COMPARATIVE STUDY OF BRACING SYSTEMS FOR IRREGULAR TALL STEEL STRUCTURES BASED IN DIFFERENT CITIES

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Abstract

In a high-rise steel building, bracing system is an essential commodity for inadequate lateral reinforcements in the structure. Therefore, bracing system is a necessary solution for these lateral deflections caused by lateral loads. The resistance to wind and seismic load is one of the factor for the sustainability of the high rise building. For present study, plan irregularity with (A/L) ratio of (40/65) = 0.62 is considered as per IS 1893 (Part 1): 2002. In this study, the steel structure is assumed to be at 4 different cities with different seismic zones those cities are Agra, Bengaluru, Mumbai and Roorkee with five types of bracing systems. All cities are compared with an unbraced model of Roorkee city. A G+14 structure is analyzed for seismic zone II, zone III and zone IV as per IS: 1893-2002 using STAAD pro software. Dead and live loads are sustained by beams and columns whereas; the lateral loads are carried by bracing systems only. The bracings are provided at every corner of the structure. The structure is studied for nodal displacements in X-direction and Z direction in all the floors, axial force and bending moment for the ground level column is compared and finally, drift index and corresponding percentage change in top roof is calculated.

Keywords: *Lateral Loads, Bracing Systems, Axial Force, Bending Moment, Drift Index.*

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1. INTRODUCTION

Tall structures are subjected to high intensity wind load, and the displacement increases with increase in height. Seismic zones play an important role in the variation of these displacements in the structure. Due to repeated swaying of the structure by the lateral forces the resulting swaying motion increases the discomfort of the occupants and also it will increase the possibility of failure of the structure. As far as the ultimate limit state is concerned, lateral deflections must be limited to prevent second order p-delta effect due to gravity loading being of such a magnitude which may be sufficient to precipitate collapse. The strength and serviceability of the structure depends upon lateral stiffness and is a major consideration in the design of tall structure. The simple parameter that is used to estimate the lateral stiffness of a building is the drift index defined as the ratio of the maximum deflections at the top of the building to the total height.

Different bracing systems are used to improve lateral stiffness and reduce the drift index of the tall structure. In this study, different arrangements of bracing system are compared with various cities, in another word different lateral load condition. Bracing is a highly efficient and economical method to increase the lateral stiffness of the framed structures against lateral loads. Bracing systems helps in reducing the sizes of columns and beams thus, reducing the economy of the building.

2. BRACING SYSTEM

A bracing system is a structural system which is designed primarily to resist wind and seismic forces. Braced frames are designed to work in tension and compression similar to a truss. Braced-frames virtually eliminate the columns and girder bending factors and thus improve the efficiency of the pure rigid frame actions.

There are two types of bracing systems.
1) Concentric bracing system
2) Eccentric bracing system

1) **Concentric bracing-** These are the type of bracings whose centroid axis coincides with each other. They mainly increase the lateral stiffness of the frame which in turn increases the natural frequency and also decreases the lateral storey drift. Further, the bracing increases the axial compression in the columns to which they are connected by decreasing the bending moments and shear forces in the column.

2) **Eccentric bracing**- These are the type of bracing whose centerline braces are offset from the intersection of the centerline of columns and beams. It mainly improves the energy dissipation capacity and reduces the lateral stiffness of the system. At the point of connection of eccentric bracings on the beams, the vertical component of the bracing force due to earthquake causes concentrated load.

3. OBJECTIVE

The objective of this study is to compare the effects of lateral loads on a tall structure subjected to basic loads and lateral loads, hypothetically located in 4 cities namely Agra, Bengaluru, Mumbai and Roorkee. 5 types of bracing arrangements are made and the displacements, axial force, bending moment and drift index are compared.

4. MODELING AND ANALYSIS

In the present study a three dimensional L shaped framed structure with 65m*65m plan size and 15 numbers of stories is selected for the study. Storey height of 3m with 13 bays of 5m each along X and Z direction is provided for structure. The columns and beams are designed to withstand the live and dead loads adequately. The bracing sections are provided at the corners of the whole section. The lateral loads to be applied on the building are based on the Indian standards. The study is performed for seismic zone II, III, IV as per IS-1893 (Part1):2002 and wind speed of 47, 33, 44 and 39 m/s as per IS-875:1987 for the cities Agra, Bengaluru, Mumbai and Roorkee respectively. The frames are assumed to be firmly fixed and the soil structure interaction is neglected. The load combinations are taken as per IS codes.

Five major bracing systems are analyzed with an un-braced reference model structure. They are as follows:

I. Diagonal bracing system
II. Eccentric bracing system
III. Knee bracing system
IV. V bracing system
V. X bracing system

4.1 Data Considered for Analysis

Table 1. Basic modeling data

Type of structure	Steel moment resisting frame
Number of stories	15
Height of each storey	3
Type of building	Industrial

4.2 Specification based on Cities

4.2.1 Agra

Table 2. Seismic zone and wind speed

Seismic zone	III
Basic wind speed	47 m/s

4.2.2 Bengaluru

Table 3. Seismic zone and wind speed

Seismic zone	II
Basic wind speed	33 m/s

4.2.3 Mumbai

Table 4. Seismic zone and wind speed

Seismic zone	III
Basic wind speed	44 m/s

4.2.4 Roorkee

Table 5. Seismic zone and wind speed

Seismic zone	IV
Basic wind speed	39 m/s

An I section of ISMB 200 @ 25.4 Kg/m is used throughout the structure as a beam member. To withstand the dead and live loads, a column of ISMB 300 @ 44.2 Kg/m is chosen. The channel section used for present study is ISMC 150 @ 16.4 Kg/m.

Table 6. Loads considered for analysis

Dead load on slab	4 kN/m^2
Live load on slab	4 kN/m^2
Wall load on beams	10 kN/m

Table 7. Earthquake load parameter for Agra

Zone factor, Z	0.16 for zone III
Importance factor, I	1.0
Type of soil	II (medium)
Response reduction factor, R	5
Percentage of imposed load considered during seismic load calculations	50 %

Table 8. Earthquake load parameter for Bengaluru

Zone factor, Z	0.1 for zone II
Importance factor, I	1.0
Type of soil	II (medium)
Response reduction factor, R	5
Percentage of imposed load considered during seismic load calculations	50 %

Table 9. Earthquake load parameter for Mumbai

Zone factor, Z	0.16 for zone III
Importance factor, I	1.0
Type of soil	II (medium)
Response reduction factor, R	5
Percentage of imposed load considered during seismic load calculations	50 %

Table 10. Earthquake load parameter for Roorkee

Zone factor, Z	0.24 for zone IV
Importance factor, I	1.0
Type of soil	II (medium)
Response reduction factor, R	5
Percentage of imposed load considered during seismic load calculations	50 %

Table 11. Wind load parameters for Agra

Basic wind speed , V_b	47 m/s
Risk co-efficient factor, k1	1
Terrain, height and structure size factor, k2	1
Topography factor, k3	1
Class of structure	B

Table 12. Wind load parameters for Bengaluru

Basic wind speed , V_b	33 m/s
Risk co-efficient factor, k1	1
Terrain, height and structure size factor, k2	1
Topography factor, k3	1
Class of structure	C

Table 13. Wind load parameters for Mumbai

Basic wind speed , V_b	44 m/s
Risk co-efficient factor, k1	1
Terrain, height and structure size factor, k2	1
Topography factor, k3	1
Class of structure	C

Table 14. Wind load parameters for Roorkee

Basic wind speed , V_b	39 m/s
Risk co-efficient factor, k1	1
Terrain, height and structure size factor, k2	1
Topography factor, k3	1
Class of structure	C

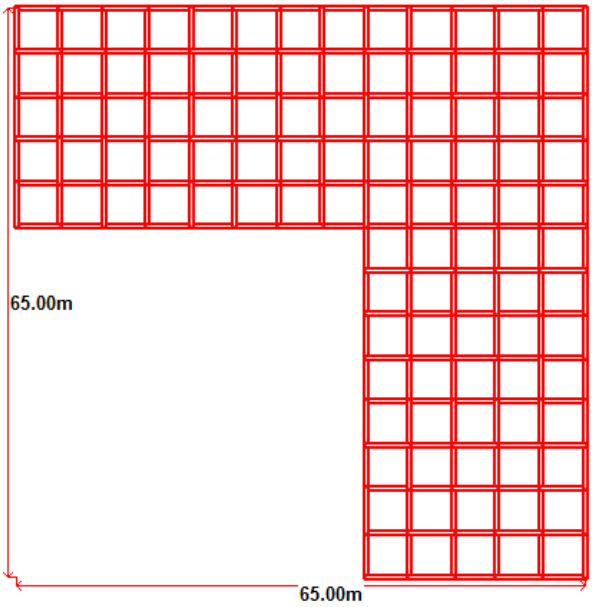

Fig.1 Plan un-braced reference model

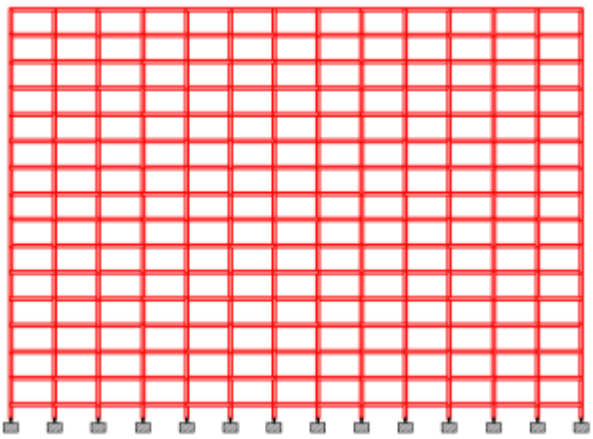

Fig.2 Elevation of un-braced reference model

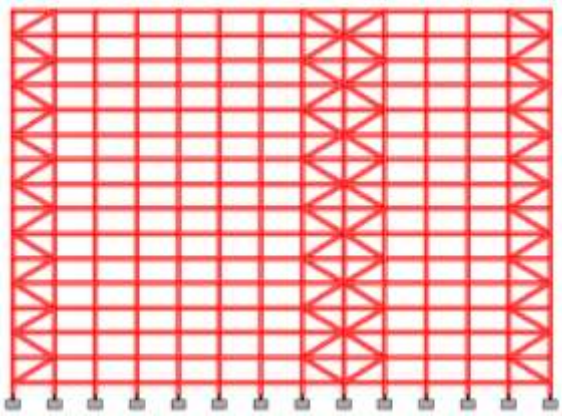

Fig.3 Elevation of Diagonal bracing system

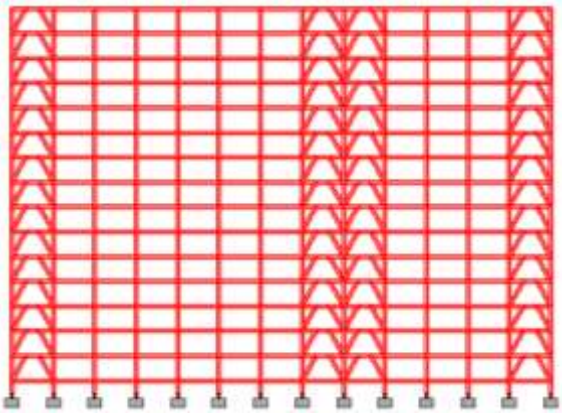

Fig.4 Elevation of Eccentric bracing system

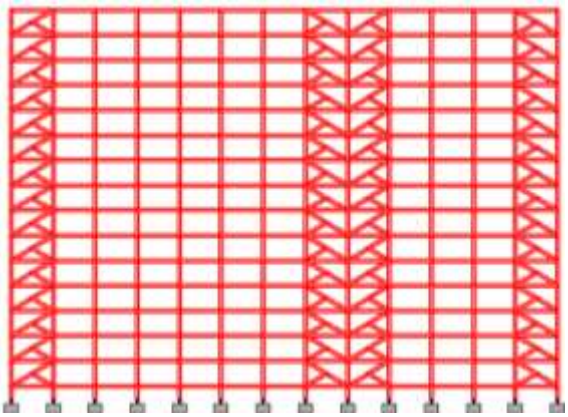

Fig.5 Elevation of Knee bracing system

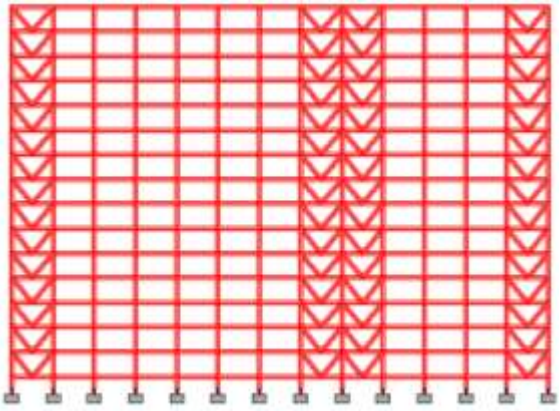

Fig.6 Elevation of V bracing system

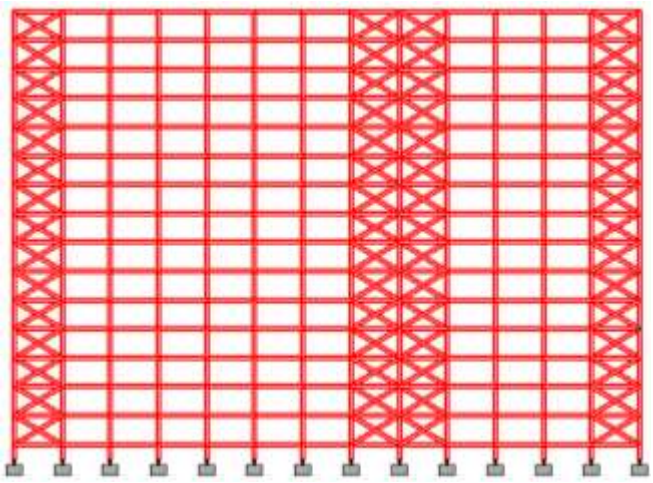

Fig.7 Elevation of X bracing system

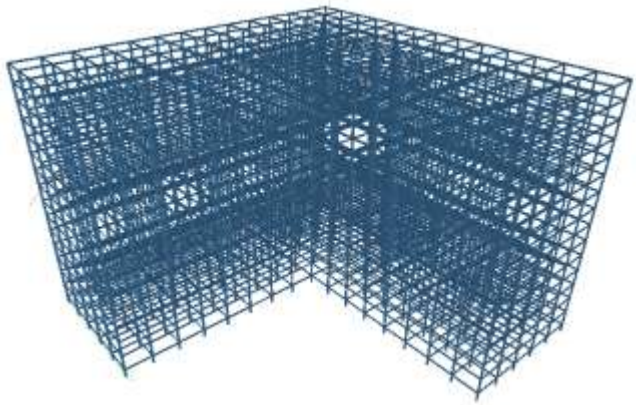

Fig.8 3D view of un-braced reference model

5. RESULTS

Table 15. Displacement in Diagonal bracing system in mm, X-DIRECTION

HEIGHT(m)	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
0	0	0	0	0	0
1.5	8.674	9.931	4.796	7.461	4.302
4.5	59.241	51.806	23.833	38.105	57.134
7.5	127.445	111.454	51.316	81.993	122.911
10.5	196.097	171.555	78.932	126.19	189.202
13.5	265.335	232.185	106.817	170.78	256.065
16.5	333.794	292.17	134.412	214.901	322.219
19.5	400.392	350.567	161.275	257.853	386.623
22.5	464.168	406.529	187.016	299.012	448.341
25.5	524.112	459.162	211.226	337.724	506.388
28.5	579.142	507.504	233.462	373.279	559.703
31.5	628.107	550.528	253.251	404.923	607.152
34.5	669.844	587.189	270.113	431.887	647.584
37.5	703.298	616.553	283.625	453.486	679.968
40.5	727.895	638.069	293.544	469.322	703.692
43.5	744.052	652.282	300.177	479.823	719.35
46.5	753.632	660.092	303.81	485.587	727.956

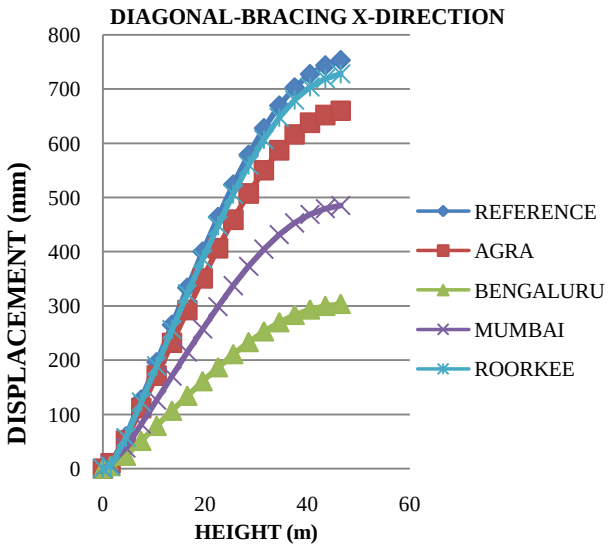

Fig.9 Displacement vs Height of Diagonal bracing system in X-direction

Table 16. Displacement in Eccentric bracing system in mm, X-DIRECTION

HEIGHT(m)	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
0	0	0	0	0	0
1.5	8.674	7.902	4.974	7.902	11.806
4.5	59.241	64.053	34.787	56.742	77.866
7.5	127.445	111.794	69.967	111.794	167.587
10.5	196.097	172.133	107.658	172.133	258.1
13.5	265.335	233.133	145.805	233.133	349.572
16.5	333.794	293.657	183.657	293.657	440.325
19.5	400.392	352.835	220.661	352.835	529.06
22.5	464.168	409.9	257.794	409.9	615.412
25.5	524.112	464.069	290.222	464.069	695.867
28.5	579.142	514.49	321.75	514.49	771.476
31.5	628.107	560.248	350.363	560.248	840.095
34.5	669.844	600.4	375.469	600.4	900.309
37.5	703.298	634.062	396.52	634.062	950.786
40.5	727.895	660.618	413.146	660.618	990.58
43.5	744.052	680.021	425.288	680.021	1019.664
46.5	753.632	692.317	433.746	692.317	1039.125

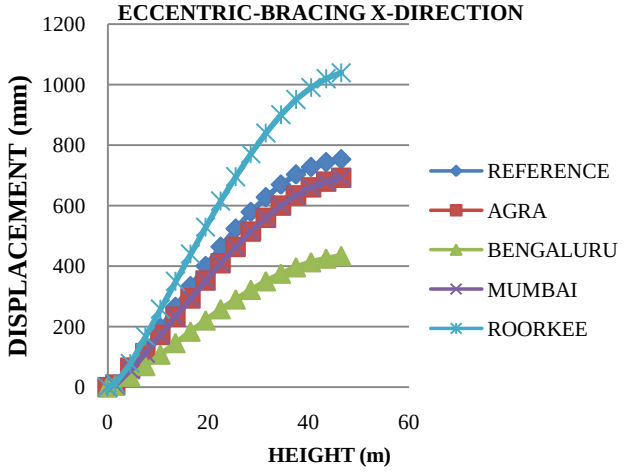

Fig.10 Displacement vs Height of Eccentric bracing system in X-direction

Table 17. Displacement in Knee bracing system in mm, X-DIRECTION

HEIGHT (m)	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
0	0	0	0	0	0
1.5	8.674	10.299	6.884	10.299	14.845
4.5	59.241	51.378	32.136	51.378	77.034
7.5	127.445	110.613	69.235	110.613	165.806
10.5	196.097	170.323	106.536	170.323	255.372
13.5	265.335	230.698	144.296	230.698	345.903
16.5	333.794	290.614	181.77	290.614	435.738
19.5	400.392	349.207	218.414	349.207	523.597
22.5	464.168	405.727	253.762	405.727	608.348
25.5	524.112	459.39	287.321	459.39	688.814
28.5	579.142	509.35	318.565	509.35	763.731
31.5	628.107	554.701	364.926	554.701	831.726
34.5	669.844	594.502	371.814	594.502	891.42
37.5	703.298	627.873	392.684	627.873	941.458
40.5	727.895	654.197	409.167	654.197	980.903
43.5	744.052	673.425	421.167	673.425	1009.723
46.5	753.632	686.475	429.582	686.475	1028.998

Table 18. Displacement in V bracing system in mm, X-DIRECTION

HEIGHT (m)	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
0	0	0	0	0	0
1.5	8.674	52.689	28.662	46.282	40.019
4.5	59.241	66.864	36.292	59.018	79.82
7.5	127.445	110.321	69.068	110.321	165.347
10.5	196.097	169.875	106.28	169.875	254.668
13.5	265.335	230.095	143.951	230.095	346.786
16.5	333.794	289.859	181.339	289.859	435.381
19.5	400.392	348.306	217.9	348.306	522.182
22.5	464.168	404.689	253.168	404.689	606.717
25.5	524.112	458.223	286.654	458.223	686.983
28.5	579.142	508.067	317.831	508.067	761.716
31.5	628.107	553.314	346.131	553.314	829.558
34.5	669.844	593.025	370.968	593.025	889.101
37.5	703.298	626.321	391.795	626.321	939.022
40.5	727.895	652.586	408.244	652.586	978.375
43.5	744.052	671.77	420.253	671.77	1007.127
46.5	753.632	684.79	428.617	684.79	1026.354

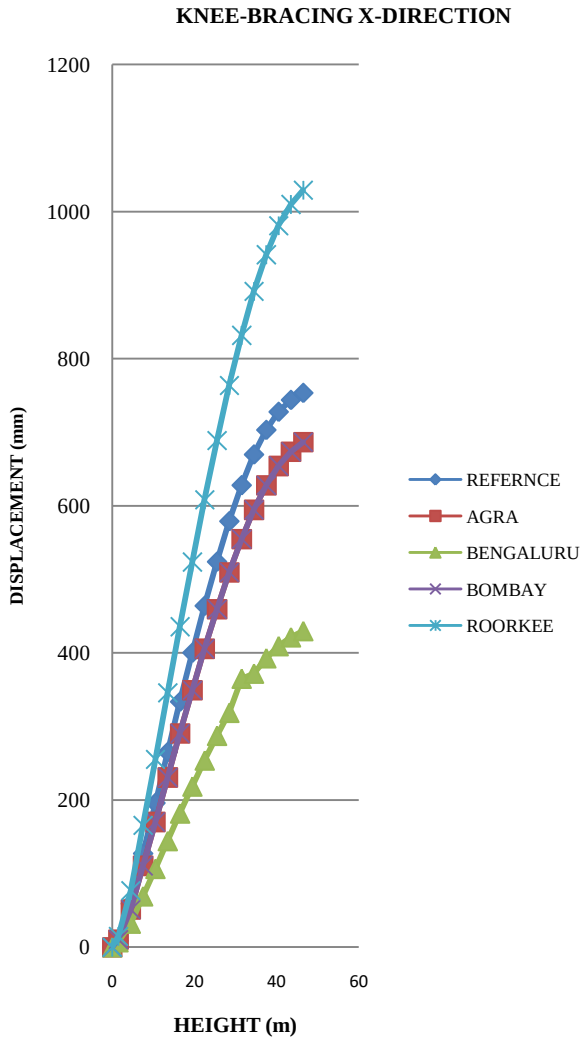

Fig. 11 Displacement vs Height of Knee bracing system in X-direction

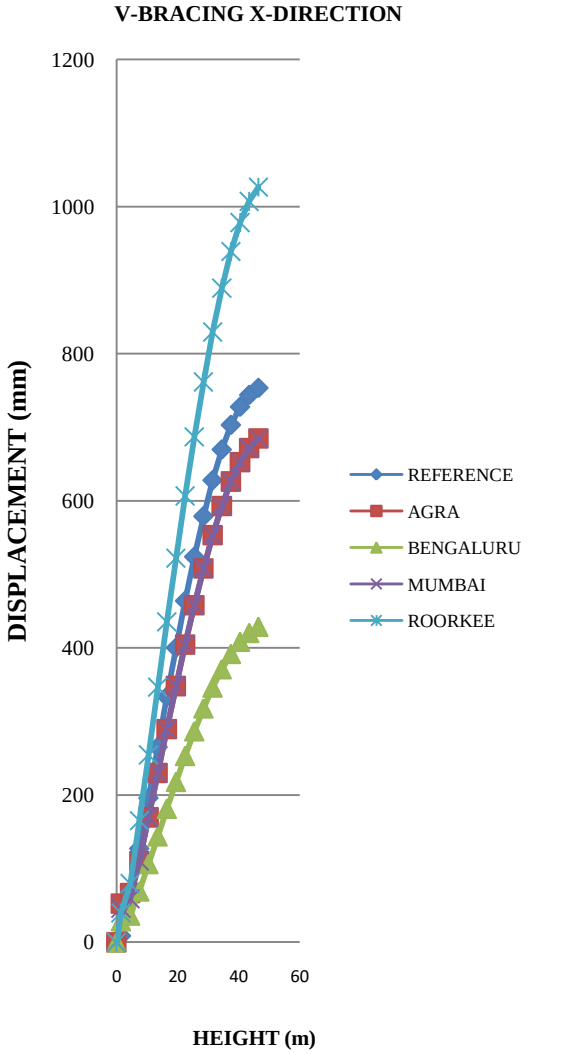

Fig. 12 Displacement vs Height of V bracing system in X-direction

Table 19. Displacement in X bracing system in mm, X-DIRECTION

HEIGHT(m)	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
0	0	0	0	0	0
1.5	8.674	7.186	4.925	7.186	10.199
4.5	59.241	37.936	23.718	37.936	56.893
7.5	127.445	81.672	51.112	81.672	122.422
10.5	196.097	125.634	78.552	125.634	188.409
13.5	265.335	170.035	106.31	170.035	255.002
16.5	333.794	213.97	133.774	213.97	320.892
19.5	400.392	256.744	160.52	256.744	385.043
22.5	464.168	297.738	186.148	297.738	446.524
25.5	524.112	336.297	210.255	336.297	504.353
28.5	579.142	371.715	232.397	371.715	557.471
31.5	628.107	403.238	252.105	403.238	604.748
34.5	669.844	430.097	268.869	430.097	645.031
37.5	703.298	451.607	282.347	451.607	677.288
40.5	727.895	467.393	292.237	467.393	700.933
43.5	744.052	477.692	298.687	477.692	716.367
46.5	753.632	483.935	302.811	483.935	725.434

Table 20. Displacement in Diagonal bracing system in mm, Z-DIRECTION

HEIGHT(m)	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
0	0	0	0	0	0
1.5	30.799	59.01	27.983	43.786	64.931
4.5	233.057	177.561	81.783	130.649	195.805
7.5	445.822	340.089	156.697	250.264	375.023
10.5	586.493	448.022	206.353	329.653	494.054
13.5	725.462	555.108	255.663	408.441	613.145
16.5	861.879	660.878	304.365	486.259	728.785
19.5	994.529	764.242	351.957	562.306	845.772
22.5	1121.768	863.902	397.831	635.626	952.676
25.5	1241.712	958.292	441.293	705.068	1056.769
28.5	1352.215	1045.598	481.482	769.296	1153.049
31.5	1450.855	1123.734	517.449	826.778	1239.217
34.5	1534.943	1190.369	548.122	875.799	1312.702
37.5	1601.522	1242.9	572.304	914.445	1370.633
40.5	1647.474	1278.574	588.752	940.703	1409.97
43.5	1670.65	1295.48	596.634	953.188	1428.594
46.5	1675.555	1296.567	597.112	953.977	1429.796

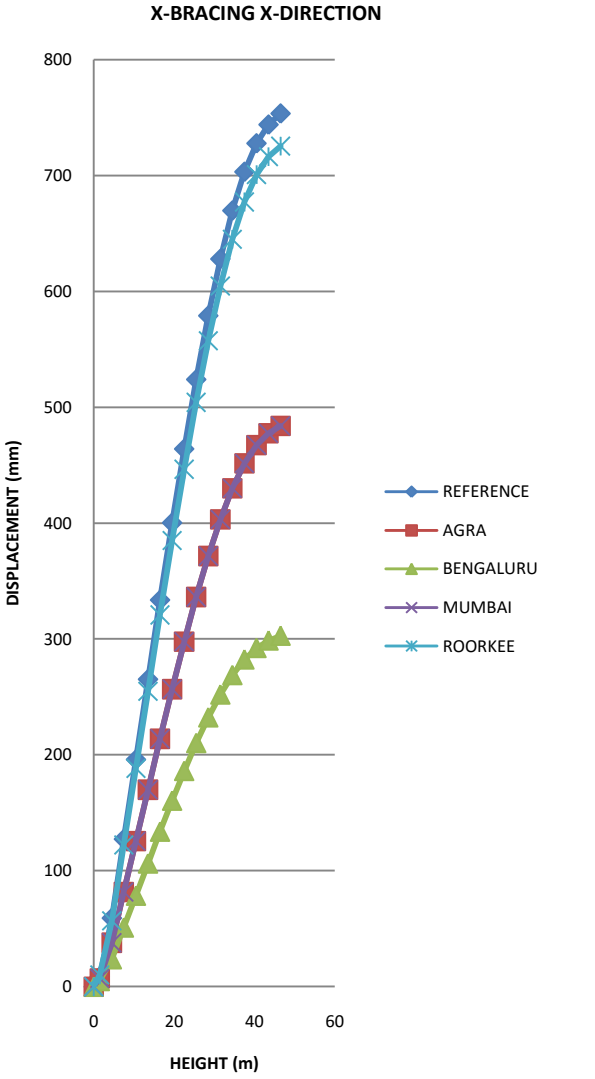

Fig. 13 Displacement vs Height of X bracing system in X-direction

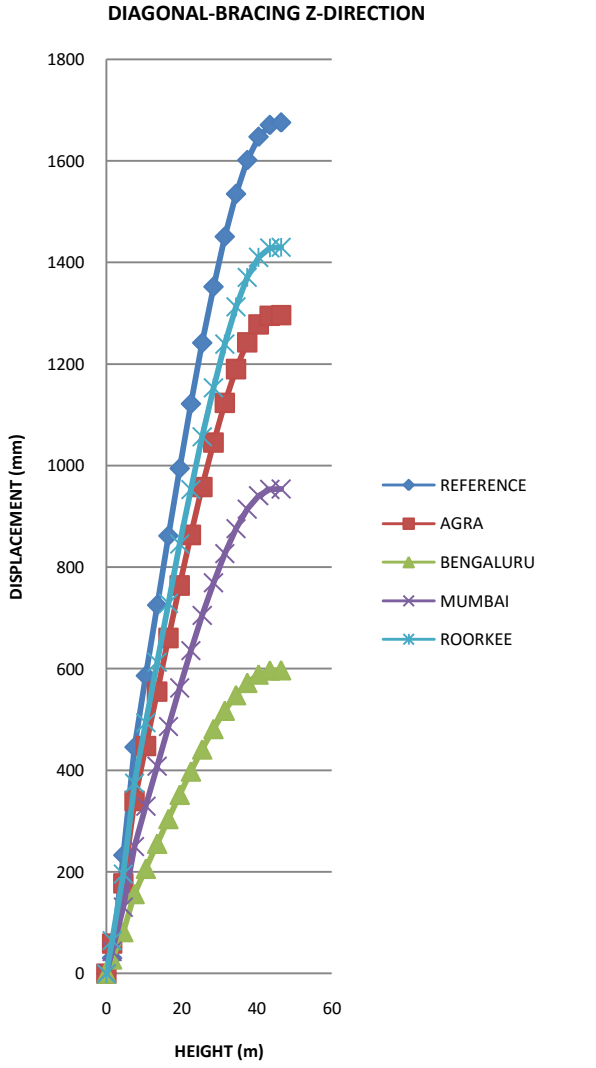

Fig. 14 Displacement vs Height of Diagonal bracing system in Z-direction

Table 21. Displacement in Eccentric bracing system in mm, Z-DIRECTION

HEIGHT(m)	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
0	0	0	0	0	0
1.5	30.799	48.767	30.714	48.767	72.837
4.5	233.057	182.381	114.156	182.381	273.351
7.5	445.822	349.347	218.717	349.347	523.523
10.5	586.493	460.17	288.024	460.17	689.698
13.5	725.462	570.251	356.915	570.251	854.699
16.5	861.879	679.17	425.075	679.17	1017.964
19.5	994.529	785.975	491.911	785.975	1178.061
22.5	1121.768	889.522	556.704	889.522	1333.281
25.5	1241.712	988.447	618.601	988.447	1481.574
28.5	1352.215	1081.158	676.609	1081.158	1620.558
31.5	1450.855	1165.84	729.589	1165.84	1747.508
34.5	1534.943	1240.451	776.268	1240.451	1859.362
37.5	1601.522	1302.724	815.226	1302.724	1952.721
40.5	1647.474	1350.21	844.953	1350.21	2023.887
43.5	1670.65	1380.614	864.037	1380.614	2069.383
46.5	1675.555	1397.031	874.344	1397.031	2093.947

Table 22. Displacement in Knee bracing system in mm, Z-DIRECTION

HEIGHT(m)	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
0	0	0	0	0	0
1.5	30.799	58.207	37.482	58.207	85.842
4.5	233.057	176.001	110.174	176.001	263.712
7.5	445.822	337.222	211.15	337.222	505.318
10.5	586.493	444.324	278.135	444.324	665.91
13.5	725.462	550.83	344.794	550.83	825.544
16.5	861.879	656.338	410.825	656.338	983.689
19.5	994.529	759.927	475.652	759.927	1138.96
22.5	1121.768	860.482	538.577	860.482	1289.691
25.5	1241.712	956.666	598.762	956.666	1433.872
28.5	1352.215	1046.912	655.229	1046.912	1569.157
31.5	1450.855	1129.428	706.865	1129.428	1692.858
34.5	1534.943	1202.194	752.381	1202.194	1801.944
37.5	1601.522	1262.96	790.398	1262.96	1893.043
40.5	1647.474	1309.755	819.404	1309.755	1962.481
43.5	1670.65	1338.716	837.994	1338.716	2006.79
46.5	1675.555	1354.712	847.919	1354.712	2030.437

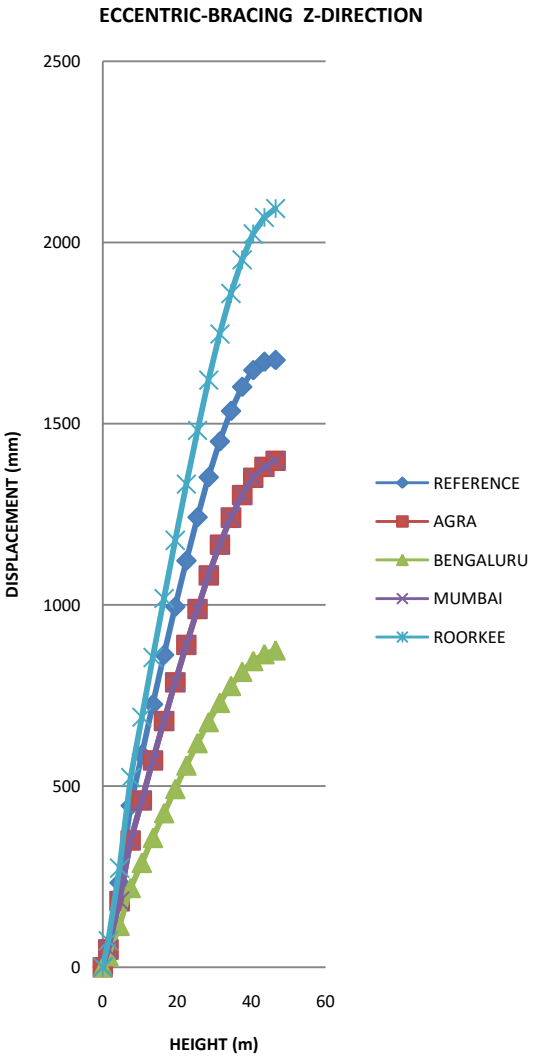

Fig. 15 Displacement vs Height of Eccentric bracing system in Z-direction

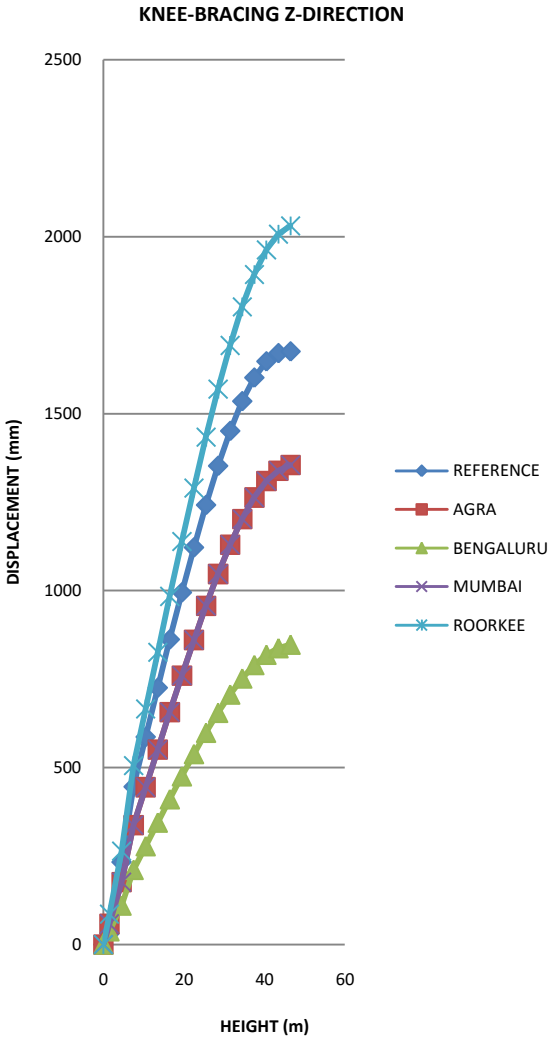

Fig. 16 Displacement vs Height of Knee bracing system in Z-direction

Table 23. Displacement in V bracing system in mm, Z-DIRECTION

HEIGHT(m)	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
0	0	0	0	0	0
1.5	30.799	67.047	35.99	59.111	84.341
4.5	233.057	174.891	109.517	174.891	262.057
7.5	445.822	335.109	209.901	335.109	502.054
10.5	586.493	441.56	276.5	441.56	661.64
13.5	725.462	547.44	342.789	547.44	820.367
16.5	861.879	652.348	408.465	652.348	977.525
19.5	994.529	755.369	472.957	755.369	1131.917
22.5	1121.768	855.394	535.569	855.394	1281.829
25.5	1241.712	951.031	595.466	951.031	1425.257
28.5	1352.215	1040.896	651.673	1040.896	1559.861
31.5	1450.855	1123.023	703.071	1123.023	1682.961
34.5	1534.943	1195.457	748.4	1195.457	1791.533
37.5	1601.522	1255.95	786.255	1255.95	1882.209
40.5	1647.474	1302.076	815.816	1302.076	1951.325
43.5	1670.65	1331.546	833.645	1331.546	1995.415
46.5	1675.555	1347.248	843.509	1347.248	2018.901

Table 24. Displacement in X bracing system in mm, Z-DIRECTION

HEIGHT (m)	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
0	0	0	0	0	0
1.5	30.799	44.206	28.506	44.206	65.138
4.5	233.057	129.178	80.884	129.178	193.569
7.5	445.822	247.514	155.034	247.514	370.821
10.5	586.493	325.992	204.914	325.992	488.499
13.5	725.462	403.952	252.914	403.952	605.336
16.5	861.879	480.974	301.125	480.974	720.773
19.5	994.529	556.271	348.254	556.271	833.628
22.5	1121.768	628.89	393.702	628.89	942.474
25.5	1241.712	697.89	436.756	697.89	1045.599
28.5	1352.215	761.335	476.584	761.335	1141.005
31.5	1450.855	818.308	512.233	818.308	1226.408
34.5	1534.943	866.891	542.632	866.891	1299.237
37.5	1601.522	905.182	566.458	905.182	1356.636
40.5	1647.474	931.172	582.875	931.172	1395.57
43.5	1670.65	943.471	590.639	943.471	1413.914
46.5	1675.555	944.261	591.174	944.261	1415.044

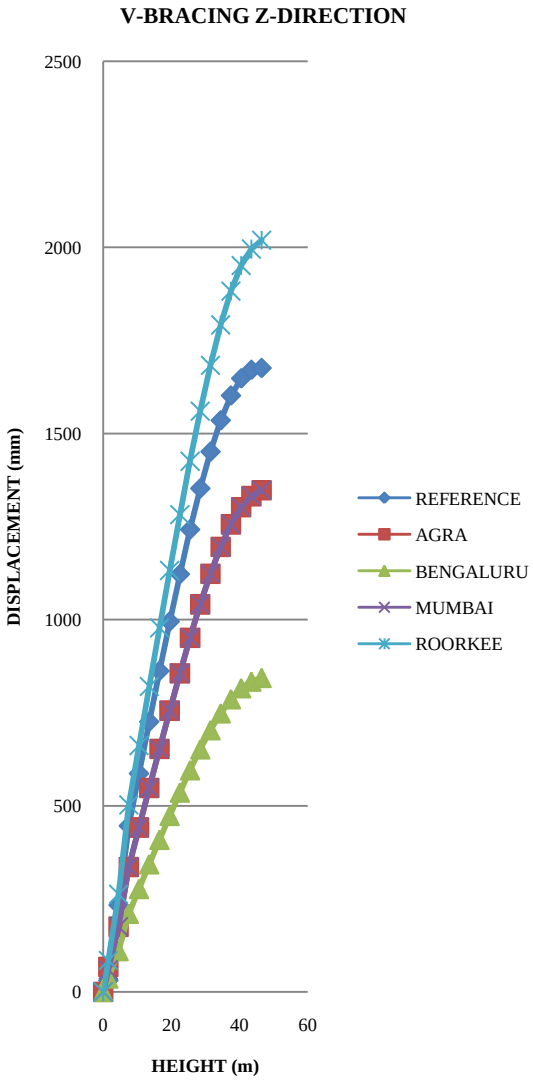

Fig. 17 Displacement vs Height of V bracing system in Z-direction

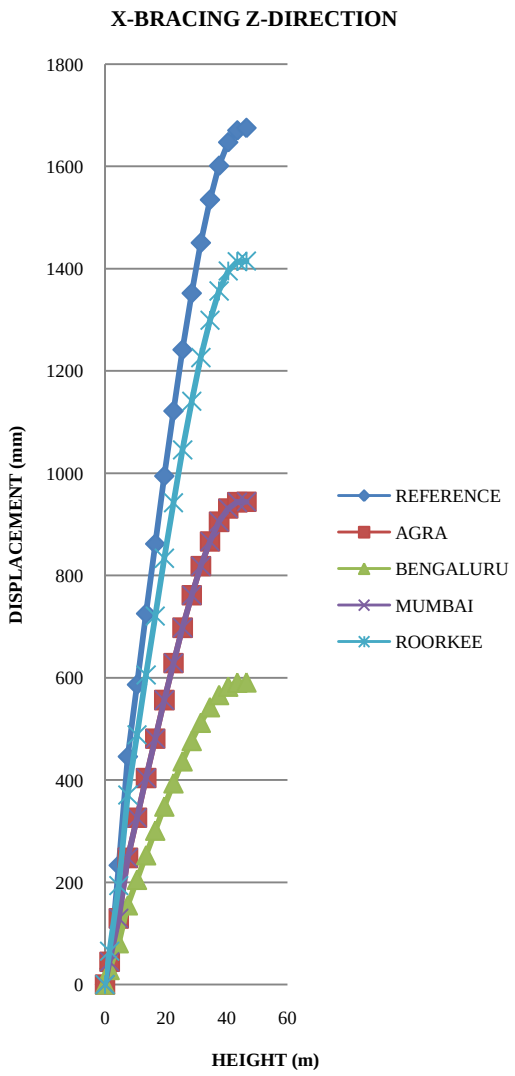

Fig. 18 Displacement vs Height of X bracing system in Z-direction

Table 25. Maximum Axial force acting on ground level column for Diagonal bracing system in kN

	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
AXIAL FORCE	6890.345	5902.611	5257.41	5257.418	6307.907

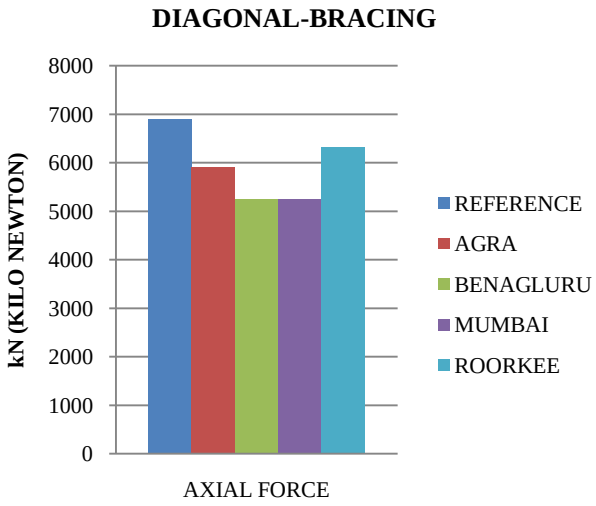

Fig. 19 Variation in Axial force for different cities in Diagonal bracing

Table 26. Maximum Axial force acting on ground level column for Eccentric bracing system in kN

	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
AXIAL FORCE	6890.345	6746.501	6746.501	6746.501	6746.501

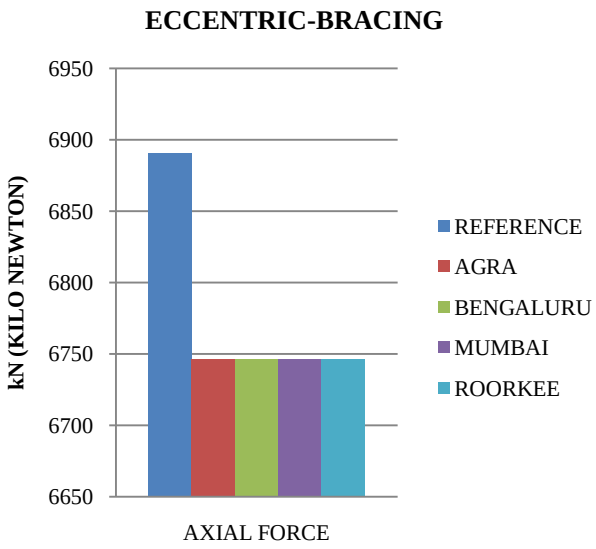

Fig. 20 Variation in Axial force for different cities in Eccentric bracing

Table 27. Maximum Axial force acting on ground level column for Knee bracing system in kN

	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
AXIAL FORCE	6890.345	7040.422	7040.422	7040.422	8108.624

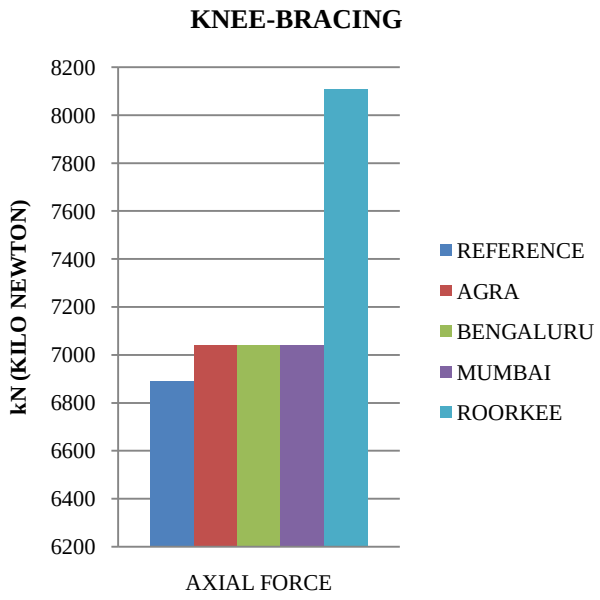

Fig. 21 Variation in Axial force for different cities in Knee bracing

Table 28. Maximum Axial force acting on ground level column for V bracing system in kN

	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
AXIAL FORCE	6890.345	6891.234	6891.234	6891.234	8144.901

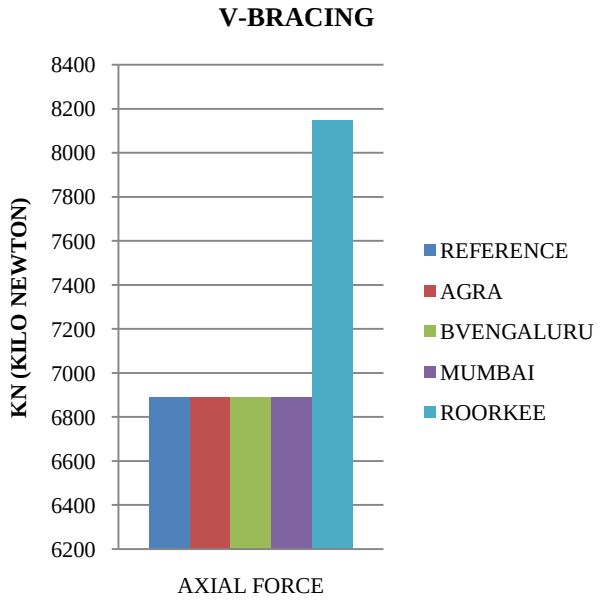

Fig. 22 Variation in Axial force for different cities in V bracing

Table 29. Maximum Axial force acting on ground level column for X bracing system in kN

	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
AXIAL FORCE	6890.345	7290.639	6960.796	7290.639	8833.08

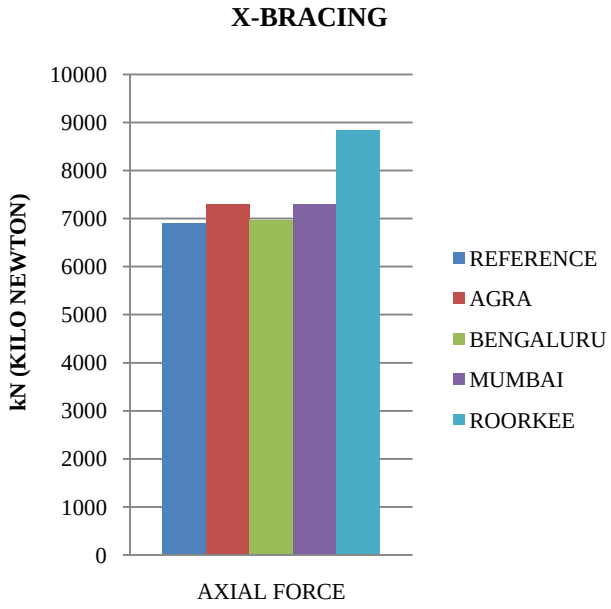

Fig. 23 Variation in Axial force for different cities in X bracing

Table 30. Maximum Bending moment acting on ground level column for Diagonal bracing system in kN-m

	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
BENDING MOMENT	168.947	214.878	97.326	154.994	238.167

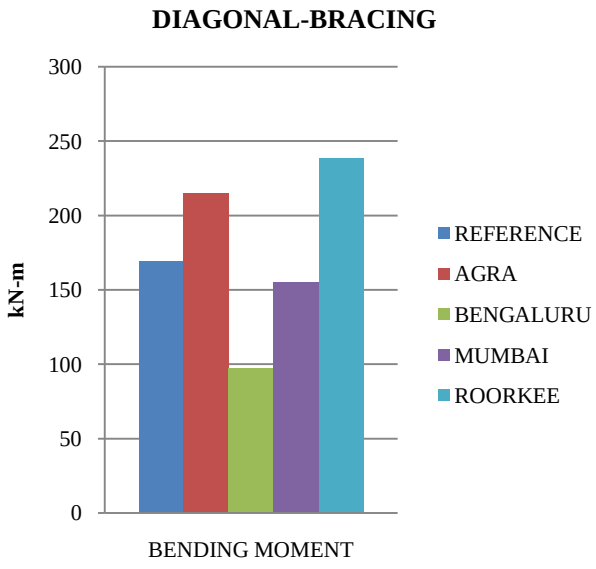

Fig. 24 Variation in Bending moment for different cities in Diagonal bracing

Table 31. Maximum Bending moment acting on ground level column for Eccentric bracing system in kN-m

	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
BENDING MOMENT	168.947	162.045	101.349	162.045	243.374

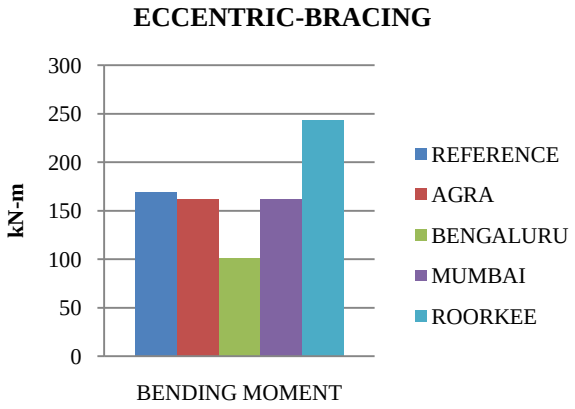

Fig. 25 Variation in Bending moment for different cities in Eccentric bracing

Table 32. Maximum Bending moment acting on ground level column for Knee bracing system in kN-m

	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
BENDING MOMENT	168.947	200.203	137.003	200.203	299.274

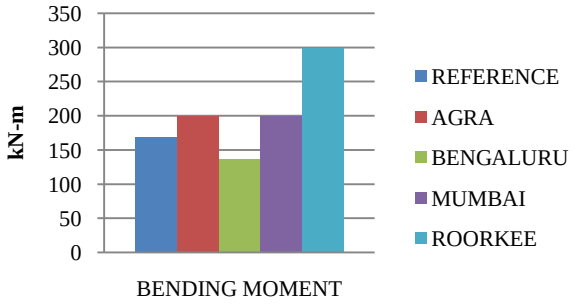

Fig. 26 Variation in Bending moment for different cities in Knee bracing

Table 33. Maximum Bending moment acting on ground level column for V bracing system in kN-m

	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
BENDING MOMENT	168.947	187.661	115.85	187.661	283.409

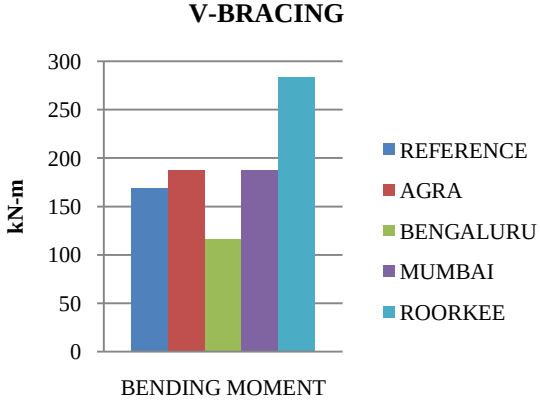

Fig. 27 Variation in Bending moment for different cities in V bracing

Table 34. Maximum Bending moment acting on ground level column for X bracing system in kN-m

	REFERENCE	AGRA	BLR	MUMBAI	ROORKEE
BENDING MOMENT	168.947	146.68	104.72	146.68	213.608

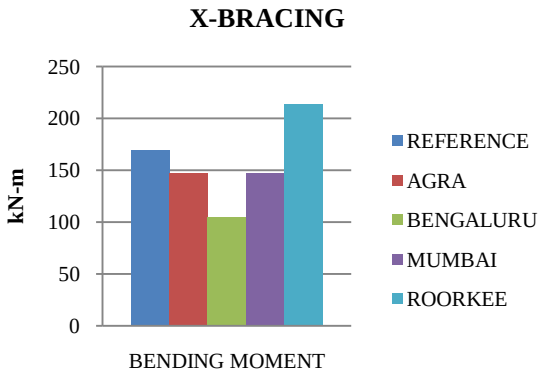

Fig. 28 Variation in Bending moment for different cities in X bracing

Table 35. Weight of steel in kN for various bracing systems in Agra

Diagonal bracing	9549.454
X bracing	9727.191
V bracing	9607.750
Knee bracing	9635.323
Eccentric bracing	9635.323
No bracing	9635.323

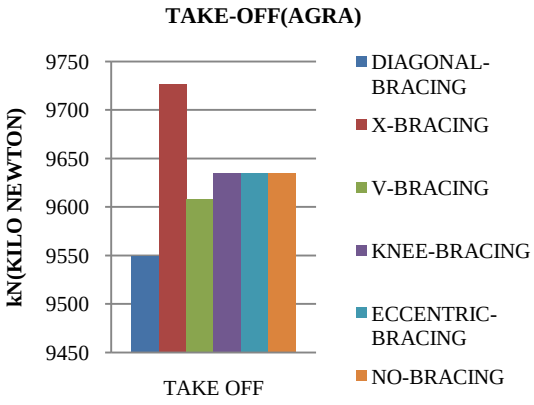

Fig. 29 Variation in Take-off for various bracing systems in Agra

Table 36. Weight of steel in kN for various bracing systems in Bengaluru

Diagonal bracing	9549.454
X bracing	9727.191
V bracing	9607.75
Knee bracing	9635.323
Eccentric bracing	9579.874
No bracing	9635.323

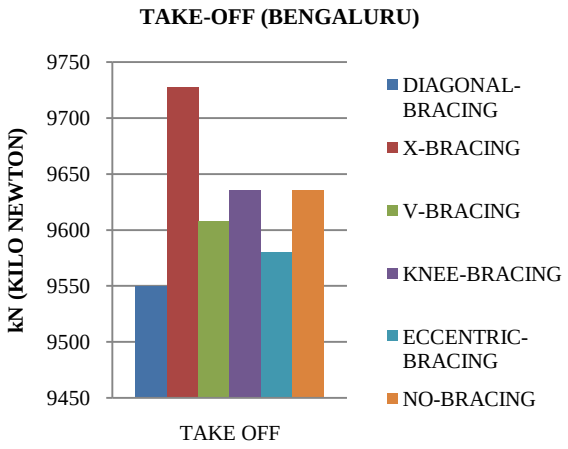

Fig. 30 Variation in Take-off for various bracing systems in Bengaluru

Table 37. Weight of steel in kN for various bracing systems in Mumbai

Diagonal bracing	9549.454
X bracing	9727.191
V bracing	9607.75
Knee bracing	9635.323
Eccentric bracing	9579.874
No bracing	9635.323

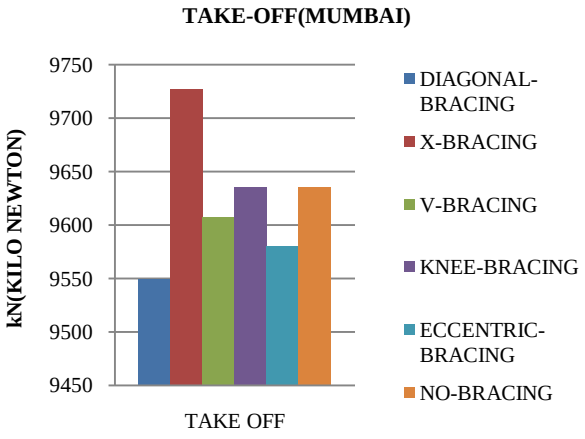

Fig. 31 Variation in Take-off for various bracing systems in Mumbai

Table 38. Weight of steel in kN for various bracing systems in Roorkee

Diagonal bracing	9549.454
X bracing	9721.191
V bracing	9607.75
Knee bracing	9635.323
Eccentric bracing	9579.874
No bracing	9635.323

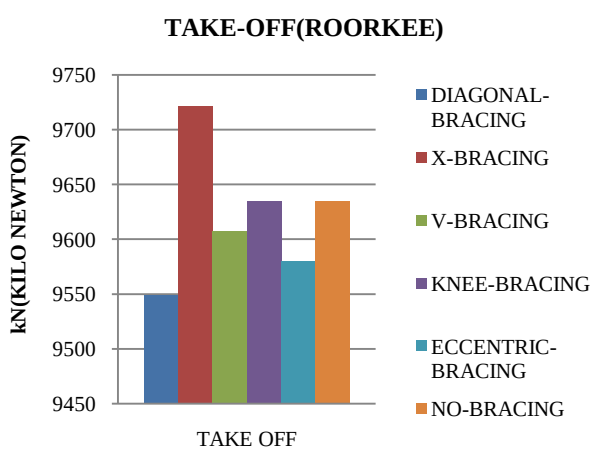

Fig. 32 Variation in Take-off for various bracing systems in Roorkee

Table 39. Percentage change (%) of drift index in X-direction for Diagonal bracing

Model	Displacement(mm)	Drift index	Percentage change
REFERENCE	753.632	0.01621	-
AGRA	660.092	0.01420	12.41
BENGALURU	303.81	0.00653	59.69
MUMBAI	485.587	0.01044	35.57
ROORKEE	727.956	0.01565	3.41

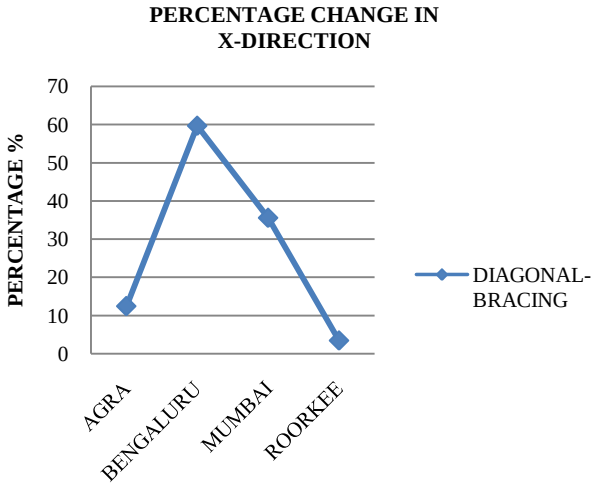

Fig. 33 Percentage change of drift index in X direction for Diagonal bracing

Table 40. Percentage change (%) of drift index in X-direction for Eccentric bracing

Model	Displacement(mm)	Drift index	Percentage change
REFERENCE	753.632	0.01621	-
AGRA	692.317	0.01489	8.14
BENGALURU	433.746	0.00933	42.45
MUMBAI	692.317	0.01489	8.14
ROORKEE	1039.125	0.02235	37.88

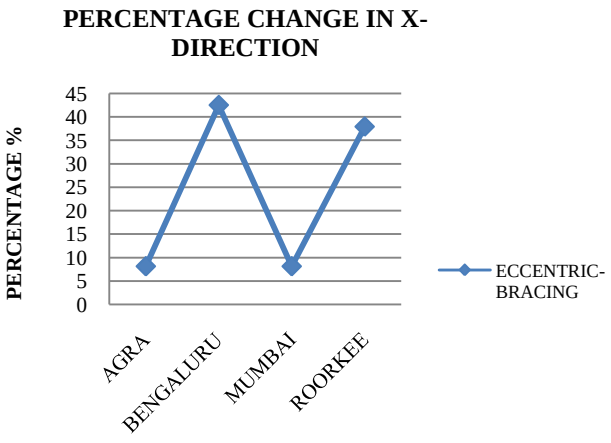

Fig. 34 Percentage change of drift index in X direction for Eccentric bracing

Table 41. Percentage change (%) of drift index in X-direction for Knee bracing

Model	Displacement(mm)	Drift index	Percentage change
REFERENCE	753.632	0.01621	-
AGRA	686.475	0.01476	8.91
BENGALURU	429.582	0.00924	43.00
MUMBAI	686.475	0.01476	8.91
ROORKEE	1028.998	0.02213	36.54

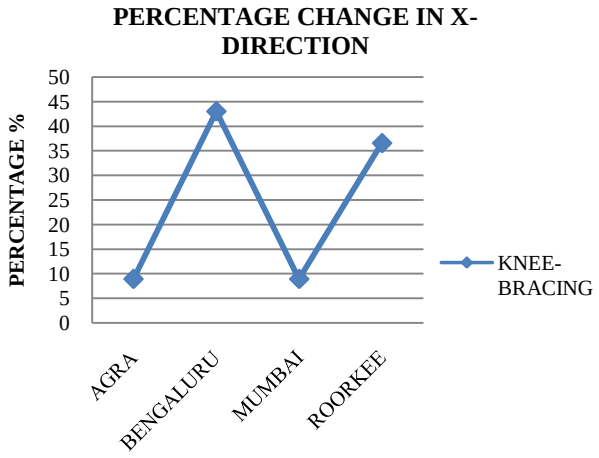

Fig. 35 Percentage change of drift index in X direction for Knee bracing

Table 42. Percentage change (%) of drift index in X-direction for V bracing

Model	Displacement(mm)	Drift index	Percentage change
REFERENCE	753.632	0.01621	-
AGRA	684.79	0.01473	9.13
BENGALURU	428.617	0.00922	43.13
MUMBAI	684.79	0.01473	9.13
ROORKEE	1026.354	0.02207	36.19

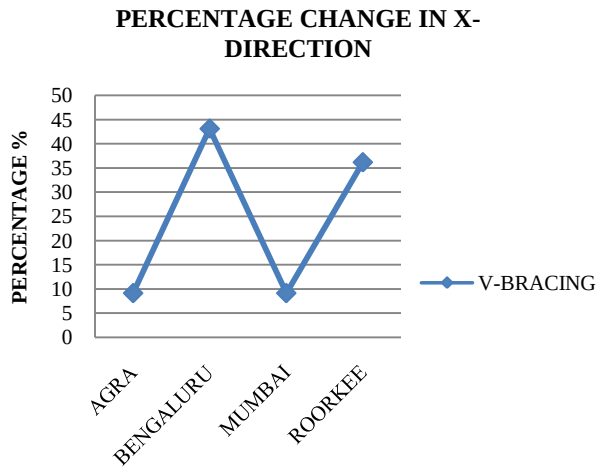

Fig. 36 Percentage change of drift index in X direction for V bracing

Table 43. Percentage change (%) of drift index in X-direction for X bracing

Model	Displacement(mm)	Drift index	Percentage change
REFERENCE	753.632	0.01621	-
AGRA	483.935	0.01041	35.79
BENGALURU	302.811	0.00651	59.82
MUMBAI	483.935	0.01041	35.79
ROORKEE	725.434	0.01560	3.74

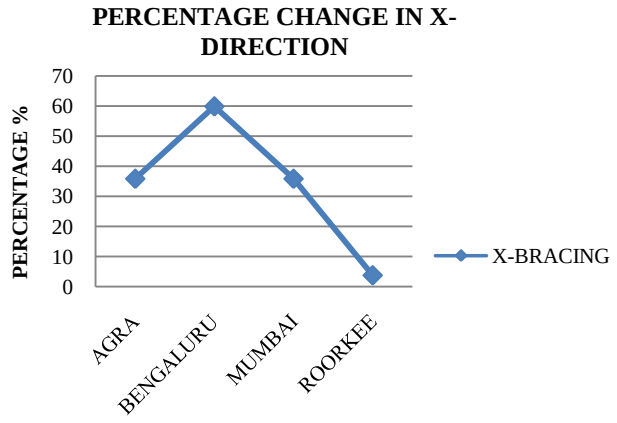

Fig. 37 Percentage change of drift index in X direction for X bracing

Table 44. Percentage change (%) of drift index in Z-direction for Diagonal bracing

Model	Displacement(mm)	Drift index	Percentage change
REFERENCE	1675.555	0.03603	-
AGRA	1296.567	0.02788	22.62
BENGALURU	597.112	0.01284	64.36
MUMBAI	953.977	0.02052	43.07
ROORKEE	1429.796	0.03075	14.67

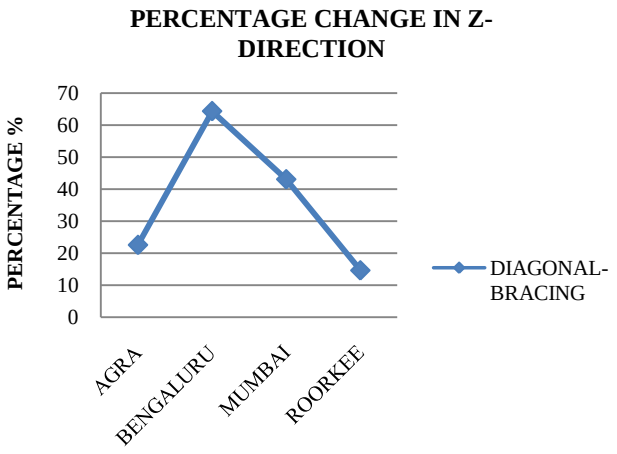

Fig. 38 Percentage change of drift index in Z direction for Diagonal bracing

Table 45. Percentage change (%) of drift index in Z-direction for Eccentric bracing

Model	Displacement(mm)	Drift index	Percentage change
REFERENCE	1675.555	0.03603	-
AGRA	1397.031	0.03004	16.62
BENGALURU	874.344	0.01880	47.82
MUMBAI	1397.031	0.03004	16.62
ROORKEE	2093.947	0.04503	24.97

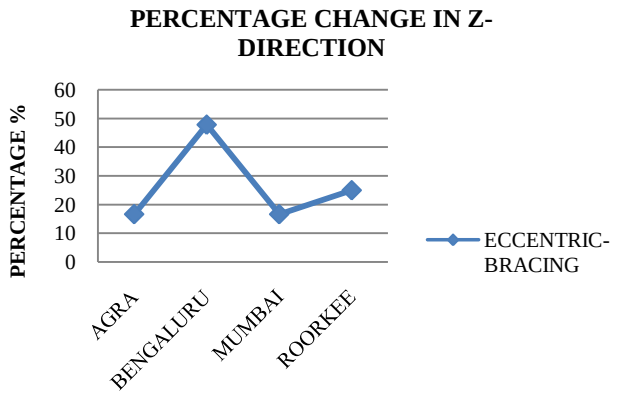

Fig. 39 Percentage change of drift index in Z direction for Eccentric bracing

Table 46. Percentage change (%) of drift index in Z-direction for Knee bracing

Model	Displacement(mm)	Drift index	Percentage change
REFERENCE	1675.555	0.03603	-
AGRA	1354.712	0.02913	19.15
BENGALURU	847.919	0.01823	49.39
MUMBAI	1354.712	0.02913	19.15
ROORKEE	2030.437	0.04367	21.18

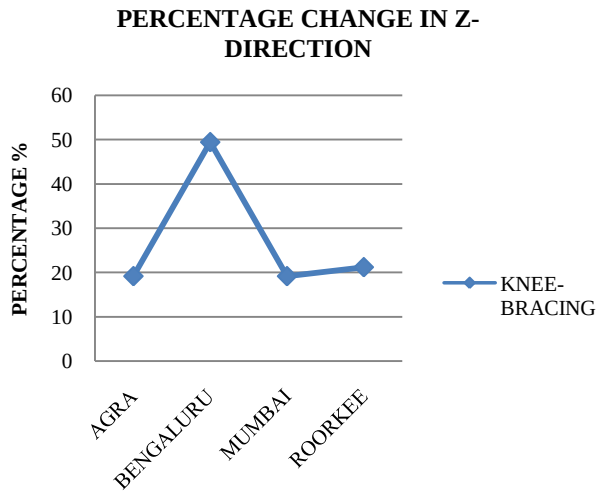

Fig. 40 Percentage change of drift index in Z direction for Knee bracing

Table 47. Percentage change (%) of drift index in Z-direction for V bracing

Model	Displacement(mm)	Drift index	Percentage change
REFERENCE	1675.555	0.03603	-
AGRA	1347.248	0.02897	19.59
BENGALURU	843.509	0.01814	49.66
MUMBAI	1347.248	0.02897	19.59
ROORKEE	2018.901	0.04342	20.49

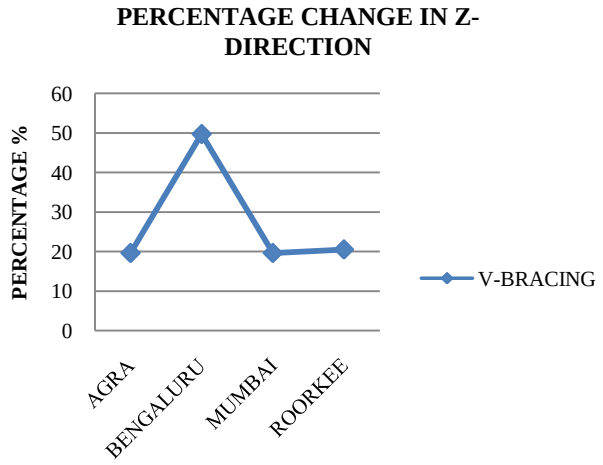

Fig. 41 Percentage change of drift index in Z direction for V bracing

Table 48. Percentage change (%) of drift index in Z-direction for X bracing

Model	Displacement(mm)	Drift index	Percentage change
REFERENCE	1675.555	0.03603	-
AGRA	944.261	0.02031	43.64
BENGALURU	591.174	0.01271	64.72
MUMBAI	944.261	0.02031	43.64
ROORKEE	1415.044	0.03043	15.55

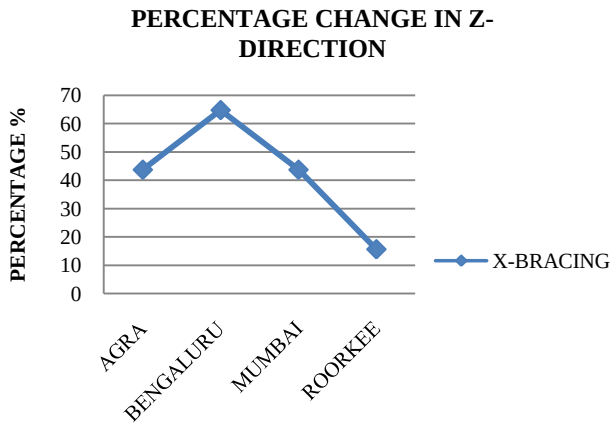

Fig. 42 Percentage change of drift index in Z direction for X bracing

6. CONCLUSION

Following conclusions were drawn after analyzing the different bracing systems with un-braced reference model:

1. Bengaluru city has the least nodal displacements with respect to storey height in both X and Z directions from all the bracing systems compared to other cities.
2. Roorkee city has the highest nodal displacements with respect to storey height in Eccentric, Knee and V bracing system whereas; in Diagonal and X bracing systems the reference has the highest nodal displacements in both X and Z directions.
3. Mumbai and Agra cities show different nodal displacements with respect to storey height in Diagonal bracing whereas; it has same nodal displacements with respect to storey height on other bracing systems.
4. There is a 2.13% increase in axial force on reference model in Eccentric bracing in all cities.
5. Roorkee city shows the highest bending moment in all the bracing systems.
6. X bracing in all the cities shows the highest amount of steel required in kN whereas; Bengaluru city has the lowest amount of steel required in kN.
7. Bengaluru city shows the highest percentage change in drift index in all the bracing systems in both X and Z directions.

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