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Controlling Seismic Effect on Bare RCC Frame by Lateral Force Resisting Systems (LFRS)

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***Abstract*—In present scenario, the construction industry required high-rise and lighter structures, as tall and lighter structures are having more flexibility and small damping value so that it is less efficient to resist seismic responses. They are more susceptible to failure possibilities, LFRS to be provided to the tall structure which will results in reduction in the vibration induced by seismic and wind actions. Lateral Force Resisting System is big, heavy piece, which is constructed or installed from bottom to top of the tall structure and at different locations of the tall structure in plan and elevation. LFRS is either shear wall or bracing or combination of Shear Wall and Bracing. LFRS is installed in the tall RCC structures at various suitable locations. This research work concerned with controlling the tall RCC structural seismic effect by using lateral force resisting system (LFRS). LFRS are arranged in combinations and attached at different locations in the building. To study the seismic behaviour of tall lateral load resisting structure by taking either shear wall or bracing or combination of Shear Wall and Bracing using Response Spectrum Analysis method on ETABS v17.0.1 software. From this study the result obtained to find most effective arrangement on the basis of seismic parameters (time period, base shear distribution, max. storey displacement, storey drift & storey stiffness) and find out best suitable arrangement at given condition.**

***Keywords*— Bracing, LFRS, Bare frame, Response Spectrum Analysis, Shear Wall etc**

1. INTRODUCTION

In structural engineering, structural system is critical to good seismic performance of buildings. While moment-frame is the most commonly used lateral load resisting structural system, other structural systems also are commonly used like structural walls, frame-wall system, and braced-frame system. Lateral loads resulting from wind and seismic activities are now dominant in design considerations. Lateral displacement of such buildings must be strictly controlled, not only for occupants comfort and safety, but also to control secondary structural effects. Currently, there are many structural systems such as:

1. moment-frame
2. Structural walls
3. Frame-wall system and
4. Braced-frame system

The main objective of the study is investigate the seismic performance of a tall RCC frame building with X-Type bracing and shear wall by using Response Spectrum Analysis method and to study the seismic behaviour of tall lateral load resisting structure by taking combinations of shear wall & X-Type bracing using Response Spectrum Analysis method. Analysis is performed by Response Spectrum Analysis using ETABS 17.0.1 software.

2. BUILDING DESCRIPTION

Description of Residential building with 28 storeys Located in Delhi (NCR) are given below

A. Geometrical properties:

<table>
<tr><th>S. No</th><th colspan="2">Property Description</th><th>Dimension</th></tr>
<tr><td>1.</td><td colspan="2">Floor height</td><td>3m</td></tr>
<tr><td>2.</td><td colspan="2">Height of building</td><td>84m</td></tr>
<tr><td>3.</td><td colspan="2">Area (plan)</td><td>31.5m x 31.5m</td></tr>
<tr><td>4.</td><td colspan="2">Beam dimension</td><td>300mm x 400mm</td></tr>
<tr><td rowspan="4">5.</td><td>Columns (Inner and Corner)</td><td rowspan="2">Storey 1st to 14th</td><td>500mm x 500mm</td></tr>
<tr><td>Columns (Periphery)</td><td>300mm x 600mm</td></tr>
<tr><td>Columns (Inner and Corner)</td><td rowspan="2">Storey 15th to 28th</td><td>400mm x 400mm</td></tr>
<tr><td>Columns (Periphery)</td><td>300mm x 500mm</td></tr>
<tr><td>6.</td><td colspan="2">Bracing</td><td>ISLB 175</td></tr>
<tr><td>7.</td><td colspan="2">No. of bays in X-direction</td><td>7No.@4.5m</td></tr>
<tr><td>8.</td><td colspan="2">No. of bays in Y-direction</td><td>7No.@4.5m</td></tr>
<tr><td>9.</td><td colspan="2">Slab thickness</td><td>150mm</td></tr>
<tr><td>10.</td><td colspan="2">Shear Wall thickness</td><td>200mm</td></tr>
</table>

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B. Material properties:

S. No	Material	Grade
1.	Concrete (column, beam ,slab & shear wall)	M30
2.	Rebar	Fe500

C. Seismic data:

1.	Earthquake Zone – IV	Z = 0.24
2.	Damping	5%
3.	Importance Factor	1.2
4.	Type of soil	Medium soil
5.	Response Reduction Factor	5
6.	Time Period	Program calculated

D. Loading:

1. Live load 3.5kN/m2 as per IS 875 part-II
2. Dead load as per IS 875 part-I
3. Earthquake load as per IS 1893:2016 part-I

3. PLAN AND 3D VIEW OF BUILDING FOR DIFFERENT MODELS

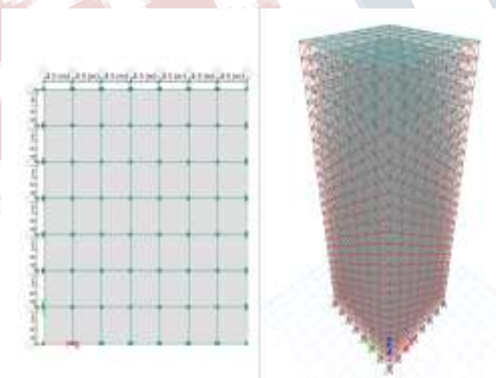

Figure1: Model 1 (X-Type bracing)

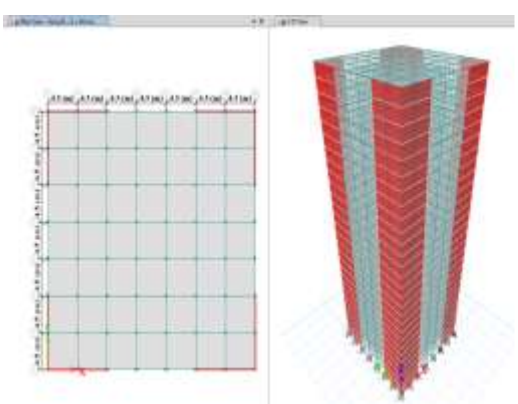

Figure2: Model 2 (Shear Wall at corner)

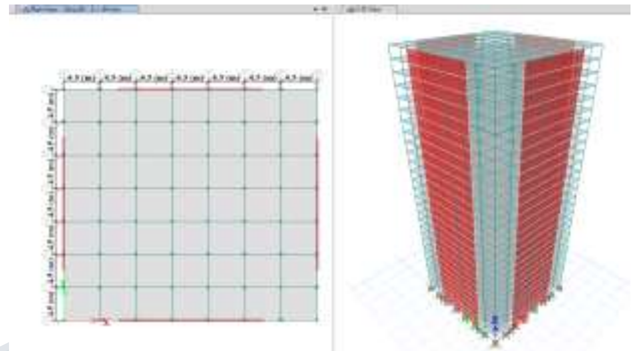

Figure3: Model 3 (Shear Wall at side center)

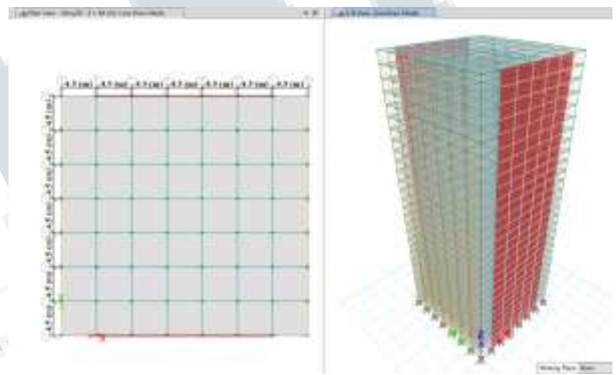

Figure4: Model 4 (Shear Wall on opposite face & X-Type bracing on opposite face)

4. METHOD OF ANALYSIS

A response spectrum is simply a plot of the peak response (displacement, velocity or acceleration) of a number of SDOF systems of varying natural period that are forced into motion by the same base vibration. The resulting plot can then be used to find the response of any structure, knowing its natural period. The plan shape used for analysis is “Square” shape tall building.

5. ANALYSIS RESULTS

The analysis of all the models that include RCC frame with X-Type bracing system, RCC frame with Shear Wall at different locations in plan and RCC frame with Shear Wall on opposite face & bracing on opposite face has been done and results are shown below. The parameters which were studied are on the behavior of building during seismic excitation are time period, base shear distribution, max. storey displacement, storey drift & storey stiffness.

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(a) Natural Time Period

Mode	MODE L 1 (sec)	MODE L 2 (sec)	MODE L 3 (sec)	MODE L 4 (sec)
1	3.747	2.655	2.273	3.735
2	3.747	2.655	2.273	2.297
3	2.144	1.434	1.369	1.577
4	1.228	0.637	0.537	1.232
5	1.228	0.637	0.537	0.689
6	0.721	0.341	0.334	0.531
7	0.681	0.285	0.244	0.483
8	0.681	0.285	0.244	0.419
9	0.479	0.175	0.153	0.37
10	0.479	0.175	0.153	0.301
11	0.431	0.155	0.153	0.253
12	0.367	0.124	0.111	0.241

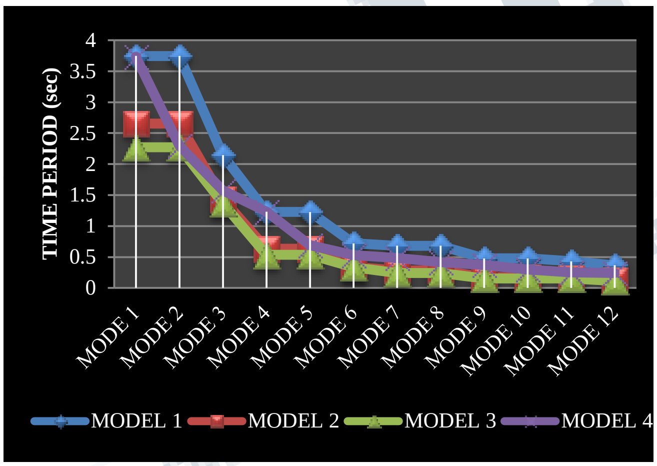

Figure5: Natural Time Period v/s Mode

All the objects of structure have a tendency to vibrate. The rate at which it wants to vibrate is its fundamental time period (natural time period) or un-damped free vibration of a structure. Structures that are weighty (with larger mass m) and flexibility (with smaller stiffness k) have greater natural time period than light and rigid structures.
The natural time period of vibration (T) in seconds are given below

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Where,

K= Stiffness
M= Mass of Structure.

Model 1 shows maximum time period while model 3 shows minimum time period which means that model 1 is most flexible and model 3 is least flexible.

(b) Base Shear Distribution X-direction

Storey	MODEL 1 (kN)	MODEL 2 (kN)	MODEL 3 (kN)	MODEL 4 (kN)
1	0.7146	1.0804	1.2621	1.2071
2	2.8586	4.3216	5.0482	4.8285
3	6.4318	9.7236	11.3585	10.8642
4	11.4343	17.2864	20.1929	19.3141
5	17.8662	27.01	31.5514	30.1783
6	25.7273	38.8945	45.434	43.4568
7	35.0177	52.9397	61.8407	59.1495
8	45.7374	69.1457	80.7716	77.2565
9	57.8863	87.5125	102.2265	97.7778
10	71.4646	108.0402	126.2056	120.713
11	86.4722	130.7286	152.7087	146.063
12	102.9091	155.5779	181.736	173.827
13	120.7752	182.5879	213.2874	204.006
14	138.8576	210.044	245.3599	234.618
15	158.2682	239.518	279.7895	267.48
16	180.074	272.5183	318.3383	304.332
17	203.2867	307.6476	359.3741	343.563
18	227.9062	344.906	402.8969	385.171
19	253.9325	384.2934	448.9068	429.156
20	281.3656	425.8099	497.4036	475.519
21	310.2056	469.4554	548.3875	524.26
22	340.4524	515.2299	601.8584	575.378
23	372.106	563.1335	657.8163	628.874
24	405.1665	613.1662	716.2612	684.748
25	439.6338	665.3279	777.1932	742.999
26	475.5079	719.6187	840.6121	803.627
27	512.7889	776.0385	906.5181	866.634
28	539.5006	790.1314	922.9805	896.573

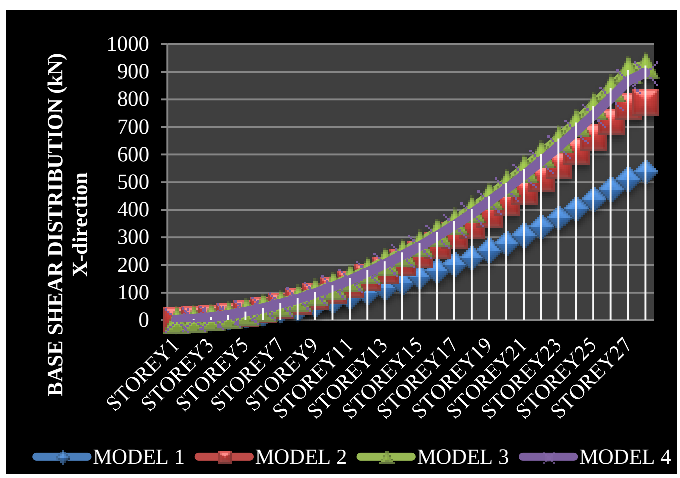

Figure6: Base Shear distribution in X-direction

Base shear is an approximation of the maximum lateral force that is occurs due to earthquake ground motion at the base of structure.
Model 1 shows minimum base shear while model 3 showing maximum base shear among these models for X-direction this means model 3 attract more shear force than model 1.

Y-direction

Storey	Model 1 (kN)	Model 2 (kN)	Model 3 (kN)	Model 4 (kN)
1	0.7146	1.0804	1.2621	0.7426
2	2.8586	4.3216	5.0482	2.9705
3	6.4318	9.7236	11.3585	6.6835
4	11.4343	17.2864	20.1929	11.8818
5	17.8662	27.01	31.5514	18.5654
6	25.7273	38.8945	45.434	26.7341
7	35.0177	52.9397	61.8407	36.3881
8	45.7374	69.1457	80.7716	47.5274
9	57.8863	87.5125	102.2265	60.1518
10	71.4646	108.0402	126.2056	74.2615
11	86.4722	130.7286	152.7087	89.8564
12	102.9091	155.5779	181.736	106.9365
13	120.7752	182.5879	213.2874	125.5019
14	138.8576	210.044	245.3599	144.3343
15	158.2682	239.518	279.7895	164.5504
16	180.074	272.5183	318.3383	187.2218
17	203.2867	307.6476	359.3741	211.3559
18	227.9062	344.906	402.8969	236.9526
19	253.9325	384.2934	448.9068	264.012
20	281.3656	425.8099	497.4036	292.5341
21	310.2056	469.4554	548.3875	322.5188
22	340.4524	515.2299	601.8584	353.9662
23	372.106	563.1335	657.8163	386.8763
24	405.1665	613.1662	716.2612	421.249
25	439.6338	665.3279	777.1932	457.0845
26	475.5079	719.6187	840.6121	494.3826
27	512.7889	776.0385	906.5181	533.1433
28	539.5006	790.1314	922.9805	551.5617

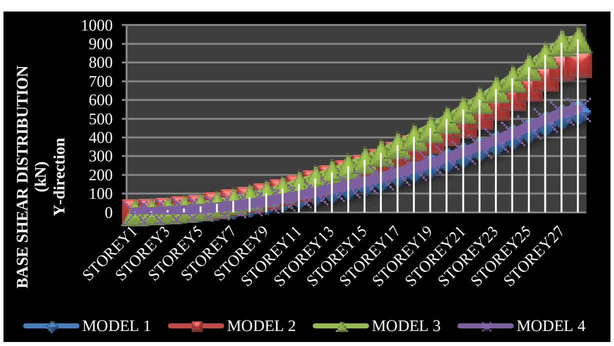

Figure7: Base Shear Distribution in Y-direction

Base shear is an approximation of the maximum lateral force that is occurs due to earthquake ground motion at the base of structure.
Model 1 shows minimum base shear while model 3 showing maximum base shear among these models for Y-direction this means model 3 attract more shear force than model 1.

(c) Max. Storey Displacement
X-direction

Storey	MODEL 1 (mm)	MODEL 2 (mm)	MODEL 3 (mm)	MODEL 4 (mm)
1	2.875	0.599	0.597	0.602
2	6.87	1.702	1.59	1.605
3	11.038	3.23	2.921	2.952
4	15.357	5.147	4.568	4.621
5	19.81	7.414	6.504	6.586
6	24.381	9.999	8.706	8.824
7	29.053	12.869	11.152	11.311
8	33.809	15.996	13.818	14.025
9	38.632	19.352	16.684	16.945
10	43.505	22.911	19.729	20.05
11	48.409	26.648	22.933	23.32
12	53.325	30.54	26.276	26.736
13	58.234	34.565	29.741	30.279
14	63.059	38.695	33.302	33.925
15	68.2	42.948	36.976	37.687
16	73.233	47.27	40.717	41.522
17	78.184	51.646	44.513	45.417
18	83.024	56.055	48.347	49.355
19	87.726	60.479	52.204	53.32
20	92.261	64.901	56.069	57.299
21	96.604	69.306	59.929	61.277
22	100.725	73.681	63.774	65.243
23	104.597	78.015	67.591	69.185
24	108.194	82.299	71.374	73.095
25	111.487	86.529	75.115	76.966
26	114.45	90.7	78.809	80.792
27	117.057	94.815	82.456	84.572
28	119.283	98.865	86.039	88.293

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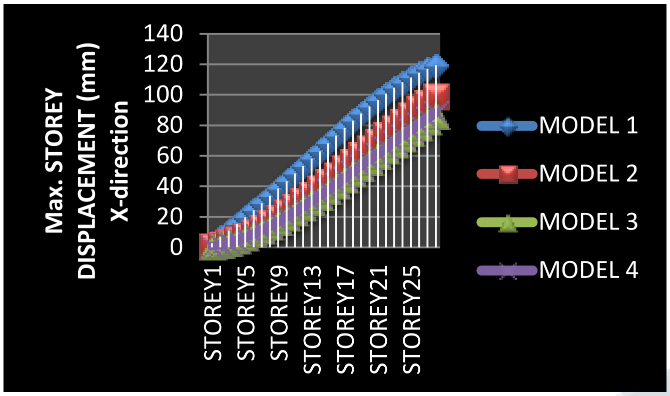

Figure8: Maximum storey displacement in X-direction

The Maximum storey displacement (X-direction) observed in model 1, model 2, model 3 & model 4 is respectively 119.283mm, 98.865mm, 86.039mm, 88.293mm which is under permissible limit of **IS1893:2016 code** i.e. 0.004 times of structure height (i.e. 336mm).
The percentage of reduction in max. storey displacement of model 2, model 3 & model 4 is respectively 17.11%, 27.86% & 25.98%.

Y-direction

Storey	MODEL 1 (mm)	MODEL 2 (mm)	MODEL 3 (mm)	MODEL 4 (mm)
1	2.875	0.599	0.597	2.686
2	6.87	1.702	1.59	6.528
3	11.038	3.23	2.921	10.567
4	15.357	5.147	4.568	14.768
5	19.81	7.414	6.504	19.111
6	24.381	9.999	8.706	23.577
7	29.053	12.869	11.152	28.149
8	33.809	15.996	13.818	32.807
9	38.632	19.352	16.684	37.533
10	43.505	22.911	19.729	42.308
11	48.409	26.648	22.933	47.113
12	53.325	30.54	26.276	51.929
13	58.234	34.565	29.741	56.733
14	63.059	38.695	33.302	61.455
15	68.2	42.948	36.976	66.511
16	73.233	47.27	40.717	71.461
17	78.184	51.646	44.513	76.322
18	83.024	56.055	48.347	81.065
19	87.726	60.479	52.204	85.665
20	92.261	64.901	56.069	90.093
21	96.604	69.306	59.929	94.322
22	100.725	73.681	63.774	98.325
23	104.597	78.015	67.591	102.077
24	108.194	82.299	71.374	105.552
25	111.487	86.529	75.115	108.724
26	114.45	90.7	78.809	111.57
27	117.057	94.815	82.456	114.067
28	119.283	98.865	86.039	116.16

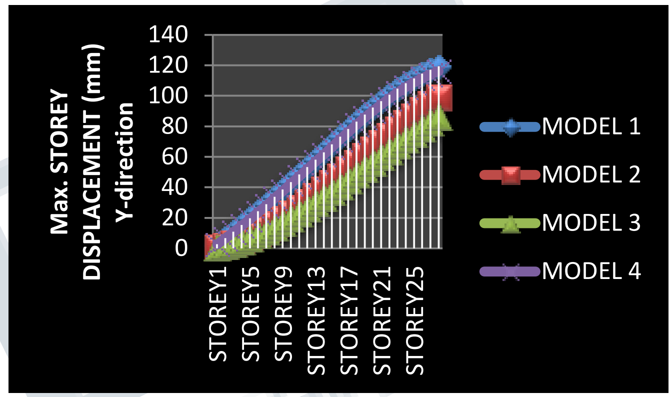

Figure9: Maximum storey displacement in Y-direction

The Maximum storey displacement (Y-direction) observed in model 1, model 2, model 3 & model 4 is respectively 119.283mm, 98.865mm, 86.039mm & 116.16mm which is under permissible limit of **IS1893:2016 code** i.e. 0.004 times of structure height (i.e. 336mm).
The percentage of reduction in max. storey displacement of model 2, model 3 & model 4 is respectively 17.11%, 27.86% & 2.61%.

(d) Storey Drift
X-direction

Storey	MODEL 1 (mm)	MODEL 2 (mm)	MODEL 3 (mm)	MODEL 4 (mm)
1	2.875	0.599	0.597	0.602
2	3.995	1.102	0.994	1.003
3	4.168	1.528	1.33	1.347
4	4.319	1.917	1.647	1.669
5	4.453	2.268	1.936	1.965
6	4.571	2.585	2.202	2.238
7	4.672	2.87	2.445	2.487
8	4.756	3.127	2.666	2.714
9	4.823	3.356	2.866	2.92
10	4.873	3.559	3.045	3.105
11	4.904	3.737	3.204	3.27
12	4.916	3.892	3.343	3.415
13	4.909	4.025	3.465	3.543
14	4.825	4.13	3.562	3.646
15	5.142	4.253	3.674	3.762
16	5.033	4.322	3.741	3.835

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17	4.951	4.376	3.796	3.895
18	4.84	4.409	3.834	3.938
19	4.702	4.424	3.857	3.966
20	4.536	4.422	3.865	3.979
21	4.342	4.405	3.861	3.978
22	4.121	4.375	3.844	3.966
23	3.872	4.334	3.818	3.942
24	3.596	4.284	3.783	3.91
25	3.293	4.229	3.741	3.871
26	2.963	4.171	3.694	3.826
27	2.607	4.116	3.647	3.78
28	2.226	4.05	3.584	3.721

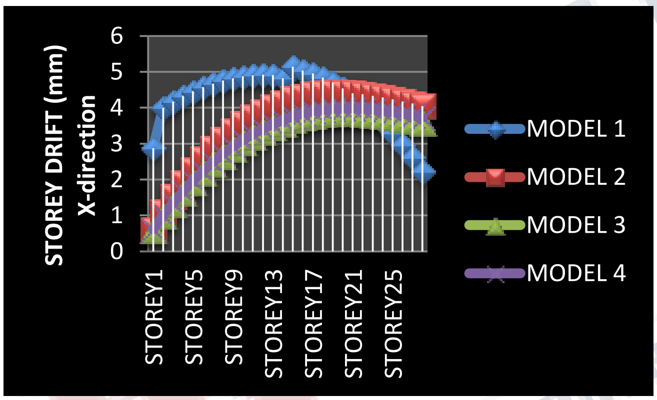

Figure10: Comparison of storey drift in X-direction

The storey drift in X-direction observed at 15th storey in model 1, model 2, model 3 & model 4 is respectively 5.142mm, 4.253mm, 3.674mm & 3.762mm which is under permissible limit of **IS 1893:2016** recommended value 0.004 times of storey height (i.e. 12 mm).
The percentage of reduction in storey drift of model 2, model 3 & model 4 is respectively 17.28% , 28.54% & 26.83%.

Y-direction

Storey	MODEL 1 (mm)	MODEL 2 (mm)	MODEL 3 (mm)	MODEL 4 (mm)
1	2.875	0.599	0.597	2.686
2	3.995	1.102	0.994	3.841
3	4.168	1.528	1.33	4.04
4	4.319	1.917	1.647	4.201
5	4.453	2.268	1.936	4.343
6	4.571	2.585	2.202	4.466
7	4.672	2.87	2.445	4.571
8	4.756	3.127	2.666	4.658
9	4.823	3.356	2.866	4.726
10	4.873	3.559	3.045	4.775
11	4.904	3.737	3.204	4.805
12	4.916	3.892	3.343	4.816
13	4.909	4.025	3.465	4.804
14	4.825	4.13	3.562	4.722
15	5.142	4.253	3.674	5.056
16	5.033	4.322	3.741	4.951
17	4.951	4.376	3.796	4.86
18	4.84	4.409	3.834	4.744
19	4.702	4.424	3.857	4.599
20	4.536	4.422	3.865	4.428
21	4.342	4.405	3.861	4.229
22	4.121	4.375	3.844	4.004
23	3.872	4.334	3.818	3.752
24	3.596	4.284	3.783	3.474
25	3.293	4.229	3.741	3.172
26	2.963	4.171	3.694	2.846
27	2.607	4.116	3.647	2.497
28	2.226	4.05	3.584	2.093

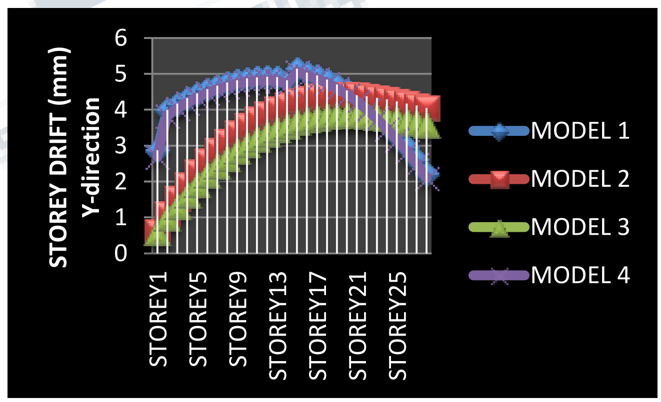

Figure11: Comparison of storey drift inY-direction

The storey drift in Y-direction observed at 15th storey in model 1, model 2, model 3 & model 4 is respectively 5.142mm, 4.253mm, 3.674mm & 5.056mm which is under permissible limit of **IS 1893:2016** recommended value 0.004 times of storey height (i.e. 12 mm).
The percentage of reduction in storey drift of model 2, model 3 & model 4 is respectively 17.28% , 28.54% & 1.67%.

(e) Storey Stiffness

X-direction

Storey	MODEL 1 (kN/m)	MODEL 2 (kN/m)	MODEL 3 (kN/m)	MODEL 4 (kN/m)
1	3111734	2581049 3	2974564 3	2947907 5
2	2243394	1553866	2007137	1983114

		8	6	8
3	2162830	11677828	15780868	15542637
4	2092963	9428489	12982085	12764558
5	2027697	7937265	11030799	10821848
6	1967378	6845548	9552438	9338440
7	1912192	5999640	8377187	8150458
8	1861434	5318193	7407018	7168664
9	1814174	4753866	6587269	6344517
10	1769969	4277186	5888276	5649207
11	1728860	3870871	5295212	5064325
12	1690736	3526939	4799894	4576769
13	1655105	3242676	4394529	4175453
14	1639634	3024769	4082284	3860779
15	1488752	2837642	3812513	3590079
16	1468865	2723941	3645666	3413820
17	1435579	2644158	3532388	3292103
18	1405574	2589631	3463297	3219478
19	1377772	2549463	3418066	3179950
20	1350867	2515304	3376024	3153699
21	1324104	2478895	3318828	3118136
22	1297312	2428879	3230560	3049752
23	1268910	2348689	3094880	2925589
24	1232691	2216511	2891445	2724126
25	1175237	2007216	2594413	2425739
26	1073740	1695487	2174861	2013269
27	891082.5	1258572	1604152	1471639
28	563129.3	684474.9	868485.2	793811.6

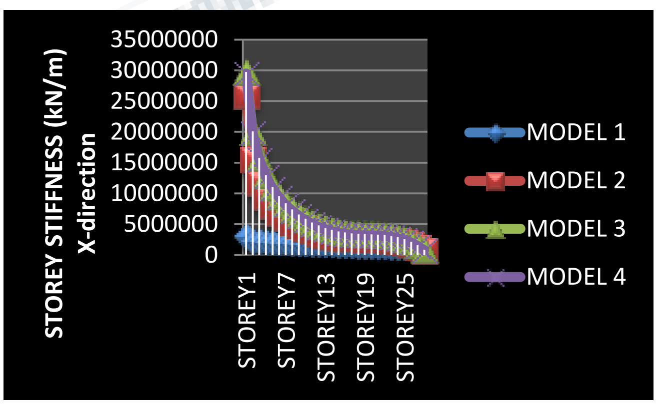

Figure12: Comparison of storey stiffness in X-direction

The maximum value of stiffness (X-direction) observed in model 3, so model 3 gives better response among all models. The storey stiffness of model 2 is 8.29 times, model 3 is 9.55 times & model 4 is 9.47 times more than the model 1.

Y-direction

Storey	MODEL 1 (kN/m)	MODEL 2 (kN/m)	MODEL 3 (kN/m)	MODEL 4 (kN/m)
1	3111734	25810493	29745643	3234613
2	2243394	15538668	20071376	2287183
3	2162830	11677828	15780868	2200559
4	2092963	9428489	12982085	2131738
5	2027697	7937265	11030799	2069369
6	1967378	6845548	9552438	2012565
7	1912192	5999640	8377187	1960634
8	1861434	5318193	7407018	1913455
9	1814174	4753866	6587269	1870850
10	1769969	4277186	5888276	1831708
11	1728860	3870871	5295212	1794788
12	1690736	3526939	4799894	1759781
13	1655105	3242676	4394529	1727873
14	1639634	3024769	4082284	1716887
15	1488752	2837642	3812513	1554527
16	1468865	2723941	3645666	1538028
17	1435579	2644158	3532388	1509858
18	1405574	2589631	3463297	1482554
19	1377772	2549463	3418066	1456089
20	1350867	2515304	3376024	1430685
21	1324104	2478895	3318828	1407289
22	1297312	2428879	3230560	1384315
23	1268910	2348689	3094880	1357680
24	1232691	2216511	2891445	1323203
25	1175237	2007216	2594413	1273902
26	1073740	1695487	2174861	1189243
27	891082.5	1258572	1604152	1021465
28	563129.3	684474.9	868485.2	683284.5

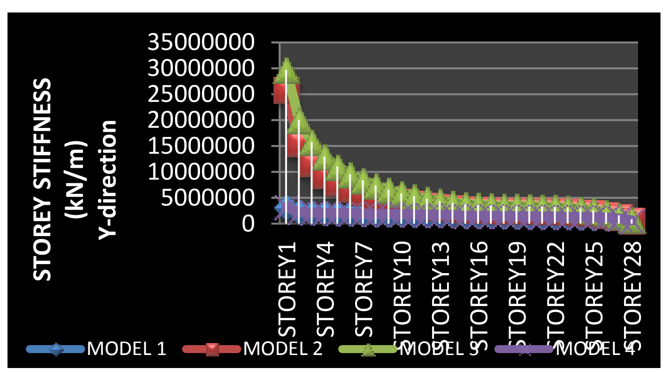

Figure13: Comparison of storey stiffness in Y-direction

The maximum value of stiffness (Y-direction) observed in model 3, so model 3 gives better response among all models. The storey stiffness of model 2 is 8.29 times, model 3 is 9.55 times & model 4 is 1.03 times more than the model 1.

6. CONCLUSION

In this paper the buildings with LFRS are studied and the seismic parameters in terms of Time period, Base shear distribution, Maximum storey displacement, Storey drift and storey stiffness are compared. The following conclusions are summarized based on analysis:

1. In this research work model 1 shows maximum time period while model 3 shows minimum time period which means that model 1 is most flexible and model 3 is least flexible.
2. The maximum displacement of the building was found to be minimum in shear wall at side center while Model 1 shows maximum displacement. and is at verge of failure as per standards. Model 1 showed higher storey displacement that it is more prone to damage during earthquake as compared to other models with LFRS.
3. Model 1 is show maximum drift while other models are shows less drift. All models with LFRS satisfying criteria maximum allowed storey drift as per Indian standards i.e. 0.004 times of storey height.
4. In tall buildings, the storey stiffness is one of the important factor. So for this lateral force resisting systems are adopted to enhance this parameter. Model 3(shear wall at side center) showing maximum stiffness while Model 1(X-type bracing) has minimum stiffness.
5. It can also be observed that as we move upward the storey stiffness decreased in all four models so no soft storey effect is observed in any model.
6. A sudden change in the stiffness has been observed at 15th storey due to change in column size at 15 storey.

From the above discuss it can be concluded that shear wall at side center shows best result when compared with X-type bracing, shear wall at corner and and RCC frame with Shear Wall on opposite face & bracing on opposite face.

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