Seismic Response of RC Frame Building with First Soft Storey

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Abstract - *Soft storey in buildings are used for the purpose of parking or reception lobbies. They are also called as stilt storey. A large number of buildings with soft storey have been built in India in recent years. But they show poor performance during earthquake. Therefore it is need of time to take measures to prevent the indiscriminate use of first soft storeys in buildings, which are designed without regard to the increased displacement and force demands in the first storey columns.*

The primary aim of this project is to analyse the response of a RC frame building with first soft storey under earthquake action using different masonry wall thickness. The designing, modeling and analysis of the building are carried out using STAAD Pro version 8.In this project the equivalent static response of a G+10 reinforced concrete frame building with first soft storey is analysed. The analysis is done using designing software STAAD Pro. Different models of a soft storey building with varying wall thickness are considered, including bare frame models and models with struts in X & Z directions, a total of 9 models were made. Struts are provided in modeling to consider the effect of stiffness of infill walls in a RC Frame. The equivalent width of struts is calculated according Paulay and Priestley's formula. Earthquake only in positive X & Z directions is considered and the struts are modeled parallel to direction of earthquake. Models with struts in X & Z directions are modeled separately and the struts are modeled as a compression member only for a positive direction earthquake. Seismic parameters, loading and designing of the models is done according to IS 1893(part 1):2002, IS 1893:1984 & IS 456:2000.

The results of Base Shear, Displacement, Axial Force, and Bending Moment-Y, Bending Moment-Z and Floor wise displacement, axial force, bending moment-Y & bending moment-Z were analysed using STAAD pro software. Different loading conditions were considered to find the maximum forces for different parameters.

Key Words: Equivalent Static Method, displacement, base shear, soft storey.

1. Introduction

As increased population from past few years there is need for car parking space in residential apartments in crowed cities, and this is a matter of major problem. The construction of multi-storey building with open first storey is implemented in the surrounding. Hence there is need to utilize the ground storey of the building itself for parking or reception lobbies in the first storey. These types of buildings have no infill masonry walls in ground storey, but all upper storeys are infilled with masonry walls. Such buildings are called "soft first storey or open ground storey building".

The devastating performances of such construction during earthquakes result in serious destruction of buildings with a soft ground floor. This storey is also known as weak storey because this storey's stiffness is lower compared to above storey, so they easily collapse during earthquake. Most of the existing buildings are vulnerable to future earthquakes, due to wrong construction practices and ignorance of earthquake resistant design for buildings in our country. So, most important is that design must be earthquake resistant.

Soft storey is also called as stilts storey. A large number of buildings with soft storey have been built in India in recent years. But it shows poor performance during earthquake. Therefore it is need of time to take immediate action to prevent the indiscriminate use of soft first storeys in buildings, which are designed without regard to the increased displacement and force demands in the first storey columns.

A Soft storey building is a multi-storey building with wide doors, large commercial spaces, or the ground storey is kept for open for the purpose of parking , i.e., columns in the ground storey do not have any partition walls between them.

- As per IS-1893:2002 (part I)

An Soft Storey is one in which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 percent of the average lateral stiffness of the three storey's above.

- Extreme Soft Storey

An extreme soft storey is one in which the lateral stiffness is less than 60 percent of that in the storey above or less than 70 percent of the average stiffness of the three storey's above.

1.1.1 Effect of Earthquake:

Due to earthquake, low –high waves which vibrate the base of structure in various manners and directions, lateral force is developed on structure. In such buildings, the stiffness of the lateral load resisting systems in soft storey is less than the stories above or below. Therefore buildings with soft storey act as an Inverted Pendulum i.e. it oscillates back and forth, this back and forth movement produces high stresses in columns and if columns are incapable of taking these stresses or do not posses enough ductility, they could get huge damaged and which can also collapse of the building. This is also known as inverted pendulum action. Soft stories go under larger lateral loads during earthquakes. These lateral forces are not easy to distribute along the height of structure. This causes the lateral forces to act on the storeys which have large displacement. The lateral force distribution along the height of a building is directly related to mass and stiffness of each storey.

Fig -1.1: Collapsed Soft Storey Building from Earthquake

Fig-1.2: Failed Soft Storey Column.

The presence of infill walls in the upper storey of the soft storey buildings increases the stiffness of the building globally, as seen in a typical infilled framed building. Due to the increase of global stiffness, the base shear demand on the building increases. In the case of typical infilled frame building, the increased base shear is shared by both frames and infill walls in the entire storey. In soft storey buildings, where the infill walls are not present in the ground storey (no truss action), the increased base shear is resisted entirely by the ground storey columns, without any load sharing possible by adjoining infill walls. The increased shear forces in the ground storey columns will induce increased bending moments and there by higher curvatures, causing relatively larger drifts at the first floor level. The large lateral deflections further enhance the bending moments due to the P-Δ effect. Plastic hinges are developed at the top and bottom ends of the ground storey columns. The upper storeys would remain undamaged and move almost like a rigid body. The damage is mostly concentrated in the ground storey columns, and this is termed as typical 'soft-storey collapse'. This is also called a 'storey-mechanism' or 'column mechanism' in the ground storey.

1.2 Objective of Work

The objectives of the project are to study the results of: -

1) Base Shear for all the models to compare and find the best possible model.
2) Displacement for all the models on each floor of the selected columns.
3) Axial Force for all the models for all the selected columns.
4) Bending Moment-Y for all the models on each floor for all the selected columns.
5) Bending Moment-Z for all the models on each floor for all the selected columns.
6) Floor wise Displacement, Axial Force, Bending moment-Y and Bending Moment-Z.

Using these results the behavior of soft storey building is studied and the best wall thickness or combination of wall thickness is found.

1.3 Methodology

• A RC-Frame, medium rise G+10 building with first soft storey and a suitable building plan were finalized.
• Modelling of selected building was done using STAAD Pro V8 software. The loading and specifications of the building are done with regard to IS 1893(Part 1)-2002, IS 1893-1984, IS 456.
• To consider the stiffness of masonry infill in STAAD, struts are provided within the frame of the building. Equivalent width of struts was calculated using Paulay and Priestley's formula. Struts are provided only to behave as a compression member, struts in tension were not provided.
• Suitable cross-section for the columns of the building is designed using STAAD Pro.
• Equivalent static analysis for Zone-III as per IS 1893:2002 is performed for 9 different columns.
• Earthquake in X & Z directions are considered seperately. Only positive direction earthquake are considered and the struts are provided parallel to the positive direction of earthquake.
• Graphs to determine the most sever load case for the selected 9 columns were made. The different load cases selected were-

- In X-direction strut models
  - i. 1.2(DL+LL+EQX)
  - ii. 1.5(DL+EQX)
  - iii. 0.9DL+1.5EQX
  - iv. 1.5(DL+LL)
  - v. 1.2(DL+LL)
  - vi. 1.5DL
- In Z-direction strut models
  - i. 1.2(DL+LL+EQZ)
  - ii. 1.5(DL+EQZ)
  - iii. 0.9DL+1.5EQZ
  - iv. 1.5(DL+LL)
  - v. 1.2(DL+LL)
  - vi. 1.5DL

From these graphs the maximum displacement, axial force, bending moment-Y, bending moment-Z were found for the most sever load case.

• Base Shear, Displacement, Axial Force, Bending Moment-Y, Bending Moment-Z & Floor wise distribution of all the above parameters are also analysed with regard to STAAD.

1.3.1 Modelling of Equivalent struts

The strength and the stiffness of infill walls in a RC-Frame building should be considered. Infill walls act as a compressive member within a frame. Non-integrated infill walls act as a diagonal strut when subjected to lateral loads. Therefore an infill wall can be modeled as a diagonal strut in compression only.

In this project the modeling of diagonal struts is performed using Paulay and Priestley paper published in 1992. In their paper they stated that the equivalent width of a diagonal strut can be taken as 1/4 th of the diagonal length of an infill wall.

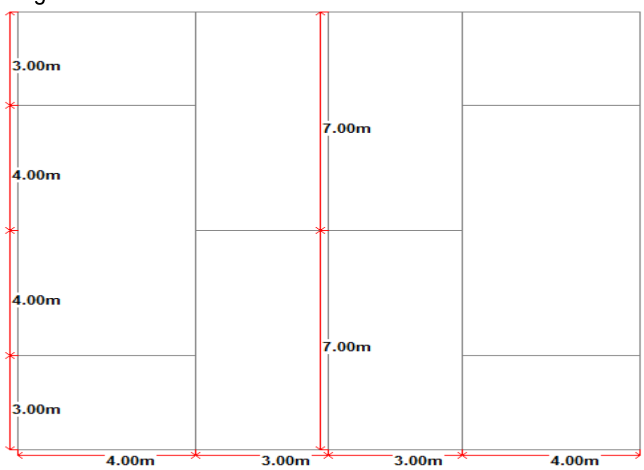

Fig -1.3: Dimensions of walls

The different widths of struts calculated are: -

Table-1.1: Equivalent Width of struts

Length x Height	Diagonal Length(m)	Equivalent width of Strut(m)
3x3m	4.24	1.06
4x3m	5	1.25
7x3m	7.62	1.9

While modelling a single strut, triangular struts are provided at both ends of the beam column joints and the equivalent width provided between the two triangular struts.

1.3.2 Specification

Table-1.2: Specifications

Sr. No.	Parameters	Dimensions/Type
1	Plan dimensions	14 m x 14 m
2	Number of stories	G+10
3	Total height of building	33.00 m
4	Height of each storey	3m
5	Size of beams	300 X 400 mm
6	Size of columns	450 X 600 mm
7	Thickness of slab	120 mm
8	Thickness of walls	250mm,150mm &250-150mm
9.	Frame Type	OMRF
9	Seismic zone	III
10	Soil condition	Medium
11	Importance	1
12	Response Reduction	3
13	Damping Ratio of structure	0.05
14	Live load a) On floor b) On roof	2.5 KN/m² none
15	Floor Finishing	35mm thick
16	Material	M30 Grade Concrete
17	Unit weights	a) Concrete = 25 KN/Cum b) Masonry =20 KN/Cum

1.3.3 Plan

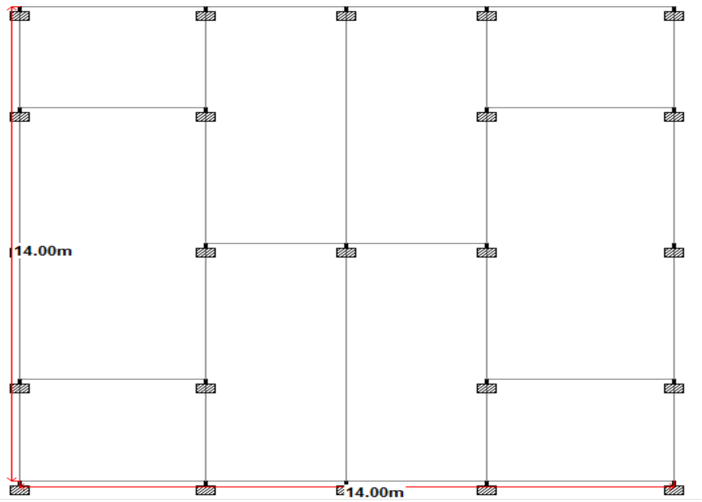

Fig -1.4: Plan Top View

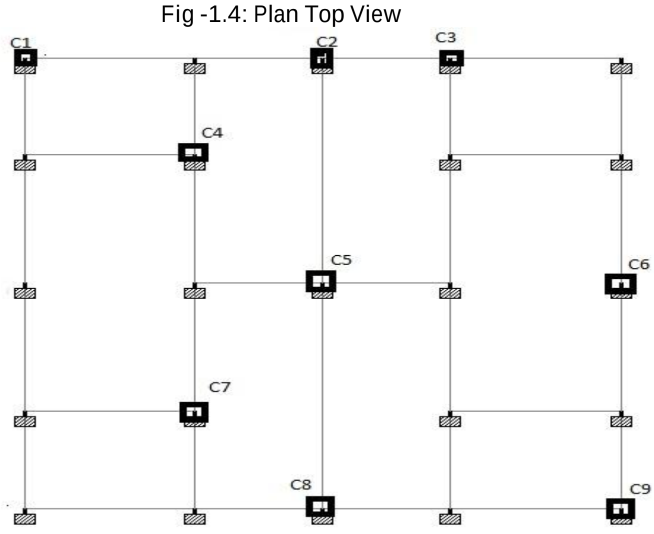

Fig -1.5: Plan with Selected Column

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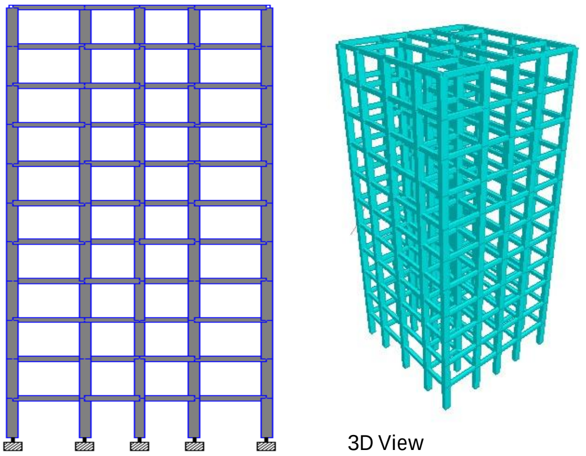
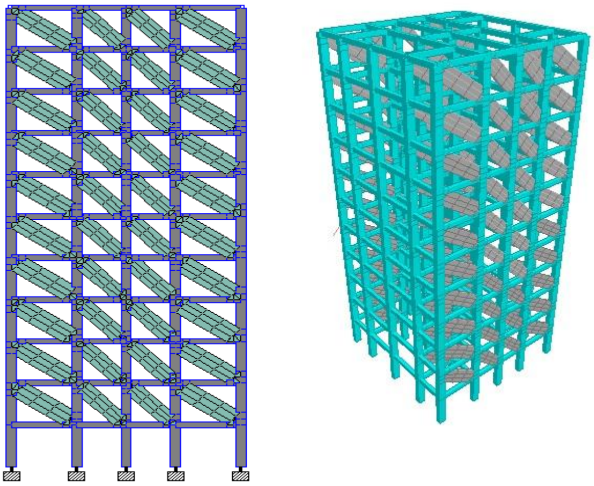
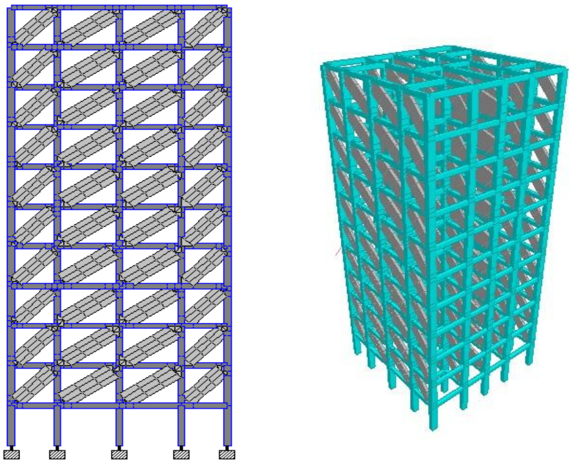
1.3.4 Structural Models

Model 1:-Bare Frame with 250mm Outer wall & 150mm Inner wall thickness.
Model 2:-250mm Outer wall & 150mm Inner wall thickness with Struts in X-Direction.
Model 3:-250mm Outer wall & 150mm Inner wall thickness with Struts in Z-Direction.
Model 4:-Bare Frame with Uniform 150mm wall thickness.
Model 5:-Uniform 150mm wall thickness with Struts in X-Direction.
Model 6:-Uniform 150mm wall thickness with Struts in Z-Direction.
Model 7:-Bare Frame with Uniform 250mm wall thickness.
Model 8:-Uniform 250mm wall thickness with Struts in X-Direction.
Model 9:-Uniform 150mm wall thickness with Struts in Z-Direction.

1.3.5 Images of STAAD Models


Front View 3D View
Fig-1.6: Bare frame model


Front View 3D View
Fig-1.7: Struts in X-Direction model


Side View 3D View
Fig-1.8: Struts in Z-Direction model

2. Analysis and Results

2.1 Base Shear

For Earthquake in X-direction

Table-1: Base shear for earthquake in X-direction

Models	Base Shear (KN)
Bare Frame 250-150 mm	1144.732
250-150mm with Struts in X-Direction	1489.21
Bare Frame Full 150mm	1004.601
Full 150mm with Struts in X-Direction	1306.909
Bare Frame Full 250mm	1244.826
Full 250mm with Struts in X-Direction	1619.425

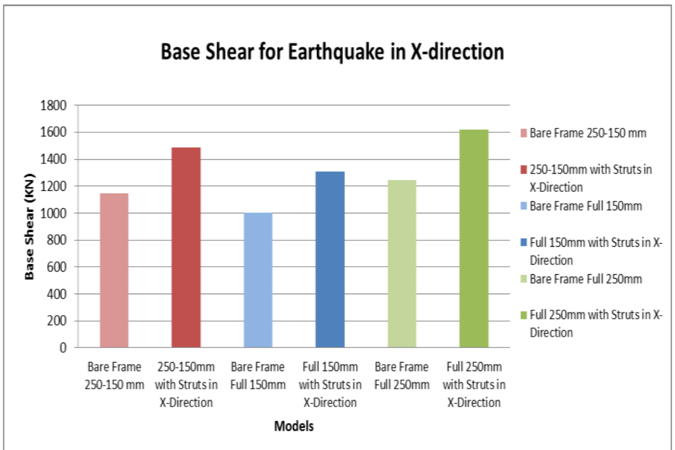


Figure-2.1: Base shear for earthquake in X-direction

For Earthquake in Z-direction

Table-2: Base shear for earthquake in Z-direction

Models	Base Shear (KN)
Bare Frame 250-150mm	1144.732
250-150mm with Struts in Z-Direction	1519.336
Bare Frame Full 150mm	1004.601
Full 150mm with Struts in Z-Direction	1328.515
Bare Frame Full 250mm	1244.826
Full 250mm with Struts in Z-Direction	1655.433

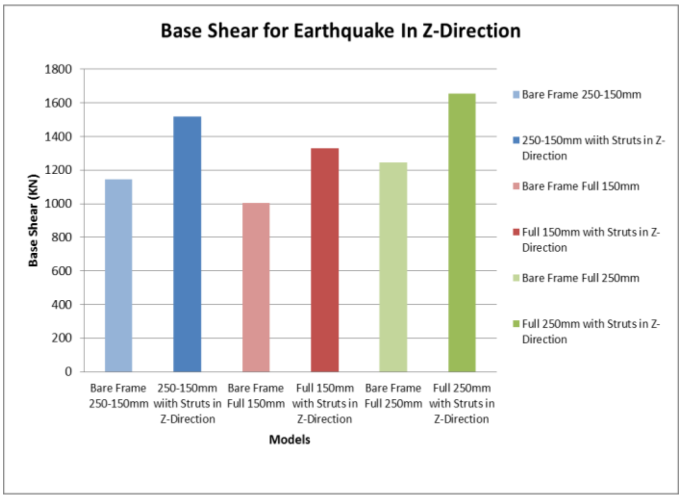


Figure-2.2: Base shear for earthquake in Z-direction

2.2 Displacement

Maximum Displacement for Column

For Earthquake in X-Direction

Table-3: Displacement by column for earthquake in X-direction

Columns	Bare Frame 250-150 mm	250-150 mm with struts in X-Direction	Bare Frame Full 150 mm	Full 150mm with Struts in X-Direction	Bare Frame Full 250 mm	Full 250mm with Struts in X-Direction
C1	68.7	17.13	60.73	18.44	74.63	17.56
C2	68.9	17.30	60.86	18.56	74.73	17.74
C3	68.9	17.37	60.85	18.60	74.71	17.82
C4	69.1	17.41	60.88	18.68	74.75	17.91
C5	69.1	17.55	61.03	18.76	74.93	18.05
C6	68.8	17.39	60.78	18.62	74.63	17.84
C7	68.9	17.43	60.83	18.69	74.70	17.93
C8	69.1	17.34	60.78	18.58	74.64	17.79
C9	69.1	17.64	60.75	18.77	74.60	18.11

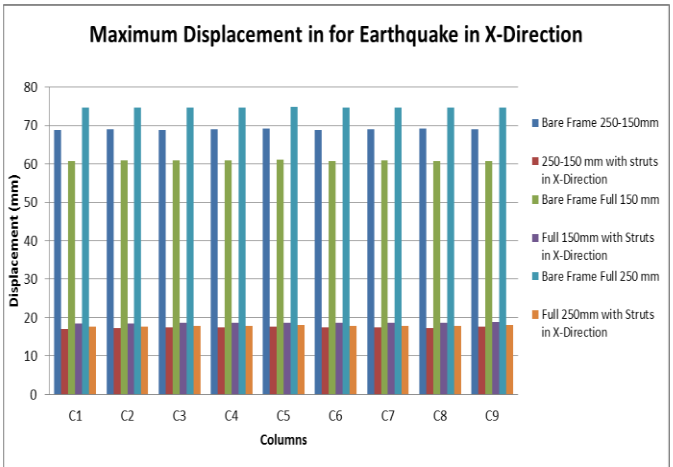


Fig-2.3: Displacement by column for earthquake in X-direction

For Earthquake in Z-Direction

Table-4: Displacement by column for earthquake in Z-direction

Columns	Bare Frame 250-150mm	250-150 mm with struts in Z-Direction	Bare Frame Full 150 mm	Full 150mm with Struts in Z-Direction	Bare Frame Full 250 mm	Full 250mm with Struts in Z-Direction
C1	64.17	12.91	56.84	13.36	69.5	12.69
C2	64.30	13.05	56.72	13.46	69.6	12.84
C3	64.22	12.98	56.58	13.41	69.5	12.76
C4	64.21	13.07	56.89	13.50	69.8	12.88
C5	64.58	13.78	57	13.93	70	13.69
C6	64.28	13.08	56.50	13.49	69.4	12.87
C7	64.29	13.28	56.86	13.67	69.8	13.29
C8	64.43	14.08	56.83	14.01	69.8	13.97
C9	64.37	13.34	56.54	13.66	69.4	13.15

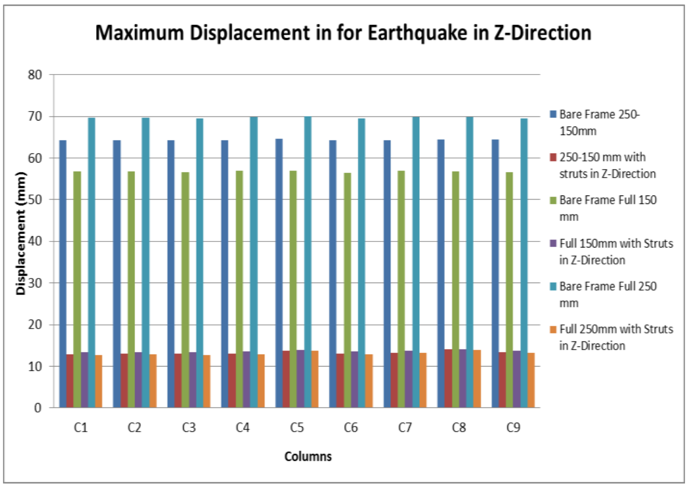


Fig-2.4: Displacement by column for earthquake in Z-direction

Maximum Displacement by Model

For Earthquake in X-Direction

Table5: Displacement by model for earthquake in X-direction

Models with struts in X-direction	Maximum Displacement (mm)
Bare Frame 250-150mm	69.146
250-150 mm with struts in X-Direction	17.645
Bare Frame Full 150 mm	61.031
Full 150mm with Struts in X-Direction	18.776
Bare Frame Full 250 mm	74.939
Full 250mm with Struts in X-Direction	18.11

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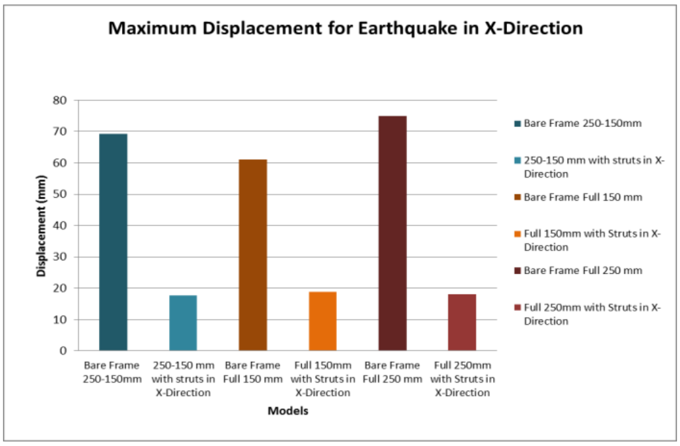

Fig-2.5: Displacement by model for earthquake in X-direction

For Earthquake in Z-Direction

Table-6: Displacement by model for earthquake in Z-direction

Models with struts in Z-direction	Maximum Displacement (mm)
Bare Frame 250-150mm	64.58
250-150 mm with struts in Z-Direction	14.089
Bare Frame Full 150 mm	57
Full 150mm with Struts in Z-Direction	14.018
Bare Frame Full 250 mm	70.006
Full 250mm with Struts in Z-Direction	13.973

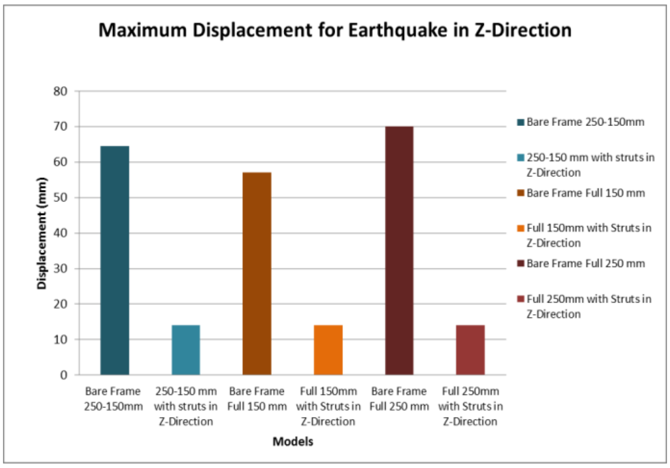

Fig-2.6: Displacement by model for earthquake in Z-direction

Maximum Floor wise Displacement Graphs
For Earthquake in X-Direction

Table-7: Floor wise Displacement for earthquake in X-direction

Height	Bare Frame 250-150 mm	250-150 mm with struts In X-Direction	Bare Frame Full 150 mm	Full 150mm with Struts In X-Direction	Bare Frame Full 250 mm	Full 250mm with Struts In X-Direction
0	0	0	0	0	0	0
3	1.83	1.288	1.615	1.381	2.854	1.36
6	9.74	3.62	8.097	3.691	9.964	3.72
9	17.9	5.153	15.09	5.431	19.53	5.12
12	25.1	6.752	23.27	7.207	28.06	6.75
15	34.8	8.417	30.69	9.082	36.51	8.43
18	42.3	10.12	37.77	10.96	46.71	10.1
21	50.3	11.82	44.29	12.76	54.71	11.9
24	56.3	13.38	49.95	14.51	61.70	13.5
27	62.0	14.87	54.67	16.07	66.96	15.0
30	65.9	16.12	58.14	17.39	70.94	16.4
33	68.5	17.14	60.50	18.44	74.27	17.5

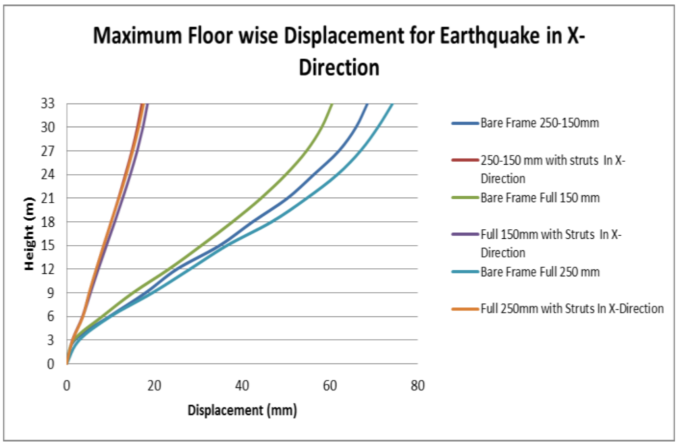

Fig-2.7: Floor wise displacement for earthquake in X-direction

For Earthquake in Z-Direction

Table-8: Floor wise Displacement for earthquake in Z-direction

Floor	Height	Bare Frame 250-150 mm	250-150 mm with struts In Z-Direction	Bare Frame Full 150 mm	Full 150mm with Struts In Z-Direction	Bare Frame Full 250 mm	Full 250 mm with Struts In Z-Direction
FL	0	0	0	0	0	0	0
GF	3	1.09	0.574	0.97	0.653	1.199	0.61
1F	6	8.48	3.973	5.724	3.88	9.224	4.08
2F	9	16.7	4.95	14.12	4.993	17.48	4.98
3F	12	24.8	6.036	21.79	6.192	26.98	6.00
4F	15	32.5	7.154	28.59	7.42	35.39	7.06
5F	18	39.9	8.289	35.10	8.654	43.42	8.16
6F	21	46.7	9.423	41.13	9.837	50.84	9.22
7F	24	52.8	10.48	46.47	10.94	57.38	10.2
8F	27	57.8	11.42	50.90	11.94	62.77	11.2
9F	30	61.2	12.24	54.21	12.72	66.44	11.9
10F	33	63.7	12.85	56.29	13.32	69.12	12.6

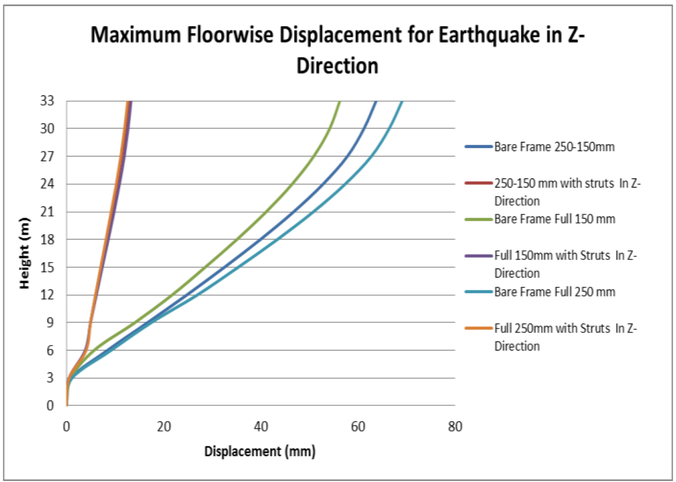

Fig-2.8: Floor wise displacement for earthquake in Z-direction

2.3 Maximum Axial Force

Maximum Axial Force by Column
For Earthquake in X-Direction

Table-9: Axial force by column for earthquake in X-direction

Columns	Bare Frame 250-150mm	250-150 mm with struts in X-Direction	Bare Frame Full 150 mm	Full 150mm with Struts in X-Direction	Bare Frame Full 250 mm	Full 250mm with Struts in X-Direction
C1	1713	1924	1424	1592	1756.7	2003.6
C2	2769	2404	2313	2073	2828.1	2481.0
C3	2208	2242	1906	1873	2375.3	2348.9
C4	2498	2433	2415	2305	2885.8	2792.2
C5	4115	3671	3691	3366	4427.9	3956.2
C6	2177	2191	1845	1870	2210.8	2239.6
C7	2498	2434	2415	2306	2885.8	2793.6
C8	2769	2409	2313	2076	2828.0	2486.2
C9	2158	2735	1798	2221	2250.9	2824.4

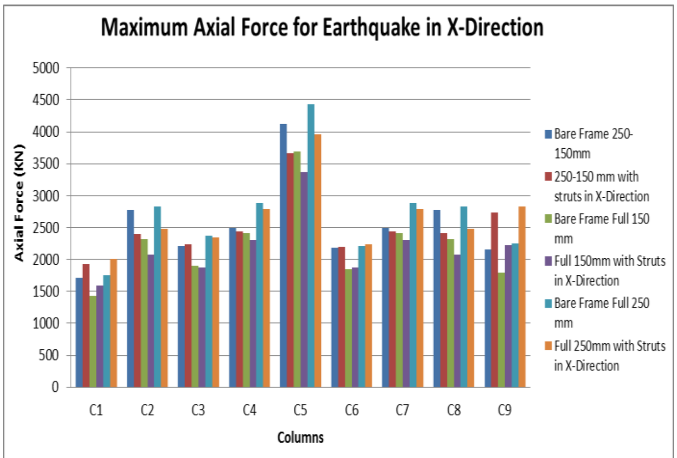

Fig-2.9: Axial force by column for earthquake in X-direction

For Earthquake in Z-Direction

Table-10: Axial force by column for earthquake in Z-direction

Columns	Bare Frame 250-150mm	250-150 mm with struts in Z-Direction	Bare Frame Full 150 mm	Full 150mm with Struts in Z-Direction	Bare Frame Full 250 mm	Full 250mm with Struts in Z-Direction
C1	1713	1856.8	1424	1559.0	1756	1937.6
C2	2769	3094.3	2313	2590.3	2828	3224.9
C3	2200	2301.9	1906	2061.9	2345	2535.8
C4	2402	2525.8	2415	2396.7	2885	2883.6
C5	4115	3670.3	3691	3292.1	4427	3886.2
C6	2177	2180.4	1845	1855.7	2210	2253.4
C7	2498	2535.4	2415	2406.7	2885	2885.1
C8	2769	3253.3	2313	2665.2	2851	3368.1
C9	2293	2509.8	1917	2016.5	2397	2560.5

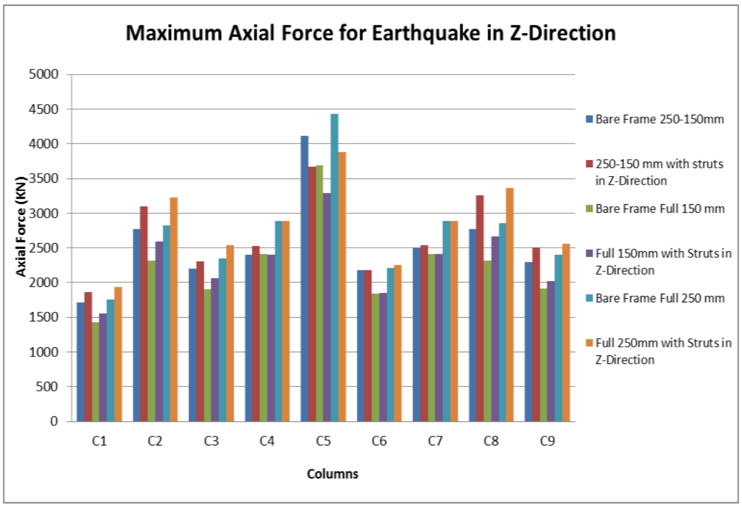

Fig-2.10: Axial force by column for earthquake in Z-direction

Maximum Axial Force by Model
For Earthquake in X-Direction

Table-11: Axial force by model for earthquake in X-direction

Models with struts in X-direction	Maximum Axial Fore (KN)
Bare Frame 250-150mm	4115.813
250-150 mm with struts in X-Direction	3671.029
Bare Frame Full 150 mm	3691.237
Full 150mm with Struts in X-Direction	3366
Bare Frame Full 250 mm	4427.938
Full 250mm with Struts in X-Direction	3956.225

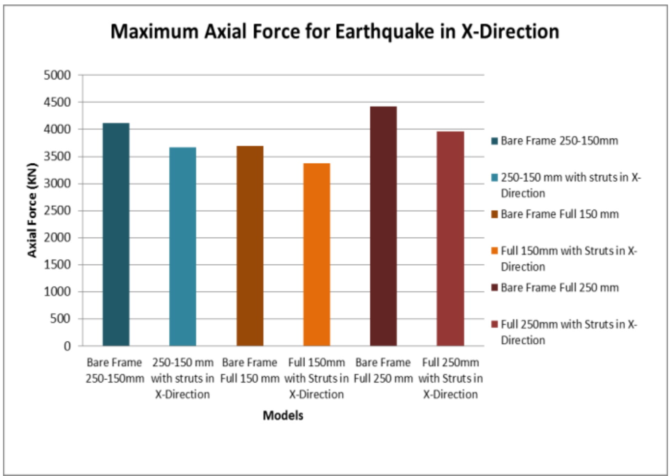

Fig-2.11: Axial force by model for earthquake in X-direction

For Earthquake in Z-Direction

Table-12: Axial force by model for earthquake in Z-direction

Models with struts in Z-direction	Maximum Axial Fore (KN)
Bare Frame 250-150mm	4115.813
250-150 mm with struts in Z-Direction	3670.326
Bare Frame Full 150 mm	3691.237
Full 150mm with Struts in Z-Direction	3292.141
Bare Frame Full 250 mm	4427.938
Full 250mm with Struts in Z-Direction	3886.215

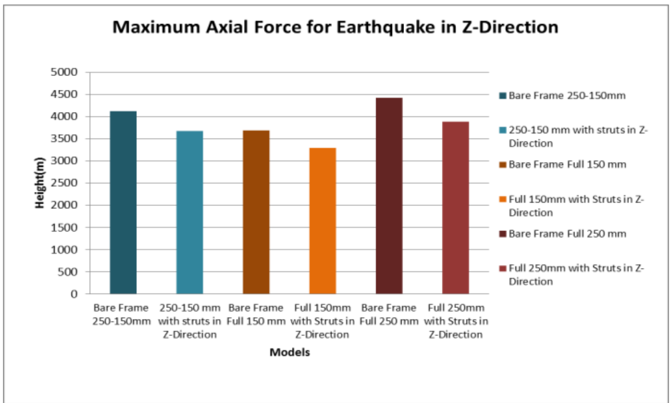

Fig-2.12: Axial force by model for earthquake in Z-direction

Maximum Floor wise Axial Force
For Earthquake in X-Direction

Table-13: Floor wise axial force for earthquake in X-direction

Height	Bare Frame 250-150mm	250-150 mm with struts In X-Direction	Bare Frame Full 150 mm	Full 150mm with Struts In X-Direction	Bare Frame Full 250 mm	Full 250mm with Struts In X-Direction
0	4115	3671	3691	3366	4427	3956
3	3665	3164	3296	2914	3950	3394
6	3232	2778	2915	2569	3488	2992
9	2813	2413	2544	2239	3039	2608
12	2405	2061	2182	1919	2601	2236
15	2006	1721	1827	1607	2171	1871
18	1615	1388	1477	1301	1748	1512
21	1229	1059	1131	999.3	1331	1156
24	847.6	734.5	789.3	699.7	917.3	802
27	467.9	409.8	448.8	401.2	505.5	448
30	111.7	129.4	121.8	118	107.2	131

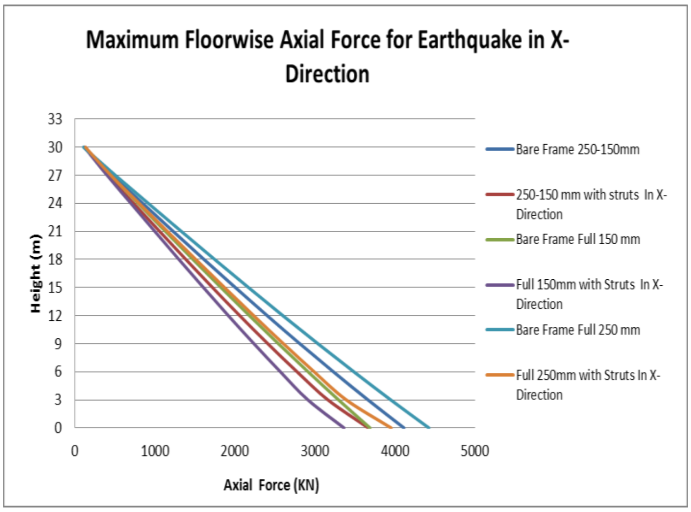

Fig-2.13: Floor wise axial force for earthquake in X-direction

For Earthquake in Z-Direction

Table-14: Floor wise axial force for earthquake in Z-direction

Floor	Height	Bare Frame 250-150mm	250-150 mm with struts In Z-Direction	Bare Frame Full 150 mm	Full 150mm with Struts In Z-Direction	Bare Frame Full 250 mm	Full 250mm with Struts In Z-Direction
GF	0	4115	3670	3691	3292	4427	3886
1F	3	3665	3236	3296	2902	3950	3430
2F	6	3232	2827	2915	2541	3488	2996
3F	9	2813	2447	2544	2202	3039	2594
4F	12	2405	2082	2182	1877	2601	2207
5F	15	2006	1729	1827	1562	2171	1833
6F	18	1615	1386	1477	1270	1748	1469
7F	21	1229	1060	1131	985.5	1331	1114
8F	24	847.6	753.5	789.3	705.1	917.3	788.3
9F	27	467.9	471.9	448.8	427.2	505.5	497.5
10F	30	124.4	204.9	121.8	195.5	116.3	217.0

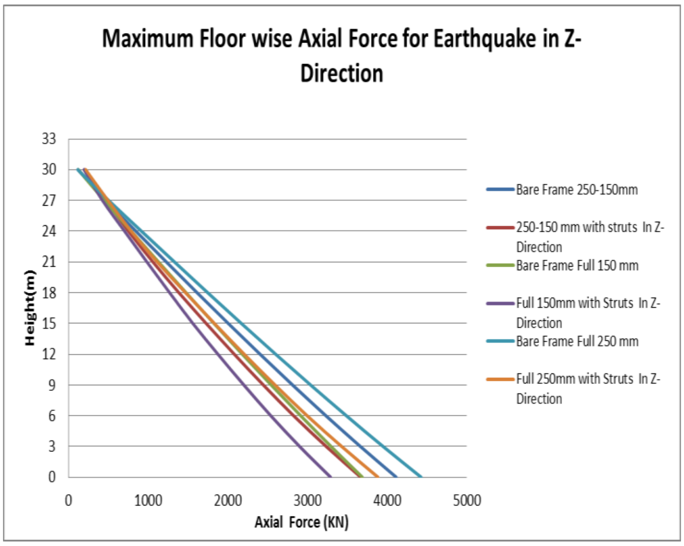

Fig-2.14: Floor wise axial force for earthquake in Z-direction

2.4 Bending Moment-Y

Maximum Bending Moment-Y by Column

For Earthquake in X-Direction

Table-15: Bending moment-Y by column for earthquake in X-direction

Columns	Bare Frame 250-150mm	250-150 mm with struts in X-Direction	Bare Frame Full 150 mm	Full 150mm with Struts in X-Direction	Bare Frame Full 250 mm	Full 250mm with Struts in X-Direction
C1	115.9	30.69	101.7	29.4	126.0	35.71
C2	113.0	110.4	94.94	94.1	117.6	110.8
C3	115.8	20.54	101.6	26.2	125.9	27.01
C4	127.7	35.82	112.1	39.9	138.9	44.45
C5	116.4	0.038	102.2	0.02	126.6	0.038
C6	124.8	0.352	109.6	0.19	135.7	0.367
C7	127.7	35.86	112.1	39.9	138.9	44.49
C8	113.0	110.5	94.94	94.1	117.6	110.8
C9	115.9	22.19	101.7	25.5	126.0	28.57

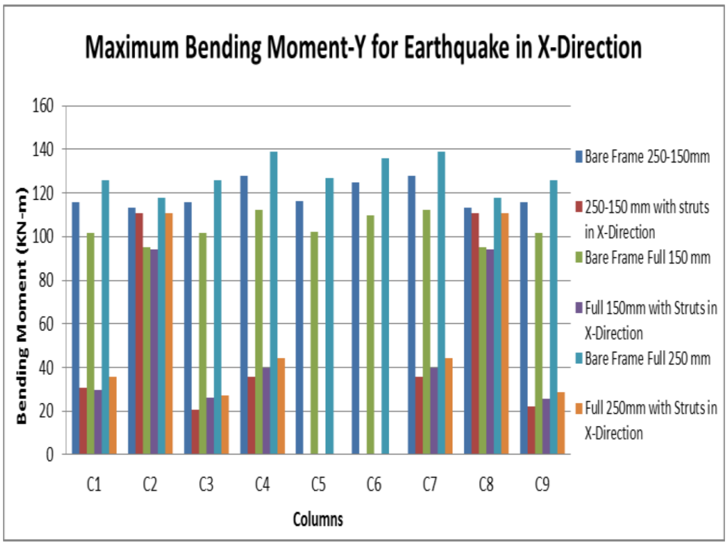

Fig-2.15: Bending moment-Y by column for earthquake in X-direction

For Earthquake in Z-Direction

Table-16: Bending moment-Y by column for earthquake in Z-direction

Columns	Bare Frame 250-150mm	250-150 mm with struts in Z-Direction	Bare Frame Full 150 mm	Full 150mm with Struts in Z-Direction	Bare Frame Full 250 mm	Full 250mm with Struts in Z-Direction
C1	171.1	164.62	150.4	147.59	186.2	177.1
C2	143.4	147.94	127.3	130.56	157.5	159.2
C3	171.1	164.52	149.7	146.84	185.4	176.4
C4	189.4	176.38	165.8	157.75	205.5	190.3
C5	174.6	177.76	153.3	156.77	189.9	191.0
C6	187.3	180.61	164.4	160.34	203.6	193.8
C7	195.3	182.63	172.2	164.51	213.2	198.1
C8	193.6	200.19	167.4	174.56	207.9	212.7
C9	178.3	177.72	156.0	156.26	193.7	190.5

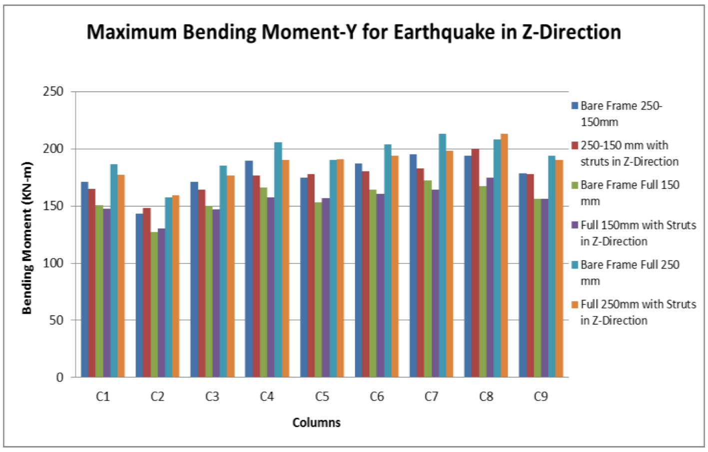

Fig-2.16: Bending moment-Y by column for earthquake in Z-direction

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Maximum Bending Moment-Y by Model
For Earthquake in X-Direction

Table-17: Bending moment-Y by model for earthquake in X-direction

Models with struts in X-direction	Maximum Bending Moment-Y (KN-m)
Bare Frame 250-150mm	127.799
250-150 mm with struts in X-Direction	110.505
Bare Frame Full 150 mm	112.164
Full 150mm with Struts in X-Direction	94.164
Bare Frame Full 250 mm	138.966
Full 250mm with Struts in X-Direction	110.85

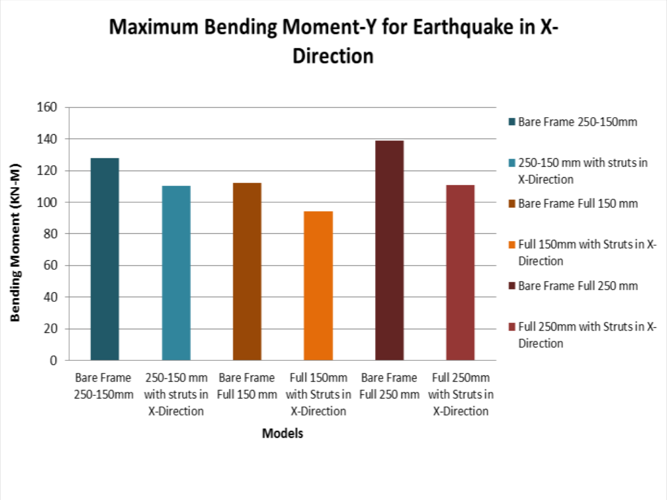

Fig-2.17: Bending moment-Y by model for earthquake in X-direction

For Earthquake in Z-Direction

Table-18: Bending moment-Y by model for earthquake in Z-direction

Models with struts in Z-direction	Maximum Bending Moment-Y (KN-m)
Bare Frame 250-150mm	195.389
250-150 mm with struts in Z-Direction	200.195
Bare Frame Full 150 mm	172.24
Full 150mm with Struts in Z-Direction	174.563
Bare Frame Full 250 mm	213.25
Full 250mm with Struts in Z-Direction	212.768

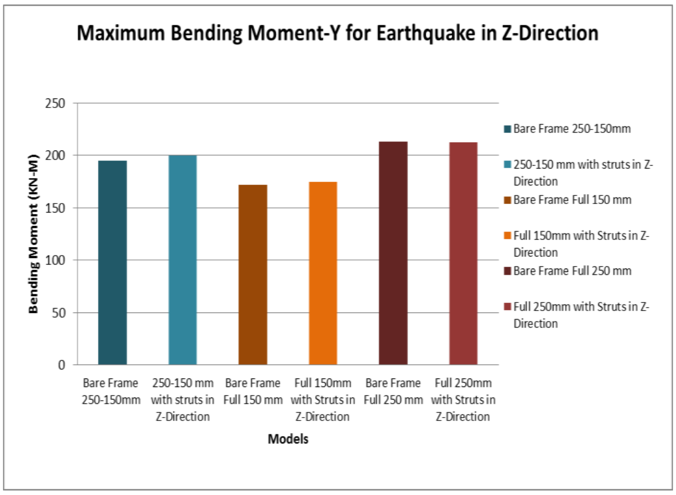

Fig-2.18: Bending moment-Y by model for earthquake in Z-direction

Maximum Floor wise Bending Moment-Y Graphs
For Earthquake in X-Direction

Table-19: Floor wise bending moment-Y by model for earthquake in X-direction

Floor	Height	Bare Frame 250-150 mm	250-150 mm with struts In X-Direction	Bare Frame Full 150 mm	Full 150 mm with Struts In X-Direction	Bare Frame Full 250 mm	Full 250mm with Struts In X-Direction
GF	0	127.7	80.96	112	68.5	138.9	81.20
1F	3	113.1	110.5	94.8	94.1	116.7	110.5
2F	6	100.4	97.17	86.9	83.6	107.7	97.65
3F	9	102.6	99.25	86.6	85.4	103.6	99.81
4F	12	103.1	99.53	87.2	85.9	104.2	100.2
5F	15	103.7	100.2	88.0	86.6	105.0	100.9
6F	18	104.2	100.6	88.5	87.1	105.6	101.4
7F	21	105.1	101.3	89.1	87.7	106.5	102.2
8F	24	104.5	100.8	89.1	87.5	106	101.8
9F	27	111.7	107.8	92.6	91.2	113	108.6
10F	30	96.86	93.64	85.5	83.9	98.8	94.88

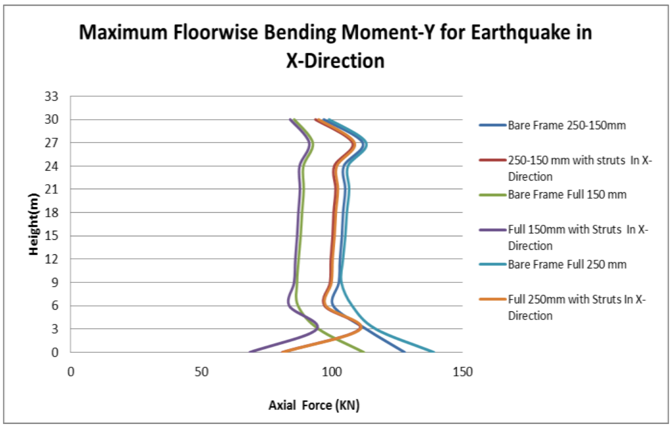

Fig-2.19: Floor wise bending moment-Y by model for earthquake in X-direction

For Earthquake in Z-Direction

Table-20: Floor wise bending moment-Y by model for earthquake in Z-direction

Floor	Height	Bare Frame 250-150mm	250-150 mm with struts In Z-Direction	Bare Frame Full 150 mm	Full 150mm with Struts In Z-Direction	Bare Frame Full 250 mm	Full 250mm with Struts In Z-Direction
GF	0	195.3	200	172	174.5	213.2	212.7
1F	3	172.3	147	153	117.2	190.0	159.2
2F	6	160.2	107	143	84.74	177.3	107.7
3F	9	155.9	102	141	83.20	173.9	102.1
4F	12	153.8	97.9	140	82.54	172.2	97.60
5F	15	148.3	95.9	135	81.49	166.7	95.85
6F	18	139.1	92.8	128	79.55	157.0	93.10
7F	21	129.8	88.6	116	76.56	142.4	89.17
8F	24	125.6	85.8	105	76.77	130.5	87.52
9F	27	123.4	82.8	100	75.17	127.6	84.40
10F	30	96.86	73.8	85.5	70.76	98.86	75.53

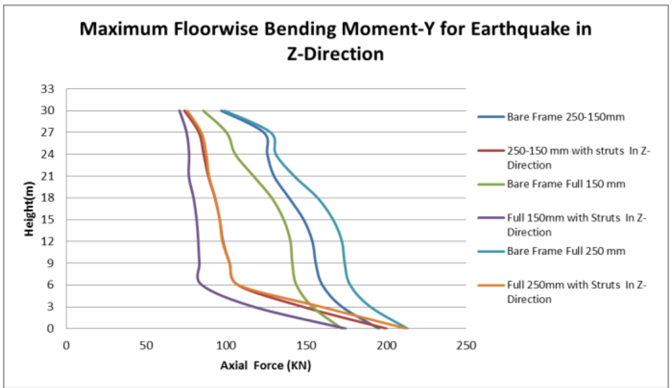

Fig-2.20: Floor wise bending moment-Y by model for earthquake in X-direction

2.5 Maximum Bending Moment-Z

Max Bending Moment-Z by Column
For Earthquake in X-Direction

Table-21: Bending moment-Z by column for earthquake in X-direction

Columns	Bare Frame 250-150mm	250-150 mm with struts in X-Direction	Bare Frame Full 150 mm	Full 150mm with Struts in X-Direction	Bare Frame Full 250 mm	Full 250mm with Struts in X-Direction
C1	228.5	183.4	201.2	168.16	248.9	196.1
C2	260.5	204.8	228.6	187.32	283.3	218.1
C3	254.5	201.0	223.5	183.42	276.8	214.3
C4	241.5	200.8	212.7	184.74	263.9	217.5
C5	260.3	203.8	228.5	186.79	283.1	217.7
C6	214.6	180.7	188.4	164.67	233.4	193.2
C7	241.5	201.4	212.7	185.08	263.9	218.1
C8	260.5	205.8	228.6	187.87	283.3	219.1
C9	242.0	206.9	211.3	185.33	262.5	219.6

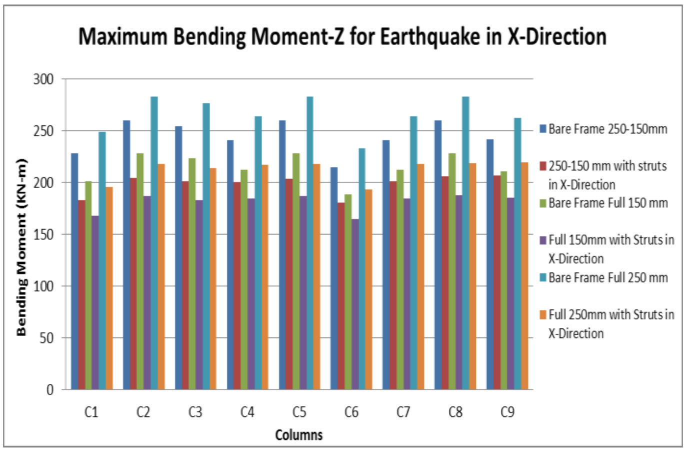

Fig-2.21: Bending moment-Z by column for earthquake in X-direction

For Earthquake in Z-Direction

Table-22: Bending moment-Z by column for earthquake in Z-direction

Columns	Bare Frame 250-150mm	250-150 mm with struts in Z-Direction	Bare Frame Full 150 mm	Full 150mm with Struts in Z-Direction	Bare Frame Full 250 mm	Full 250 mm with Struts in Z-Direction
C1	155.7	31.46	136.7	26.762	169.3	33.6
C2	173.6	0.416	152.4	0.254	188.8	0.42
C3	170.6	32.38	149.8	25.388	185.6	31.5
C4	156.0	27.54	136.9	26.941	169.6	32.5

C5	173.5	0.184	152.3	0.113	188.7	0.18
C6	142.9	0.56	125.5	0.871	155.4	0.62
C7	156.0	27.67	136.9	27	169.6	32.6
C8	173.6	0.387	152.4	0.213	188.8	0.39
C9	155.7	31.89	136.7	27.241	169.3	34.2

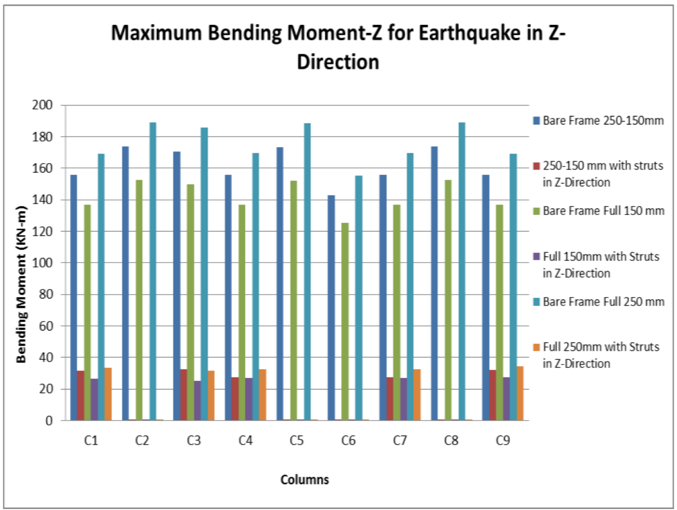

Fig-2.22: Bending moment-Z by column for earthquake in Z-direction

Max Bending Moment-Z by Model

For Earthquake in X-Direction

Table-23: Bending moment-Z by model for earthquake in X-direction

Models with struts in X-direction	Maximum Bending Moment-Z (KN-m)
Bare Frame 250-150mm	260.547
250-150 mm with struts in X-Direction	206.979
Bare Frame Full 150 mm	228.691
Full 150mm with Struts in X-Direction	187.873
Bare Frame Full 250 mm	283.302
Full 250mm with Struts in X-Direction	219.612

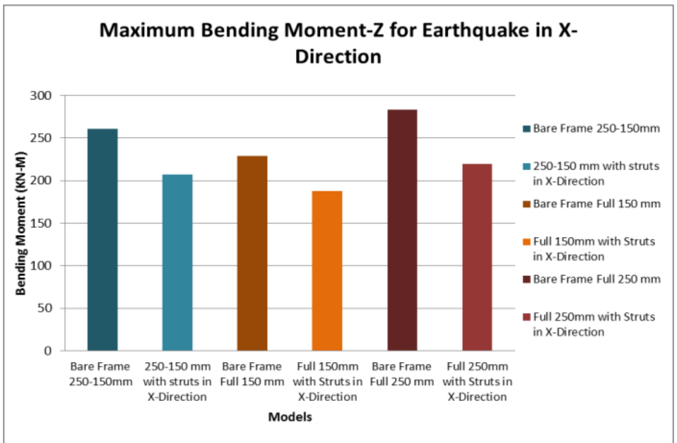

Fig-2.23: Bending moment-Z by model for earthquake in X-direction

For Earthquake in Z-Direction

Table-24: Bending moment-Z by model for earthquake in Z-direction

Models with struts in Z-direction	Maximum Bending Moment-Z (KN-m)
Bare Frame 250-150mm	173.698
250-150 mm with struts in Z-Direction	32.385
Bare Frame Full 150 mm	152.46
Full 150mm with Struts in Z-Direction	27.241
Bare Frame Full 250 mm	188.868
Full 250mm with Struts in Z-Direction	34.284

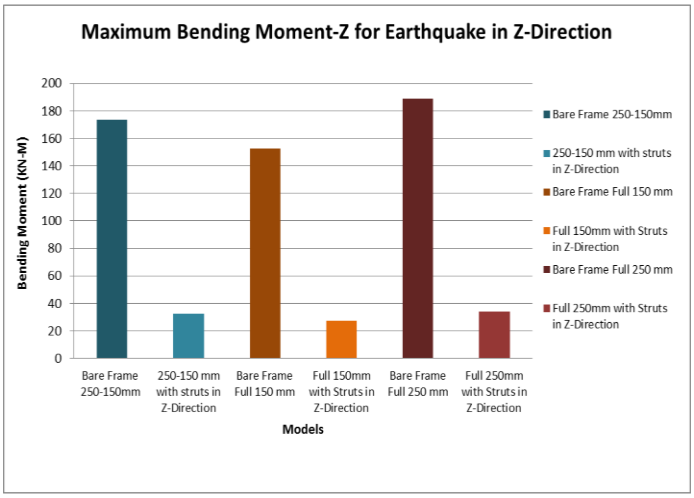

Fig-2.24: Bending moment-Z by model for earthquake in Z-direction

Floor wise Max Bending Moment-Z Graphs

For Earthquake in X-Direction

Table-25: Floor wise bending moment-Z for earthquake in X-direction

Floor	Height	Bare Frame 250-150mm	250-150 mm with struts In X-Direction	Bare Frame Full 150 mm	Full 150mm with Struts In X-Direction	Bare Frame Full 250 mm	Full 250mm with Struts In X-Direction
GF	0	127.7	80.96	112.1	68.56	138.9	81.20
1F	3	113.0	110.5	94.87	94.16	116.7	110.8
2F	6	100.4	97.17	86.98	83.63	107.7	97.65
3F	9	102.6	99.25	86.62	85.49	103.6	99.81
4F	12	103.2	99.53	87.22	85.96	104.2	100.2
5F	15	103.7	100.2	88.00	86.65	105.0	100.9
6F	18	104.2	100.6	88.53	87.13	105.6	101.4
7F	21	105.1	101.3	89.17	87.73	106.5	102.2
8F	24	104.5	100.8	89.04	87.58	106.0	101.8
9F	27	111.7	107.8	92.63	91.26	113.0	108.6
10F	30	96.86	93.64	85.54	83.99	98.86	94.88

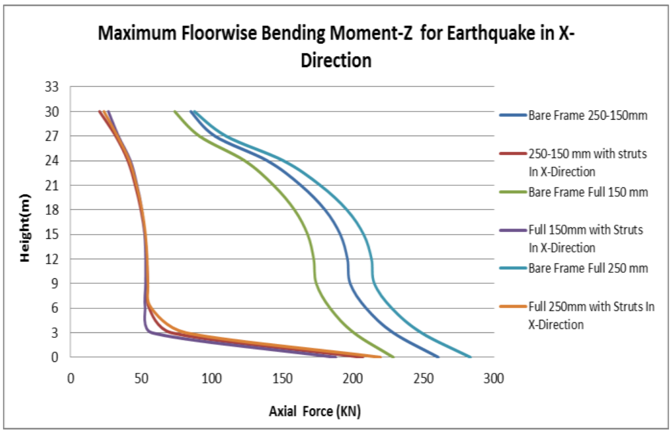

Fig-2.25: Floor wise bending moment-Z for earthquake in X-direction

For Earthquake in Z-Direction

Table-26: Floor wise bending moment-Z for earthquake in Z-direction

Floor	Height	Bare Frame 250-150mm	250-150 mm with struts In Z-Direction	Bare Frame Full 150 mm	Full 150 mm with Struts In Z-Direction	Bare Frame Full 250 mm	Full 250mm with Struts In Z-Direction
GF	0	173.6	20.72	152.4	20.3	188.8	24.63
1F	3	152.3	28.47	133.7	27	165.6	32.61
2F	6	139.5	26.26	122.5	21.7	151.6	27.78
3F	9	132.2	27.43	116.0	23.0	143.4	29.34
4F	12	130.7	28.18	114.8	23.9	142.1	30.40
5F	15	127.3	28.88	111.9	24.8	138.4	31.35
6F	18	120.	29.42	105.7	25.4	130.4	32.08
7F	21	108.7	29.98	95.84	25.9	117.8	32.74
8F	24	92.85	29.94	82.19	26.3	100.4	32.85
9F	27	68.14	31.89	60.79	26.5	73.38	34.28
10F	30	46.78	32.38	42.91	27.2	49.52	32.30

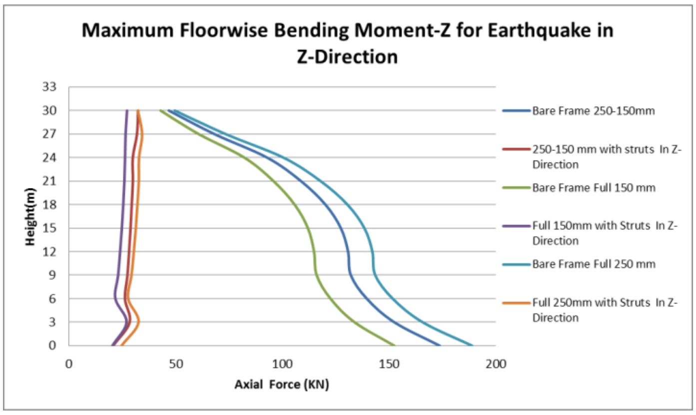

Fig-2.26: Floor wise bending moment-Z for earthquake in Z-direction

2.6 Percentage variation of different Models

Percentage variation of Base Shear

For Earthquake in X-Direction

Table-27: Percentage variation of base shear for earthquake in X-direction

Models	% variation w.r.t Bare Frame Full 150mm
Bare Frame 250-150 mm	13.95
250-150mm with Struts in X-Direction	48.240
Bare Frame Full 150mm	1.000
Full 150mm with Struts in X-Direction	30.1
Bare Frame Full 250mm	23.9
Full 250mm with Struts in X-Direction	61.2

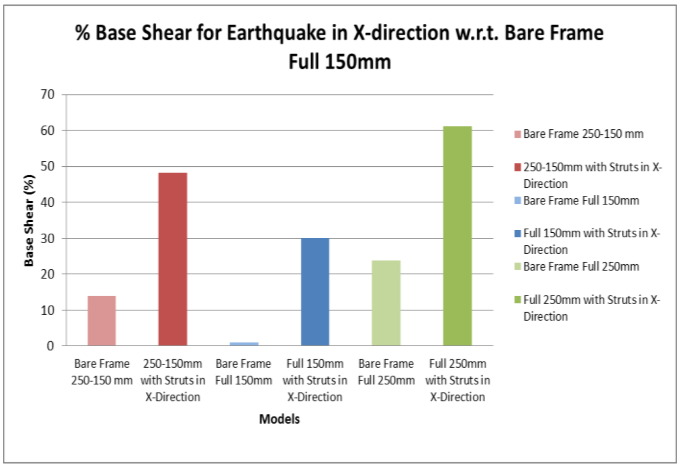

Fig-2.27: Percentage variation of base shear for earthquake in X-direction

For Earthquake in Z-Direction

Table-28: Percentage variation of base shear for earthquake in Z-direction

Models	% variation w.r.t Bare Frame Full 150mm
Bare Frame 250-150mm	13.95
250-150mm with Struts in Z-Direction	51.45
Bare Frame Full 150mm	1.000
Full 150mm with Struts in Z-Direction	32.240
Bare Frame Full 250mm	23.9
Full 250mm with Struts in Z-Direction	64.790

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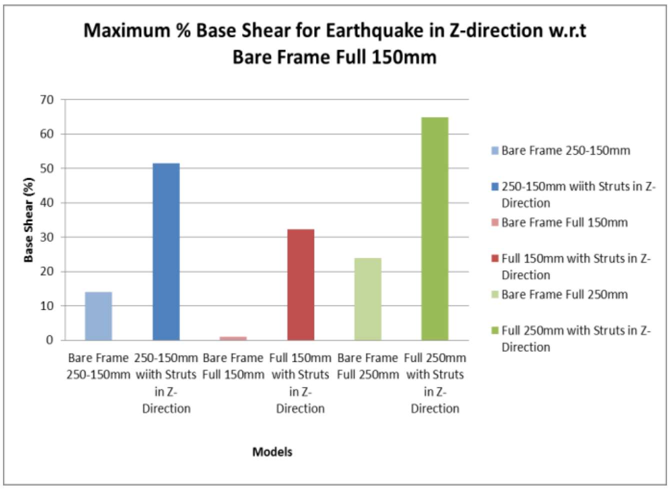

Fig-2.28: Percentage variation of base shear for earthquake in Z-direction

Percentage variation of Displacement

For Earthquake in X-Direction

Table-29: Percentage variation of displacement for earthquake in X-direction

Models with struts in X-direction	% variation w.r.t 250-150 mm with struts in X-Direction
Bare Frame 250-150mm	391.8
250-150 mm with struts in X-Direction	1
Bare Frame Full 150 mm	345.8
Full 150mm with Struts in X-Direction	6.41
Bare Frame Full 250 mm	424.7
Full 250mm with Struts in X-Direction	2.63

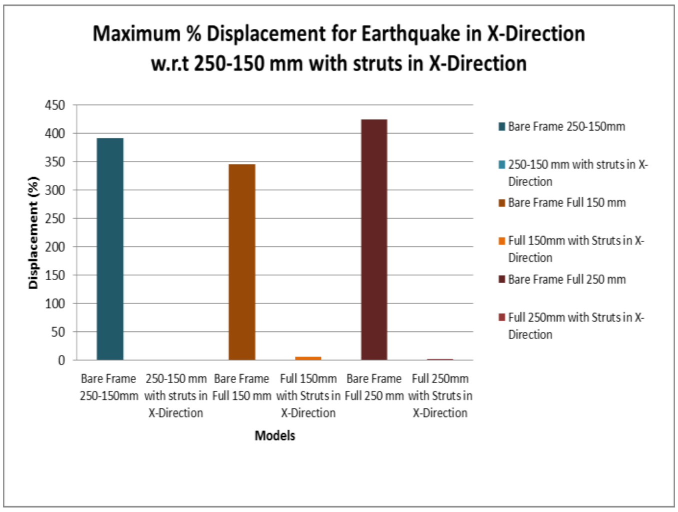

Fig-2.29: Percentage variation of displacement for earthquake in X-direction

For Earthquake in Z-Direction

Table-30: Percentage variation of displacement for earthquake in Z-direction

Models with struts in Z-direction	% variation w.r.t Full 250mm with Struts in Z-Direction
Bare Frame 250-150mm	462.2
250-150 mm with struts in Z-Direction	0.83
Bare Frame Full 150 mm	407.9
Full 150mm with Struts in Z-Direction	0.32
Bare Frame Full 250 mm	501
Full 250mm with Struts in Z-Direction	1

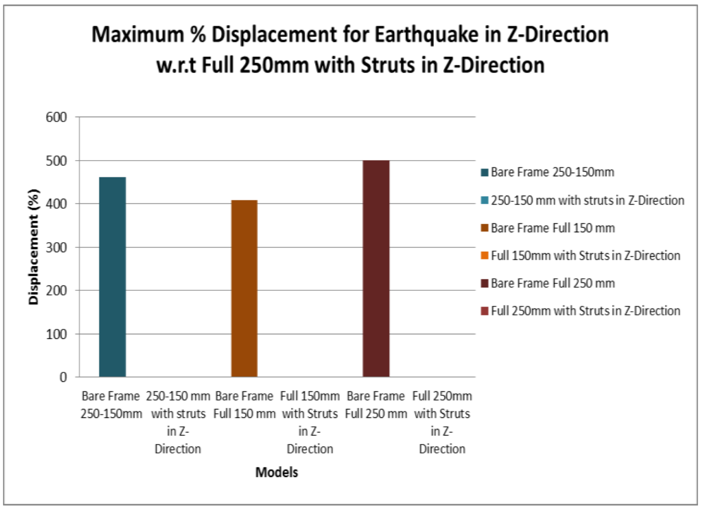

Fig-2.30: Percentage variation of displacement for earthquake in Z-direction

Percentage variation of Axial Force

For Earthquake in X-Direction

Table-31: Percentage variation of axial force for earthquake in X-direction

Models with struts in X-direction	% variation w.r.t Full 150mm with Struts in X-Direction
Bare Frame 250-150mm	22.3
250-150 mm with struts in X-Direction	9.06
Bare Frame Full 150 mm	9.66
Full 150mm with Struts in X-Direction	1
Bare Frame Full 250 mm	31.55
Full 250mm with Struts in X-Direction	17.53

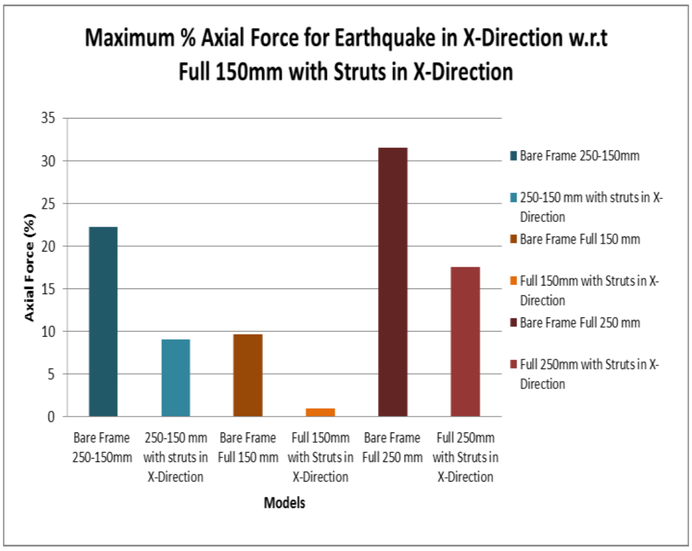

Fig-2.31: Percentage variation of axial force for earthquake in X-direction

For Earthquake in Z-Direction

Table-32: Percentage variation of axial force for earthquake in Z-direction

Models with struts in Z-direction	% variation w.r.t Full 150mm with Struts in Z-Direction
Bare Frame 250-150mm	25.02
250-150 mm with struts in Z-Direction	11.49
Bare Frame Full 150 mm	12.12
Full 150mm with Struts in Z-Direction	1
Bare Frame Full 250 mm	34.5
Full 250mm with Struts in Z-Direction	18.05

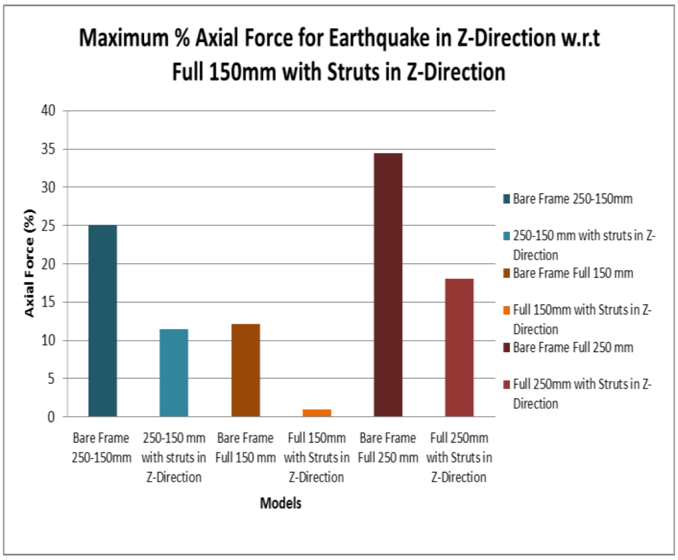

Fig-2.32: Percentage variation of axial force for earthquake in Z-direction

Percentage variation of Bending Moment-Y

For Earthquake in X-Direction

Table-33: Percentage variation of bending moment-Y for earthquake in X-direction

Models with struts in X-direction	% variation w.r.t Full 150mm with Struts in X-Direction
Bare Frame 250-150mm	35.72
250-150 mm with struts in X-Direction	17.35
Bare Frame Full 150 mm	19.12
Full 150mm with Struts in X-Direction	1
Bare Frame Full 250 mm	47.58
Full 250mm with Struts in X-Direction	17.72

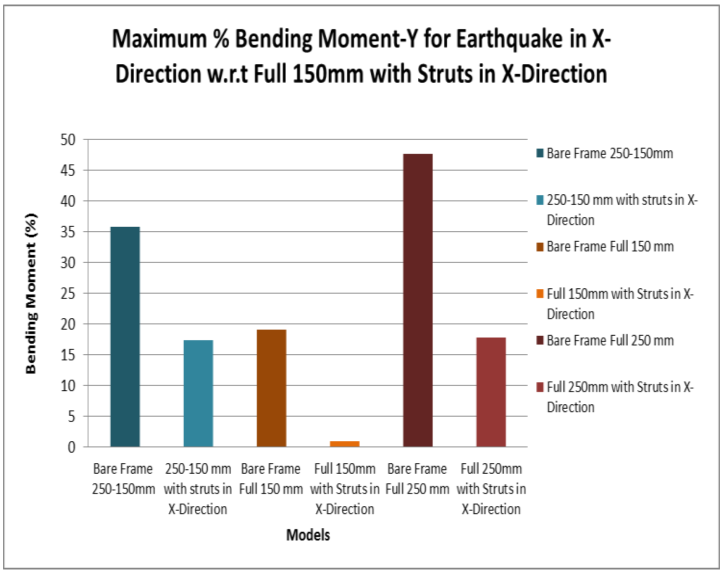

Fig-2.33: Percentage variation of bending moment-Y for earthquake in X-direction

For Earthquake in Z-Direction

Table-34: Percentage variation of bending moment-Y for earthquake in Z-direction

Models with struts in Z-direction	% variation w.r.t Bare Frame Full 150 mm
Bare Frame 250-150mm	13.44
250-150 mm with struts in Z-Direction	16.23
Bare Frame Full 150 mm	1
Full 150mm with Struts in Z-Direction	1.35
Bare Frame Full 250 mm	23.81
Full 250mm with Struts in Z-Direction	23.45

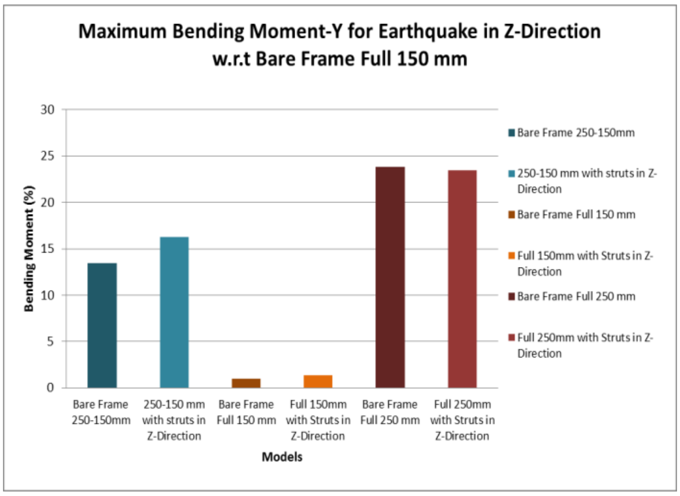

Fig-2.34: Percentage variation of bending moment-Y for earthquake in Z-direction

Percentage variation of Bending Moment-Z

For Earthquake in X-Direction

Table-35: Percentage variation of bending moment-Z for earthquake in X-direction

Models with struts in X-direction	% variation w.r.t Full 150mm with Struts in X-Direction
Bare Frame 250-150mm	38.68
250-150 mm with struts in X-Direction	10.17
Bare Frame Full 150 mm	21.72
Full 150mm with Struts in X-Direction	1
Bare Frame Full 250 mm	50.79
Full 250mm with Struts in X-Direction	16.89

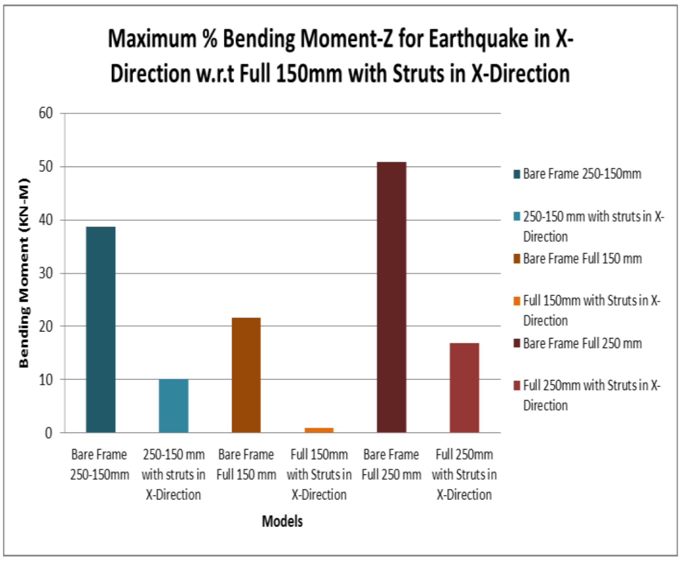

Fig-2.35: Percentage variation of bending moment-Z for earthquake in X-direction

For Earthquake in Z-Direction

Table-36: Percentage variation of bending moment-Z for earthquake in Z-direction

Models with struts in Z-direction	% variation w.r.t Full 150mm with Struts in Z-Direction
Bare Frame 250-150mm	637.6
250-150 mm with struts in Z-Direction	18.88
Bare Frame Full 150 mm	559.6
Full 150mm with Struts in Z-Direction	1
Bare Frame Full 250 mm	693.3
Full 250mm with Struts in Z-Direction	25.85

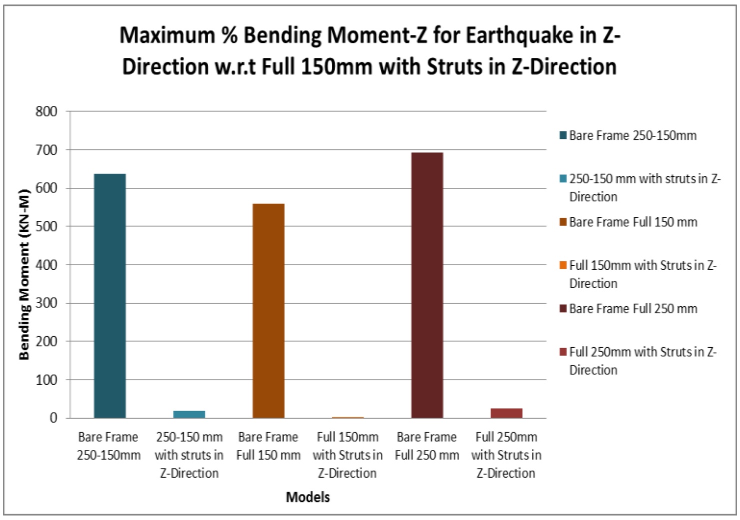

Fig-2.36: Percentage variation of bending moment-Z for earthquake in Z-direction

3. CONCLUSIONS

3.1 Base Shear

- For earthquake in X-direction: - All the Bare Frames models have less base shear than their respective models with struts in X-direction by a factor of 1.3
- For earthquake in Z-direction: - All the Bare Frames models have less base shear than their respective models with struts in Z-direction by a factor of 1.33

3.2 Displacement

- For earthquake in X-direction

  i. The 250mm outer and 150mm inner walls model with strut in X-direction shows decreased displacement as compared to its Bare Frame model by a factor of 3.9

ii. The uniform 150mm walls model with strut in X-direction shows decreased displacement as compared to its Bare Frame model by a factor of 3.25
iii. The uniform 250mm walls model with strut in X-direction shows decreased displacement as compared to its Bare Frame model by a factor of 4.14

- For earthquake in Z-direction

i. The 250mm outer and 150mm inner walls model with strut in Z-direction shows decreased displacement as compared to its Bare Frame model by a factor of 4.58
ii. The uniform 150mm walls model with strut in Z-direction shows decreased displacement as compared to its Bare Frame model by a factor of 4.1
iii. The uniform 250mm walls model with strut in Z-direction shows decreased displacement as compared to its Bare Frame model by a factor of 5.01

3.3 Axial Force

The axial force comparison between bare frame models and their respective with strut models shows that the axial forces are almost same between them.

3.4 Bending moment-Y

- For earthquake in X-direction

i. The 250mm outer and 150mm inner walls model with strut in X-direction shows decreased bending moment-Y as compared to its Bare Frame model by a factor of 1.16
ii. The uniform 150mm walls model with strut in X-direction shows decreased bending moment-Y as compared to its Bare Frame model by a factor of 1.19
iii. The uniform 250mm walls model with strut in X-direction shows decreased bending moment-Y as compared to its Bare Frame model by a factor of 1.25

- For earthquake in Z-direction

The bending moment-Y is same for Models with Struts in Z-direction and their respective bare frame models.

3.5 Bending moment-Z

- For earthquake in X-direction

i. The 250mm outer and 150mm inner walls model with strut in X-direction shows decreased bending moment-Z as compared to its Bare Frame model by a factor of 1.26
ii. The uniform 150mm walls model with strut in X-direction shows decreased bending moment-Z as compared to its Bare Frame model by a factor of 1.22
iii. The uniform 250mm walls model with strut in X-direction shows decreased bending moment-Z as compared to its Bare Frame model by a factor of 1.29

- For earthquake in Z-direction

i. The 250mm outer and 150mm inner walls model with strut in Z-direction shows decreased bending moment-Z as compared to its Bare Frame model by a factor of 5.36
ii. The uniform 150mm walls model with strut in Z-direction shows decreased bending moment-Z as compared to its Bare Frame model by a factor of 5.59
iii. The uniform 250mm walls model with strut in Z-direction shows decreased bending moment-Z as compared to its Bare Frame model by a factor of 5.51

Observing all the conclusions the Uniform 150mm wall thickness with struts model and its bare frame model are the best models according to the parameters studied in this project.

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