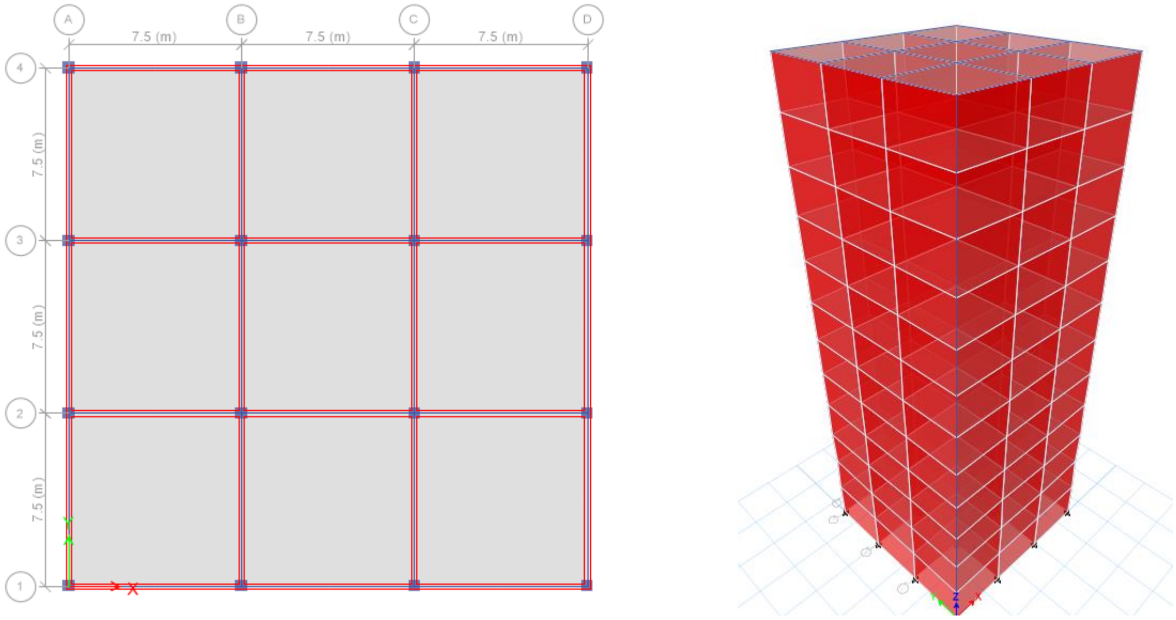


Figure 3 Plan and 3D View of the structure with modelled infill walls

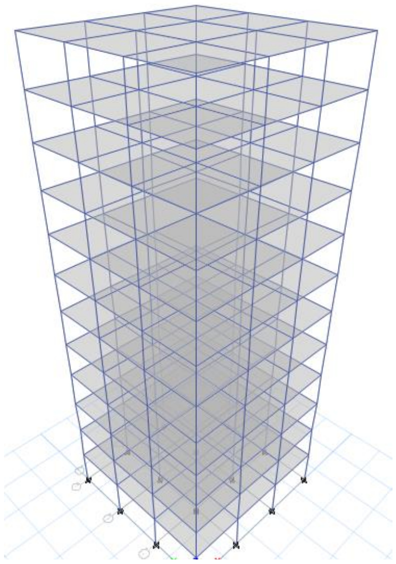


Figure 4 3D view of the bare frame

METHODOLOGY

- Three cases were considered for the models for analysis and comparison.
- In the first case models with the below mentioned propertied were modelled in ETABS with just the RC frame present. The infill walls were not considered here.
- In the second case Infill walls were modelled in all directions with the above-mentioned properties and dimensions the 12-story building.

- In the third case, the instead of the infill walls the calculated equivalent strut was modelled between the frames as Pin-Ended Diagonal compression members as suggested by the latest addition in the Indian code IS 1893-Part 1-2016.
- The resultant 3 models were analysed for Seismic loadings as per Indian standards.
- The response of these cases was compared such as Base Shear and Maximum Joint Displacement.

The steps followed for the manual calculation of the response of the structure can be summarised in the following points-:

i. Dead Loads were calculated as per the dimensions and Live loads were obtained according to IS 875: Part I and II respectively. The total load on each floor was calculated and the structure is converted to be a lumped mass system.

ii. The stiffness between the masses were obtained by combining the stiffness of the columns as well as the infill panels (converting it to equivalent diagonal strut as per is 1893:2016).

a) <u>Stiffness of columns</u>

$$k_c = \frac{12EI}{l^3}$$

k = Stiffness of a column in kN/m (to be multiplied by the number of columns to get the total stiffness of a set of columns)
E = Modulus of Elasticity of Concrete in kN/m^2
I = Moment of Inertia of column in m^4
l = effective length of column in m

b) <u>Stiffness of Infill Panels as per IS 1893:2016</u>

Width of equivalent diagonal strut

$$w_{ds} = 0.175\alpha_h^{-0.4}L_{ds}$$

$$\alpha_h = h\left[\sqrt[4]{\frac{E_m t\, Sin2\theta}{4E_f I_c h}}\right]$$

E_m = Modulus of Elasticity of infill material in kN/m^2
t = Thickness of the infill panel in m
θ = angle made by the diagonal strut with the horizontal in degrees
E_f = Modulus of Elasticity of RC Frame material in kN/m^2
I_c = Moment of Inertia of column in m^4
h = height of the column
L_{ds}= Diagonal Length of the equivalent strut

$$k_p = \frac{A\,E_m}{L_{ds}} * cos^2\theta$$

c) <u>Stiffness of a floor in a direction</u> = $\Sigma\ k_c + \Sigma\ k_p$ (in that direction)

iii. The combined stiffness and mass matrix for the lumped mass system is obtained. Using MATLAB, the eigen value problem is solved to obtain the modal matrix(Φ) and the corresponding frequency matrix(ω) from which the time periods corresponding to each mode is calculated(T).

iv. Simplified method for dynamic analysis of buildings

a) <u>Modal mass (M_k)</u>

$$M_k = \frac{[\sum_{i=1}^{n} W_i\, \Phi_{ik}]^{\wedge}2}{g \sum_{i=1}^{n} W_i\, (\Phi_{ik})^2}$$

g = acceleration due to gravity
Φ_{ik} = mode shape coefficient at floor i in mode k
Wi = Seismic weight of floor I of the structure
n = number of floors of the structure

b) Mode participation factor

$$P_k = \frac{\sum_{i=1}^{n} W_i \Phi_{ik}}{g \sum_{i=1}^{n} W_i\, (\Phi_{ik})^2}$$

c) Design lateral force at each storey

$$Q_{ik} = A_k \Phi_{ik} P_k W_i$$

A_k= Design acceleration spectrum value

d) Storey shear forces in each mode – Peak shear force V_{ik} acting in storey i in mode k is given by

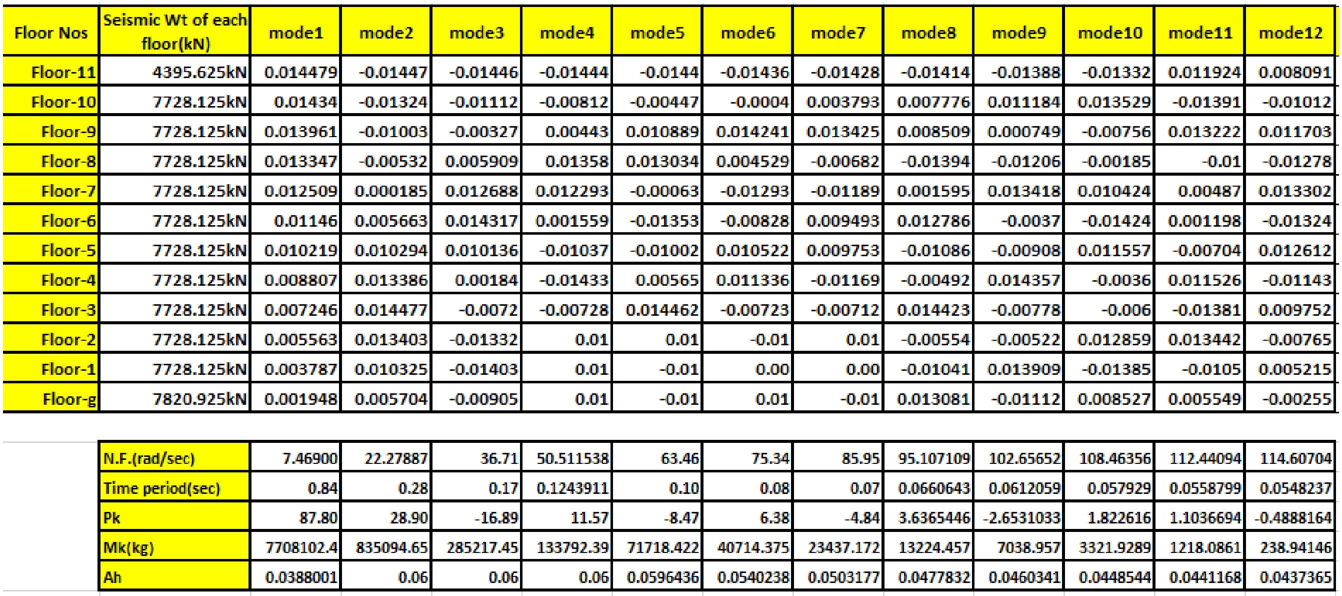
$$V_{ik} = \sum_{j=i+1}^{n} Q_{ik}$$

e) Storey displacement values can be obtained by using the expression

$$U_{ik} = P_k \Phi_{ik} \left(\frac{A_k}{\omega_k^2}\right)$$

RESULTS

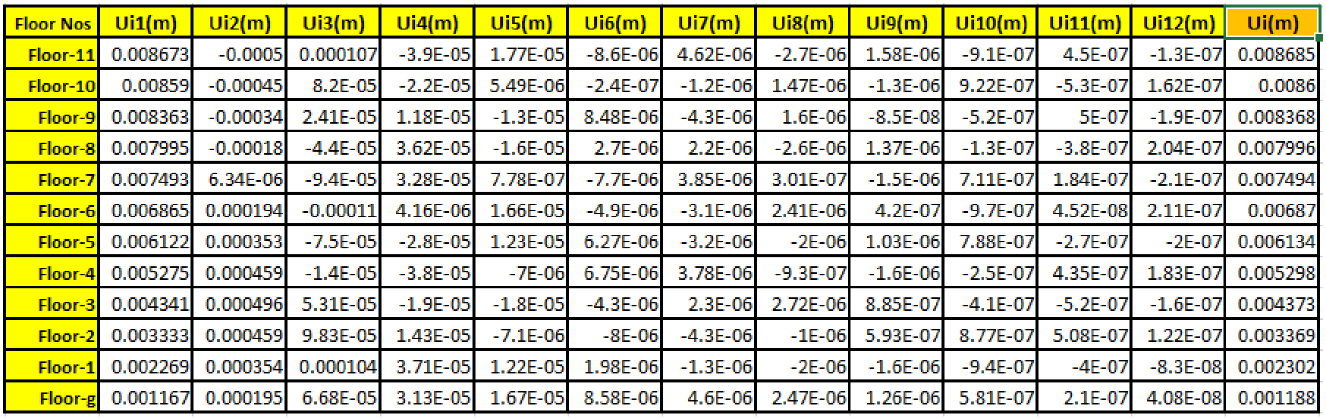
The seismic analysis of all the frame models were carried out in ETABS. The models included bare frame model, framed model with masonry infill and framed model with equivalent struts. The parameters which are to be studied are Time period, Base shear and maximum storey displacement. For analysis on ETABS all three models were taken whereas for manual analysis the case considering presence of infill wall is not done.



Floor Nos	Seismic Wt of each floor(kN)	mode1	mode2	mode3	mode4	mode5	mode6	mode7	mode8	mode9	mode10	mode11	mode12
Floor-11	4395.625kN	0.014479	-0.01447	-0.01446	-0.01444	-0.0144	-0.01436	-0.01428	-0.01414	-0.01388	-0.01332	0.011924	0.008091
Floor-10	7728.125kN	0.01434	-0.01324	-0.01112	-0.00812	-0.00447	-0.0004	0.003793	0.007776	0.011184	0.013529	-0.01391	-0.01012
Floor-9	7728.125kN	0.013961	-0.01003	-0.00327	0.00443	0.010889	0.014241	0.013425	0.008509	0.000749	-0.00756	0.013222	0.011703
Floor-8	7728.125kN	0.013347	-0.00532	0.005909	0.01358	0.013034	0.004529	-0.00682	-0.01394	-0.01206	-0.00185	-0.01	-0.01278
Floor-7	7728.125kN	0.012509	0.000185	0.012688	0.012293	-0.00063	-0.01293	-0.01189	0.001595	0.013418	0.010424	0.00487	0.013302
Floor-6	7728.125kN	0.01146	0.005663	0.014317	0.001559	-0.01353	-0.00828	0.009493	0.012786	-0.0037	-0.01424	0.001198	-0.01324
Floor-5	7728.125kN	0.010219	0.010294	0.010136	-0.01037	-0.01002	0.010522	0.009753	-0.01086	-0.00908	0.011557	-0.00704	0.012612
Floor-4	7728.125kN	0.008807	0.013386	0.00184	-0.01433	0.00565	0.011336	-0.01169	-0.00492	0.014357	-0.0036	0.011526	-0.01143
Floor-3	7728.125kN	0.007246	0.014477	-0.0072	-0.00728	0.014462	-0.00723	-0.00712	0.014423	-0.00778	-0.006	-0.01381	0.009752
Floor-2	7728.125kN	0.005563	0.013403	-0.01332	0.01	0.01	-0.01	0.01	-0.00554	-0.00522	0.012859	0.013442	-0.00765
Floor-1	7728.125kN	0.003787	0.010325	-0.01403	0.01	-0.01	0.00	0.00	-0.01041	0.013909	-0.01385	-0.0105	0.005215
Floor-g	7820.925kN	0.001948	0.005704	-0.00905	0.01	-0.01	0.01	-0.01	0.013081	-0.01112	0.008527	0.005549	-0.00255

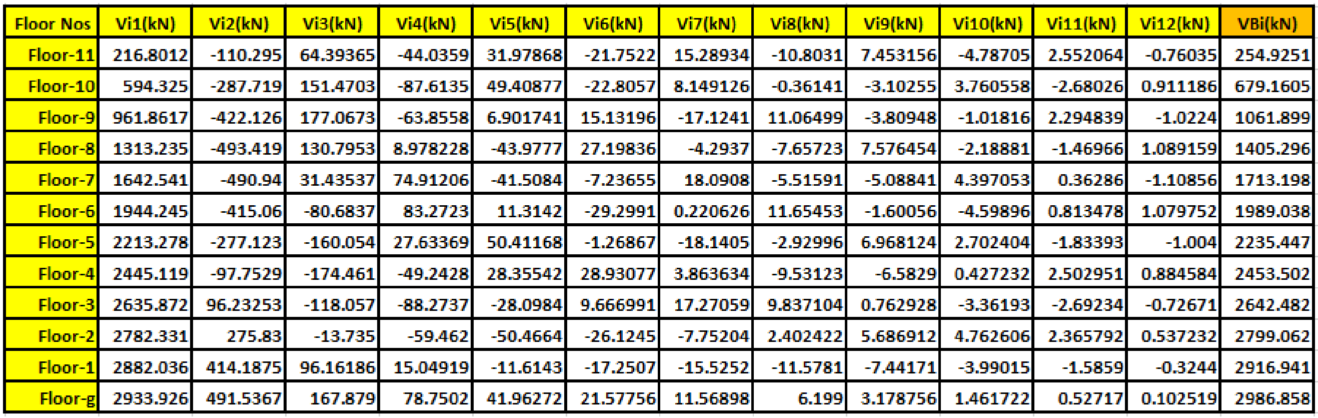
N.F.(rad/sec)	7.46900	22.27887	36.71	50.511538	63.46	75.34	85.95	95.107109	102.65652	108.46356	112.44094	114.60704
Time period(sec)	0.84	0.28	0.17	0.1243911	0.10	0.08	0.07	0.0660643	0.0612059	0.057929	0.0558799	0.0548237
Pk	87.80	28.90	-16.89	11.57	-8.47	6.38	-4.84	3.6365446	-2.6531033	1.822616	1.1036694	-0.4888164
Mk(kg)	7708102.4	835094.65	285217.45	133792.39	71718.422	40714.375	23437.172	13224.457	7038.957	3321.9289	1218.0861	238.94146
Ah	0.0388001	0.06	0.06	0.06	0.0596436	0.0540238	0.0503177	0.0477832	0.0460341	0.0448544	0.0441168	0.0437365

Figure 5 Excel sheet results for mode shapes and time period for different modes (with infill panels)



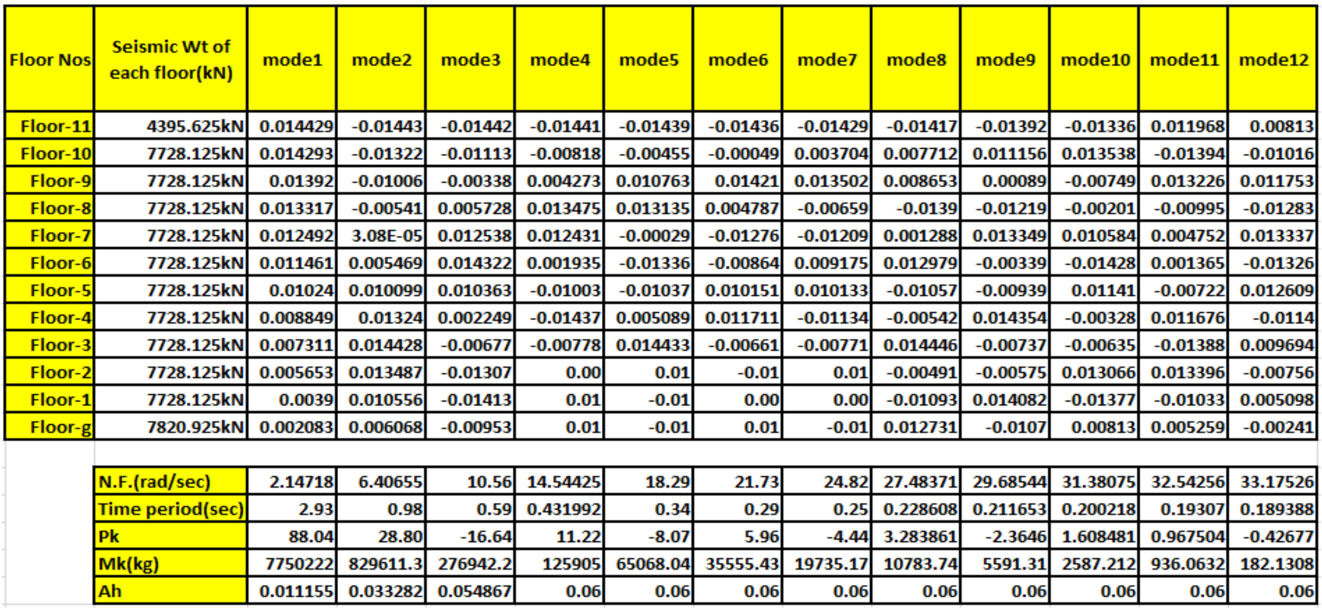
Floor Nos	Ui1(m)	Ui2(m)	Ui3(m)	Ui4(m)	Ui5(m)	Ui6(m)	Ui7(m)	Ui8(m)	Ui9(m)	Ui10(m)	Ui11(m)	Ui12(m)	Ui(m)
Floor-11	0.008673	-0.0005	0.000107	-3.9E-05	1.77E-05	-8.6E-06	4.62E-06	-2.7E-06	1.58E-06	-9.1E-07	4.5E-07	-1.3E-07	0.008685
Floor-10	0.00859	-0.00045	8.2E-05	-2.2E-05	5.49E-06	-2.4E-07	-1.2E-06	1.47E-06	-1.3E-06	9.22E-07	-5.3E-07	1.62E-07	0.0086
Floor-9	0.008363	-0.00034	2.41E-05	1.18E-05	-1.3E-05	8.48E-06	-4.3E-06	1.6E-06	-8.5E-08	-5.2E-07	5E-07	-1.9E-07	0.008368
Floor-8	0.007995	-0.00018	-4.4E-05	3.62E-05	-1.6E-05	2.7E-06	2.2E-06	-2.6E-06	1.37E-06	-1.3E-07	-3.8E-07	2.04E-07	0.007996
Floor-7	0.007493	6.34E-06	-9.4E-05	3.28E-05	7.78E-07	-7.7E-06	3.85E-06	3.01E-07	-1.5E-06	7.11E-07	1.84E-07	-2.1E-07	0.007494
Floor-6	0.006865	0.000194	-0.00011	4.16E-06	1.66E-05	-4.9E-06	-3.1E-06	2.41E-06	4.2E-07	-9.7E-07	4.52E-08	2.11E-07	0.00687
Floor-5	0.006122	0.000353	-7.5E-05	-2.8E-05	1.23E-05	6.27E-06	-3.2E-06	-2E-06	1.03E-06	7.88E-07	-2.7E-07	-2E-07	0.006134
Floor-4	0.005275	0.000459	-1.4E-05	-3.8E-05	-7E-06	6.75E-06	3.78E-06	-9.3E-07	-1.6E-06	-2.5E-07	4.35E-07	1.83E-07	0.005298
Floor-3	0.004341	0.000496	5.31E-05	-1.9E-05	-1.8E-05	-4.3E-06	2.3E-06	2.72E-06	8.85E-07	-4.1E-07	-5.2E-07	-1.6E-07	0.004373
Floor-2	0.003333	0.000459	9.83E-05	1.43E-05	-7.1E-06	-8E-06	-4.3E-06	-1E-06	5.93E-07	8.77E-07	5.08E-07	1.22E-07	0.003369
Floor-1	0.002269	0.000354	0.000104	3.71E-05	1.22E-05	1.98E-06	-1.3E-06	-2E-06	-1.6E-06	-9.4E-07	-4E-07	-8.3E-08	0.002302
Floor-g	0.001167	0.000195	6.68E-05	3.13E-05	1.67E-05	8.58E-06	4.6E-06	2.47E-06	1.26E-06	5.81E-07	2.1E-07	4.08E-08	0.001188

Figure 6 Excel sheet displacement for each mode (with infill panels)



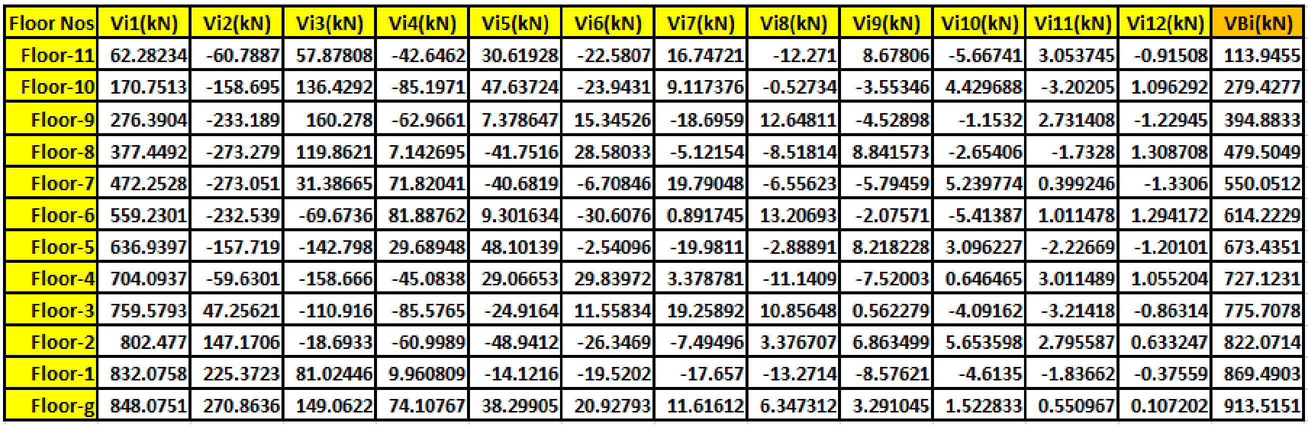
Floor Nos	Vi1(kN)	Vi2(kN)	Vi3(kN)	Vi4(kN)	Vi5(kN)	Vi6(kN)	Vi7(kN)	Vi8(kN)	Vi9(kN)	Vi10(kN)	Vi11(kN)	Vi12(kN)	VBi(kN)
Floor-11	216.8012	-110.295	64.39365	-44.0359	31.97868	-21.7522	15.28934	-10.8031	7.453156	-4.78705	2.552064	-0.76035	254.9251
Floor-10	594.325	-287.719	151.4703	-87.6135	49.40877	-22.8057	8.149126	-0.36141	-3.10255	3.760558	-2.68026	0.911186	679.1605
Floor-9	961.8617	-422.126	177.0673	-63.8558	6.901741	15.13196	-17.1241	11.06499	-3.80948	-1.01816	2.294839	-1.0224	1061.899
Floor-8	1313.235	-493.419	130.7953	8.978228	-43.9777	27.19836	-4.2937	-7.65723	7.576454	-2.18881	-1.46966	1.089159	1405.296
Floor-7	1642.541	-490.94	31.43537	74.91206	-41.5084	-7.23655	18.0908	-5.51591	-5.08841	4.397053	0.36286	-1.10856	1713.198
Floor-6	1944.245	-415.06	-80.6837	83.2723	11.3142	-29.2991	0.220626	11.65453	-1.60056	-4.59896	0.813478	1.079752	1989.038
Floor-5	2213.278	-277.123	-160.054	27.63369	50.41168	-1.26867	-18.1405	-2.92996	6.968124	2.702404	-1.83393	-1.004	2235.447
Floor-4	2445.119	-97.7529	-174.461	-49.2428	28.35542	28.93077	3.863634	-9.53123	-6.5829	0.427232	2.502951	0.884584	2453.502
Floor-3	2635.872	96.23253	-118.057	-88.2737	-28.0984	9.666991	17.27059	9.837104	0.762928	-3.36193	-2.69234	-0.72671	2642.482
Floor-2	2782.331	275.83	-13.735	-59.462	-50.4664	-26.1245	-7.75204	2.402422	5.686912	4.762606	2.365792	0.537232	2799.062
Floor-1	2882.036	414.1875	96.16186	15.04919	-11.6143	-17.2507	-15.5252	-11.5781	-7.44171	-3.99015	-1.5859	-0.3244	2916.941
Floor-g	2933.926	491.5367	167.879	78.7502	41.96272	21.57756	11.56898	6.199	3.178756	1.461722	0.52717	0.102519	2986.858

Figure 7 Excel sheet showing base shear for each mode (with infill panels)



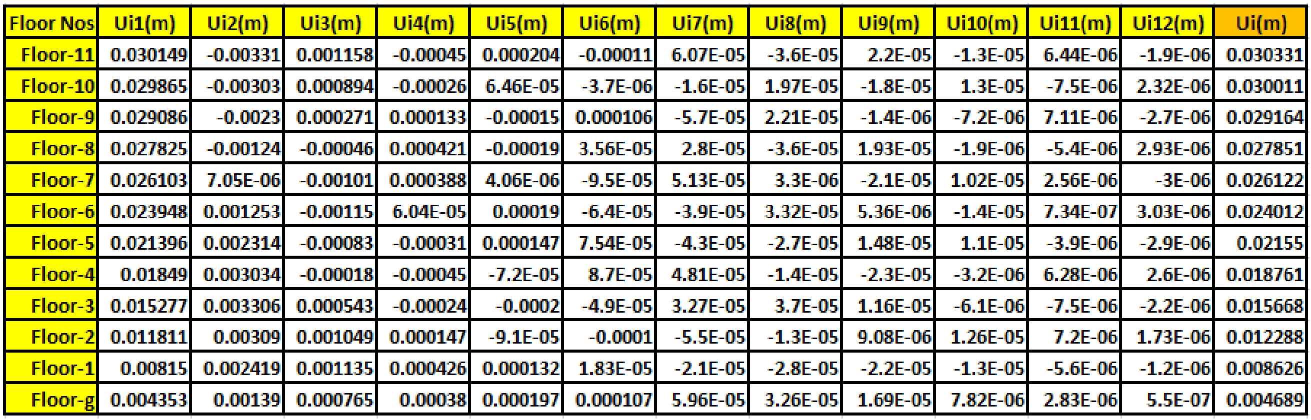
Floor Nos	Seismic Wt of each floor(kN)	mode1	mode2	mode3	mode4	mode5	mode6	mode7	mode8	mode9	mode10	mode11	mode12
Floor-11	4395.625kN	0.014429	-0.01443	-0.01442	-0.01441	-0.01439	-0.01436	-0.01429	-0.01417	-0.01392	-0.01336	0.011968	0.00813
Floor-10	7728.125kN	0.014293	-0.01322	-0.01113	-0.00818	-0.00455	-0.00049	0.003704	0.007712	0.011156	0.013538	-0.01394	-0.01016
Floor-9	7728.125kN	0.01392	-0.01006	-0.00338	0.004273	0.010763	0.01421	0.013502	0.008653	0.00089	-0.00749	0.013226	0.011753
Floor-8	7728.125kN	0.013317	-0.00541	0.005728	0.013475	0.013135	0.004787	-0.00659	-0.0139	-0.01219	-0.00201	-0.00995	-0.01283
Floor-7	7728.125kN	0.012492	3.08E-05	0.012538	0.012431	-0.00029	-0.01276	-0.01209	0.001288	0.013349	0.010584	0.004752	0.013337
Floor-6	7728.125kN	0.011461	0.005469	0.014322	0.001935	-0.01336	-0.00864	0.009175	0.012979	-0.00339	-0.01428	0.001365	-0.01326
Floor-5	7728.125kN	0.01024	0.010099	0.010363	-0.01003	-0.01037	0.010151	0.010133	-0.01057	-0.00939	0.01141	-0.00722	0.012609
Floor-4	7728.125kN	0.008849	0.01324	0.002249	-0.01437	0.005089	0.011711	-0.01134	-0.00542	0.014354	-0.00328	0.011676	-0.0114
Floor-3	7728.125kN	0.007311	0.014428	-0.00677	-0.00778	0.014433	-0.00661	-0.00771	0.014446	-0.00737	-0.00635	-0.01388	0.009694
Floor-2	7728.125kN	0.005653	0.013487	-0.01307	0.00	0.01	-0.01	0.01	-0.00491	-0.00575	0.013066	0.013396	-0.00756
Floor-1	7728.125kN	0.0039	0.010556	-0.01413	0.01	-0.01	0.00	0.00	-0.01093	0.014082	-0.01377	-0.01033	0.005098
Floor-g	7820.925kN	0.002083	0.006068	-0.00953	0.01	-0.01	0.01	-0.01	0.012731	-0.0107	0.00813	0.005259	-0.00241
	N.F.(rad/sec)	2.14718	6.40655	10.56	14.54425	18.29	21.73	24.82	27.48371	29.68544	31.38075	32.54256	33.17526
	Time period(sec)	2.93	0.98	0.59	0.431992	0.34	0.29	0.25	0.228608	0.211653	0.200218	0.19307	0.189388
	Pk	88.04	28.80	-16.64	11.22	-8.07	5.96	-4.44	3.283861	-2.3646	1.608481	0.967504	-0.42677
	Mk(kg)	7750222	829611.3	276942.2	125905	65068.04	35555.43	19735.17	10783.74	5591.31	2587.212	936.0632	182.1308
	Ah	0.011155	0.033282	0.054867	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06

Figure 8 Excel sheet showing modal matrix and time period for different modes (without infill panels)



Floor Nos	Vi1(kN)	Vi2(kN)	Vi3(kN)	Vi4(kN)	Vi5(kN)	Vi6(kN)	Vi7(kN)	Vi8(kN)	Vi9(kN)	Vi10(kN)	Vi11(kN)	Vi12(kN)	VBi(kN)
Floor-11	62.28234	-60.7887	57.87808	-42.6462	30.61928	-22.5807	16.74721	-12.271	8.67806	-5.66741	3.053745	-0.91508	113.9455
Floor-10	170.7513	-158.695	136.4292	-85.1971	47.63724	-23.9431	9.117376	-0.52734	-3.55346	4.429688	-3.20205	1.096292	279.4277
Floor-9	276.3904	-233.189	160.278	-62.9661	7.378647	15.34526	-18.6959	12.64811	-4.52898	-1.1532	2.731408	-1.22945	394.8833
Floor-8	377.4492	-273.279	119.8621	7.142695	-41.7516	28.58033	-5.12154	-8.51814	8.841573	-2.65406	-1.7328	1.308708	479.5049
Floor-7	472.2528	-273.051	31.38665	71.82041	-40.6819	-6.70846	19.79048	-6.55623	-5.79459	5.239774	0.399246	-1.3306	550.0512
Floor-6	559.2301	-232.539	-69.6736	81.88762	9.301634	-30.6076	0.891745	13.20693	-2.07571	-5.41387	1.011478	1.294172	614.2229
Floor-5	636.9397	-157.719	-142.798	29.68948	48.10139	-2.54096	-19.9811	-2.88891	8.218228	3.096227	-2.22669	-1.20101	673.4351
Floor-4	704.0937	-59.6301	-158.666	-45.0838	29.06653	29.83972	3.378781	-11.1409	-7.52003	0.646465	3.011489	1.055204	727.1231
Floor-3	759.5793	47.25621	-110.916	-85.5765	-24.9164	11.55834	19.25892	10.85648	0.562279	-4.09162	-3.21418	-0.86314	775.7078
Floor-2	802.477	147.1706	-18.6933	-60.9989	-48.9412	-26.3469	-7.49496	3.376707	6.863499	5.653598	2.795587	0.633247	822.0714
Floor-1	832.0758	225.3723	81.02446	9.960809	-14.1216	-19.5202	-17.657	-13.2714	-8.57621	-4.6135	-1.83662	-0.37559	869.4903
Floor-g	848.0751	270.8636	149.0622	74.10767	38.29905	20.92793	11.61612	6.347312	3.291045	1.522833	0.550967	0.107202	913.5151

Figure 9 Excel sheet showing base shear for each mode (without infill panels)



Floor Nos	Ui1(m)	Ui2(m)	Ui3(m)	Ui4(m)	Ui5(m)	Ui6(m)	Ui7(m)	Ui8(m)	Ui9(m)	Ui10(m)	Ui11(m)	Ui12(m)	Ui(m)
Floor-11	0.030149	-0.00331	0.001158	-0.00045	0.000204	-0.00011	6.07E-05	-3.6E-05	2.2E-05	-1.3E-05	6.44E-06	-1.9E-06	0.030331
Floor-10	0.029865	-0.00303	0.000894	-0.00026	6.46E-05	-3.7E-06	-1.6E-05	1.97E-05	-1.8E-05	1.3E-05	-7.5E-06	2.32E-06	0.030011
Floor-9	0.029086	-0.0023	0.000271	0.000133	-0.00015	0.000106	-5.7E-05	2.21E-05	-1.4E-06	-7.2E-06	7.11E-06	-2.7E-06	0.029164
Floor-8	0.027825	-0.00124	-0.00046	0.000421	-0.00019	3.56E-05	2.8E-05	-3.6E-05	1.93E-05	-1.9E-06	-5.4E-06	2.93E-06	0.027851
Floor-7	0.026103	7.05E-06	-0.00101	0.000388	4.06E-06	-9.5E-05	5.13E-05	3.3E-06	-2.1E-05	1.02E-05	2.56E-06	-3E-06	0.026122
Floor-6	0.023948	0.001253	-0.00115	6.04E-05	0.00019	-6.4E-05	-3.9E-05	3.32E-05	5.36E-06	-1.4E-05	7.34E-07	3.03E-06	0.024012
Floor-5	0.021396	0.002314	-0.00083	-0.00031	0.000147	7.54E-05	-4.3E-05	-2.7E-05	1.48E-05	1.1E-05	-3.9E-06	-2.9E-06	0.02155
Floor-4	0.01849	0.003034	-0.00018	-0.00045	-7.2E-05	8.7E-05	4.81E-05	-1.4E-05	-2.3E-05	-3.2E-06	6.28E-06	2.6E-06	0.018761
Floor-3	0.015277	0.003306	0.000543	-0.00024	-0.0002	-4.9E-05	3.27E-05	3.7E-05	1.16E-05	-6.1E-06	-7.5E-06	-2.2E-06	0.015668
Floor-2	0.011811	0.00309	0.001049	0.000147	-9.1E-05	-0.0001	-5.5E-05	-1.3E-05	9.08E-06	1.26E-05	7.2E-06	1.73E-06	0.012288
Floor-1	0.00815	0.002419	0.001135	0.000426	0.000132	1.83E-05	-2.1E-05	-2.8E-05	-2.2E-05	-1.3E-05	-5.6E-06	-1.2E-06	0.008626
Floor-g	0.004353	0.00139	0.000765	0.00038	0.000197	0.000107	5.96E-05	3.26E-05	1.69E-05	7.82E-06	2.83E-06	5.5E-07	0.004689

Figure 10 Excel sheet showing displacement for each mode (without infill panels)

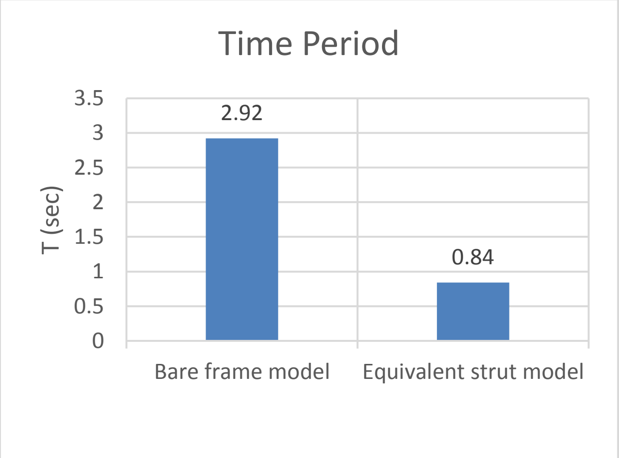


Figure 11 Graph showing comparison of time periods

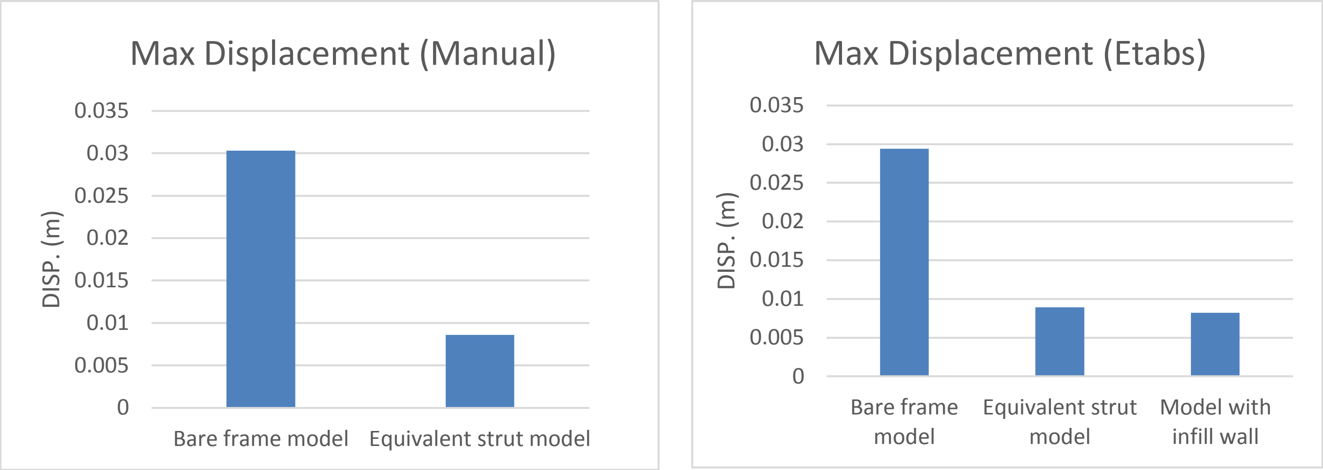


Figure 12 Graph showing comparison of max displacements obtained from ETABS and manual calculations

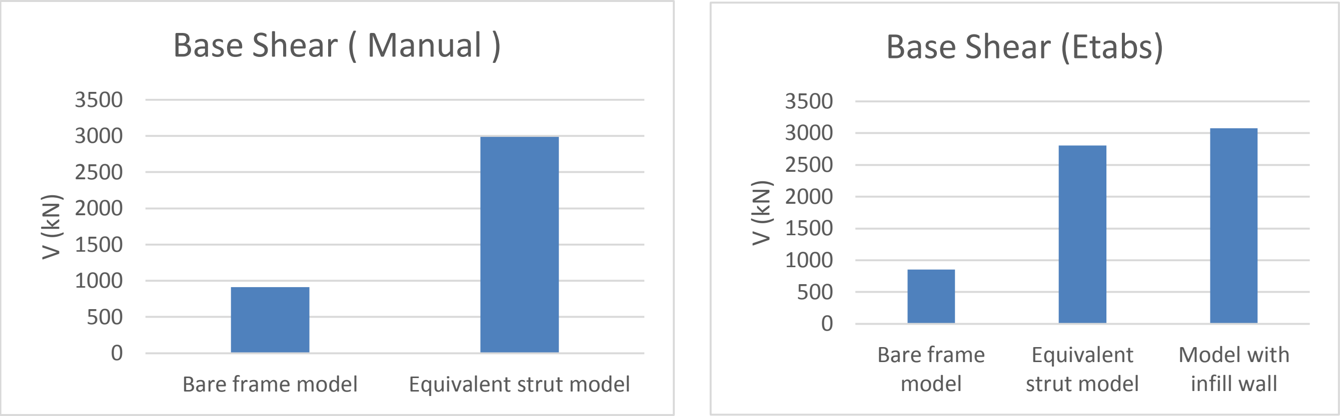


Figure 13 Graph showing comparison of max Base shear values obtained from ETABS and manual calculations

INTERPRETATION OF RESULTS

- The base shear value is more in the infilled frame than the bare frame model. This is due to the reason of inclusion of infill walls in the modal mass of the structure and increase in stiffness of the structure which as a result attracts more force.
- Considerable difference in time period and storey displacement is seen, this is due to the increase in lateral stiffness of the structure.
- The values obtained from the software as well as the manual calculations are comparable and within acceptable limits of difference.

CONCLUSION

The results showed significant effect in the base shear and displacement of the structure. As the stiffness of the structure increased, it started attracting more force on to it thereby increasing the base shear value significantly. As stiffness is inversely proportional to the deflection, the increased stiffness due to infill has caused almost four-fold decrease in the displacement values. Thus, it is clear from the study that the effect of infill panels cannot be neglected while designing for horizontal forces. Considering infill panels in analysis would influence the seismic behaviour of frame structure to great extent since the panels increases strength and stiffness of the structure.

The consideration of infill panels is important because analysis of bare frame leads to the under estimation of the base shear values. This results in underestimated design which may lead to the failure of the structure during earthquake. Therefore, it is important that infill panels are considered while performing analysis of structures.

In IS 1893-Part 1(2016), clause 7.9.2.2-(d) it is stated that the thickness of the equivalent diagonal strut can be taken as thickness (t) of the URM wall provided, $\frac{h}{t} < 12$ and $\frac{l}{t} < 12$ where h and l are the clear height and length of the URM. This, provision is not satisfied when the thickness of strut is calculated and the value of $\frac{h}{t}$ generally comes greater than 12 therefore, this clause needs some clarification.

There is no provision for the consideration of openings in the infill panels. Openings can affect the behaviour of the panels when subjected to lateral loads, therefore the recommendations provided in the code could be expanded with inclusion of effect of openings.

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