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Advantage of Steel Diagrid Building Over Conventional Building

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Abstract: **Multi-storey building construction is increasing day by day throughout the world. The design and construction of artificial infrastructure on the lines of bio-mimicking principles require the development of highly advanced structural system which has the quality of aesthetic expression, structural efficiency and most importantly geometric versatility. Recently, the use of diagonal members for carrying the gravity and lateral load has increased and these members are known as 'diagrid'. The unique geometrical configuration of the diagrid structural system has led them to be used for tall buildings providing structural efficiency and aesthetic potential. In this study, the structural response of conventional and diagrid building is investigated to evaluate the structural benefits of diagrid system. A regular G+15 storey steel building with a plan size of 18 m x 18 m, located in a seismic zone V is analysed and designed by STAAD Pro. Software. All structural members are designed as per Indian standard for general construction in steel (IS 800:2007) and the seismic forces are considered as per Indian codal provision for earthquake resistant design of structure (IS 1893 (Part 1): 2002). In diagrid structure, the major portion of lateral load is taken by the external diagonal members, which in turn releases the forces in other members of the structure. The use of diagrids significantly decreases the maximum shear force and bending moment in internal and perimeter beams. The bending moment in internal column also decreases in diagrid building. This reduces the sectional requirement of beams and columns in diagrid building. An overall economy of nearly 12% is achieved in diagrid building compared to conventional building.**

Keywords: **Diagrid building, Conventional building, STAAD Pro., Axial force, Shear force, Bending moment, etc…**

1. INTRODUCTION

The Diagrids are perimeter structural configurations characterized by a narrow grid of diagonal members which are involved both in gravity and in lateral load resistance. Diagonalized applications of structural steel members for providing efficient solutions both in terms of strength and stiffness are not new, however nowadays a renewed interest in it and a widespread application of diagrid is registered with reference to large span and high rise buildings, particularly when they are characterized by complex geometries and curved shapes. The Swiss Re tower in London, Hearst tower in New York, CCTV headquarters building in Beijing, Mode Gakuen Spiral Tower in Aichi, West tower in Guangzhou, Lotte super tower in Seoul, Capital Gate in Abu Dhabi etc. are some of the popular diagrid buildings.

The diagrid systems are the evolution of braced tube structures, since the perimeter configuration still holds for preserving the maximum bending resistance and rigidity, while, with respect to the braced tube, the mega-diagonal members are diffusely spread over the façade, giving rise to closely spaced diagonal elements and allowing for the complete elimination of the conventional vertical columns. The major difference between a braced tube building and a diagrid building is that, there are no vertical columns present in the perimeter of diagrid building, whereas in braced tube building there are vertical column present in the perimeter of the building. Therefore the diagonal members in diagrid structures act both as inclined columns and as bracing elements, and carry gravity loads as well as lateral forces; due to their triangulated configuration, mainly internal axial forces arise in the members, thus minimizing shear racking effects. The term "diagrid" is a combination of the words "diagonal" and "grid" and refers to a structural system that is single-thickness in nature and gains its structural integrity through the use of triangulation. Diagrid systems can be planar, crystalline or take on multiple curvatures. They often use crystalline forms or curvature to increase their stiffness. Perimeter diagrids normally carry the lateral and gravity loads of the building and are used to support the floor edges.

Many researchers investigate the structural performance of Diagrid structure. Some of the noteworthy contributions of researchers in the field of diagrids are discussed below.

Ghobarah et al. (1997) showed that for a low-rise building, increasing the strength of the columns is the most effective rehabilitation technique for reducing drift and damage. The increase in ductility was associated with high drift and the potential for low damage. The improvement of ductility results in modest reduction in damage and marginal effect on the storey drift due to the flexibility of the taller structure.

Moon (2005) studied the dynamic interrelationship between technology and architecture in tall buildings and provided an initial step toward for diagrid structural system.

Moon et al. (2007) studied the optimum angles of diagrid for 60-storey structures. In this study two different diagrid structural system are considered. Scheme 1 takes in account the vertical column where as in Scheme 2 no vertical column are considered. Both the schemes are then considered for the same set of seven different diagrid angles. After several calculation the result show that angles between 53^0 and 76^0 are reasonable choice with 63^0 being the optimal angle.

Leonard (2007) studied the effect of shear lag effect in the diagrid buildings and developed on the work done by Moon in 2005. He concluded that the diagrid building performed 3 times better than the framed tube building in shear lag ratio and lateral deflection and showed high efficiency in carrying lateral load in high rise buildings.

Christopoulus et al. (2008) an advanced cross bracing system has been used in University of Toronto called (SCEDs) Self centering energy dissipating frames. Alike, Special moment resisting frames and Buckling reinforced braced frames, they also dissipate energy, but they have self-centering capabilities which reduce residual

Moon (2009) studied a stiffness based design methodology for determining preliminary member sizes of steel diagrid structures for all tall buildings. The methodology when applied to diagrids of various heights and grid geometries an optimal grid configuration of the diagrid structure within a certain height range was obtained. Constructability of diagrid is a serious issue due to its complicated node design, therefore prefabricated node are constructed via several strategies.

Moon (2011) studied that since the diagrid structures are prevalently used today in tall buildings due to their structural efficiency and architectural aesthetic potentials. Their structural performance employed for complex-shaped tall buildings such as twisted, tilted etc. are investigated. The impacts of variation of important geometric configurations of complex-shaped tall buildings, such as the rate of twisting and angle of tilting was checked. Based on the study results, efficient use of diagrid structures for complex-shaped tall buildings are discussed.

Boake (2013) examined the recent development in the history of diagrid buildings including their design, detailing, fabrication and erection issue in the paper 'diagrids, the new stability system'. Also a comparative understanding of the design requirement and the detailing was discussed. Later in the year another paper was published by Boake discussing the innovation and detailing of diagrid structure.

Jani and Patel (2013) studied the analysis and design of a 36 storey steel diagrid structure having 36m X 36m plan dimension with 3.6m floor height. The angle of diagrid was kept uniform throughout the height and the inclined columns were provided at 6m spacing along the perimeter. The load distribution in diagrid system was studied along with the analysis and design of 50, 60, 70 and 80 storey diagrid structure. Top storey displacement, time period and inner storey drift was also compared.

Singh et al. (2014) studied a regular five storey RCC building with plan size 15 m × 15 m located in seismic zone V is considered for analysis. All structural members are designed as per IS 456:2000 and load combinations of seismic forces are considered as per IS 1893(Part 1): 2002. Comparison of analysis results in terms of storey drift, node to node displacement, bending moment, shear forces, area of reinforcement, and also the economical aspect is presented. In diagrid structure, the major portion of lateral load is taken by external diagonal members which in turn release the lateral load in inner columns. This cause's economical design of diagrid structure compared to conventional structure. Drift in diagrid building is approx. half to that obtained in conventional building. In this study, steel reinforcement used in diagrid structure is found to be 33% less compared to conventional building.

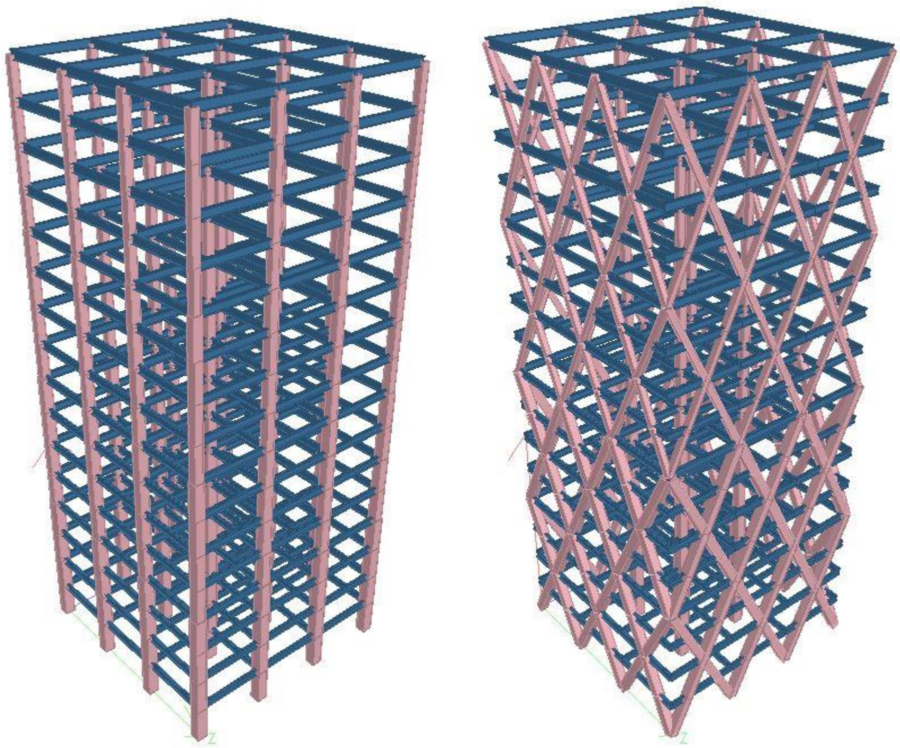
The structure should have adequate lateral strength and sufficient ductility for minimum damage of high rise building. In present study a comparison of forces between conventional and diagrid building is made to evaluate the structure advantages of diagrids. The axial force and bending moment for interior column and shear force and bending moment in interior and perimeter beams are compared for useful findings. Finally the building weights of both the building are also compared.

2. PROBLEM FOR INVESTIGATION

The modelling, analysis and design of a G+15 storey conventional and diagrid building is done with the help of STADD Pro. Software. The geometric parameters of conventional and diagrid both the building are shown in table 1. The isometric view, plan and section are shown in fig - 1 to fig - 3.

Table – 1: Geometric Parameters of Conventional and Diagrid Building

S.No.	Description	Data/Values
1	Number of Storey	G+15
2	Plan Size	18m x 18m
3	Storey Height	3.0m
4	Number of Bays along X and Z direction	3
5	Length of each bay	6m
6	Dead Load: a) Floor load b) Wall (i) Parapet wall (ii) Other wall	 3 kN/m^2 2.6 kN/m 8.5 kN/m
7	Live Load: a) At roof b) Other floors	 2 kN/m^2 4 kN/m^2
8	Seismic Zone as per IS 1893(Part 1): 2002	V
9	Response Reduction Factor	5
10	Importance Factor	1.5
11	Soil Type	Hard
12	Structure Type	Steel frame
13	Diagrid Angle	63.43^o
14	Diagrid Module	4



(a) Conventional building **(b) Diagrid building**

Fig – 1: Isometric view of Conventional building and Diagrid building

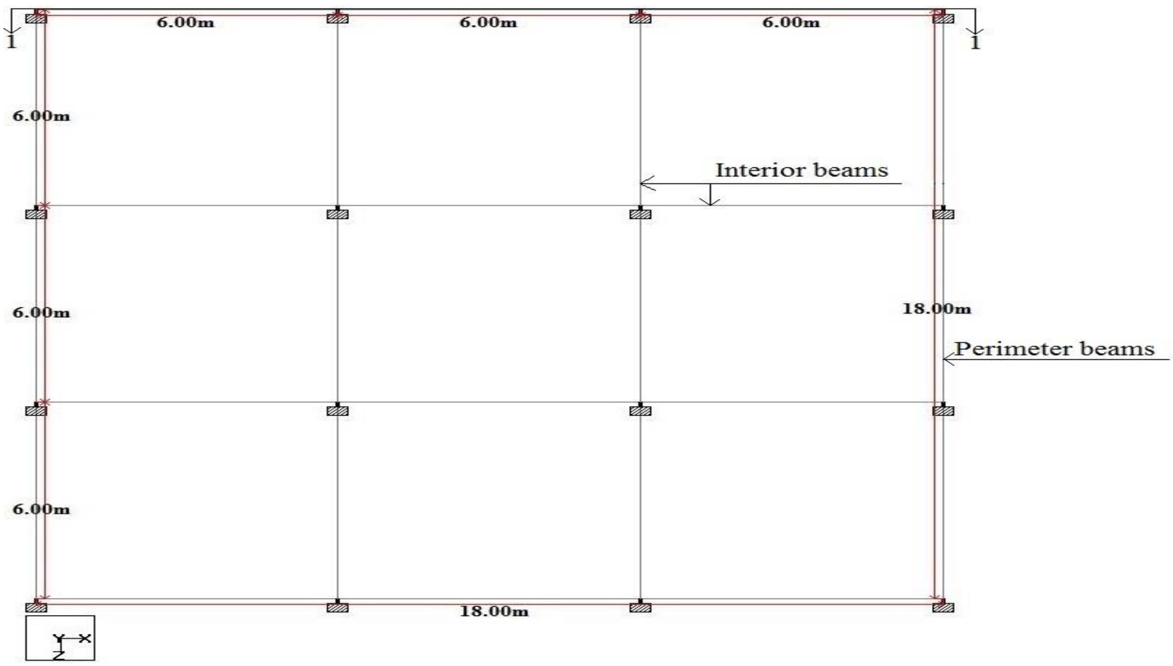
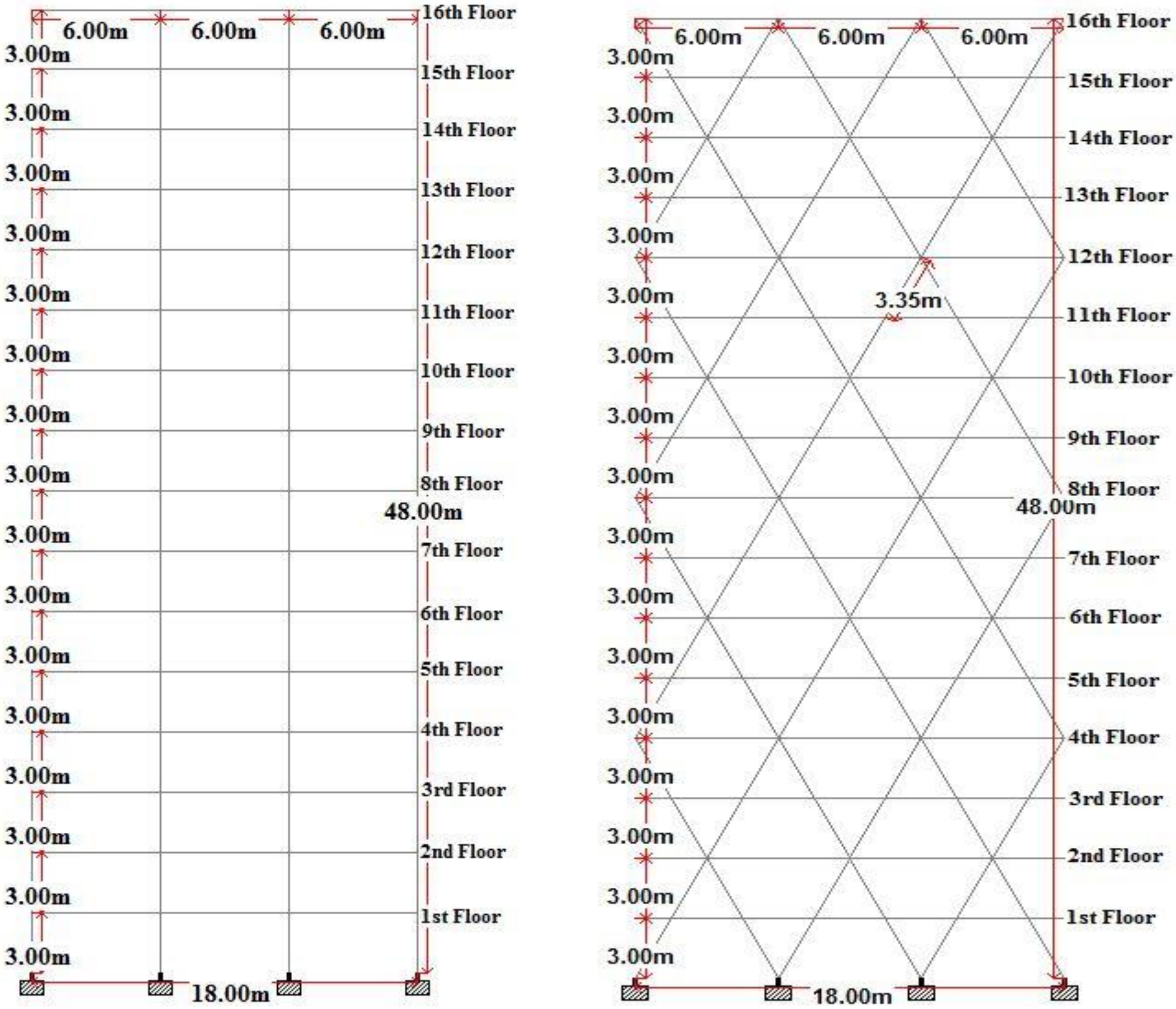


Fig - 2: Plan of Conventional/Diagrid building



(a) Conventional building **(b) Diagrid building**

Fig - 3: View of conventional and diagrid building at section 1-1

3. ANALYSIS

The Conventional and Diagrid building are analysed by means of STAAD Pro software. In present analysis 6 primary load case and 13 load combinations are taken. Dead load and live load are taken as per IS 875 (Part 1 and Part 2):1987 and seismic load are taken as per IS 1893 (Part 1):2002. Primary load case and load combination considered for analysis are shown in table 2. The base of both the buildings is considered to be fixed.

Table - 2: Load Case Details

LOAD CASE NO.	LOAD CASE DETAILS
1	E.Q. IN X DIR.
2	E.Q. IN –X DIR.
3	E.Q. IN Z DIR.
4	E.Q. IN –Z DIR.
5	DEAD LOAD
6	LIVE LOAD
7	1.5(DL+LL)
8	1.2(DL+LL+EQX)
9	1.2(DL+LL-EQX)
10	1.2(DL+LL+EQZ)
11	1.2(DL+LL-EQZ)
12	1.5(DL+EQX)
13	1.5(DL-EQX)
14	1.5(DL+EQZ)
15	1.5(DL-EQZ)
16	0.9DL+1.5EQX
17	0.9DL-1.5EQX
18	0.9DL+1.5EQZ
19	0.9DL-1.5EQZ

4. RESULT AND DISCUSSION

The effects of diagrid on column and beam forces are discussed by comparing results of diagrid structure with conventional buildings. The structural weights of both the buildings are also compared. The buildings are subjected to vibrations due to earthquake in both X direction and Z direction. Since the proposed building is symmetric in geometry and the loading hence the result are discussed for only selected portion of the building. Therefore, to achieve computational economy the following four cases are chosen from table 2 for comparison of results.

a) Load Case 7 (1.5[DL+LL])

b) Load Case 8 (1.2[DL+LL+EQ(X)])

c) Load Case 12 (1.5[DL+EQ(X)])

d) Load Case 16 (0.9DL+1.5EQ(X))

4.1. Effect of Diagrids on Forces in Interior column:

To evaluate the effect of diagrid on columns, the columns are chosen as per figure 4 and the column numbering is shown in figure 5.

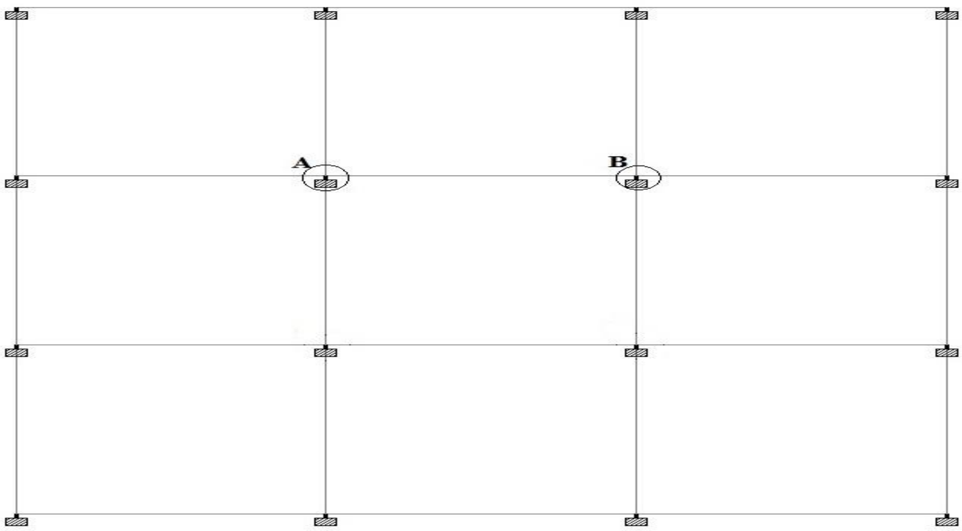


Fig - 4: Columns selected for comparison of results

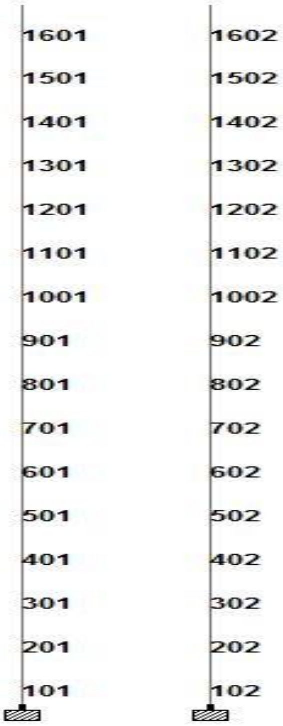


Fig - 5: Column numbering of selected members

4.1.1. Axial Force:

The comparison of axial force in interior columns between conventional and diagrid building at location A and B are shown in table 3 and 4.

The use of diagrid has increased the column axial force in all the column for the considered load cases at location A. The maximum axial force is found to be 7374.05 kN at the bottom column (101) and the minimum is found in top most column (1601) to be 69.09 kN in case of conventional building, where as in case of diagrid building the maximum axial force is found to be 9617.89 kN in the bottom column (101) and the minimum is found in top most column (1601) to be 113.48 kN.

4.1.2 Bending Moment:

The comparison of bending moment in interior columns between conventional and diagrid building at location A and B are shown in table 5 and 6.

Diagrids has effectively reduces the bending moment in columns of location A. The maximum bending moment at the bottom column (member 101) is found to be 765.83 kN-m which has been reduced to 408.22 kN-m in diagrid structure.

Diagrids reduces the bending moment in column at location B significantly. The maximum value of 772.42 kN-m (member 102) is reduced to 396.81 kN-m in diagrid structure. The pattern of bending moment can be seen in figure 6 for interior column.

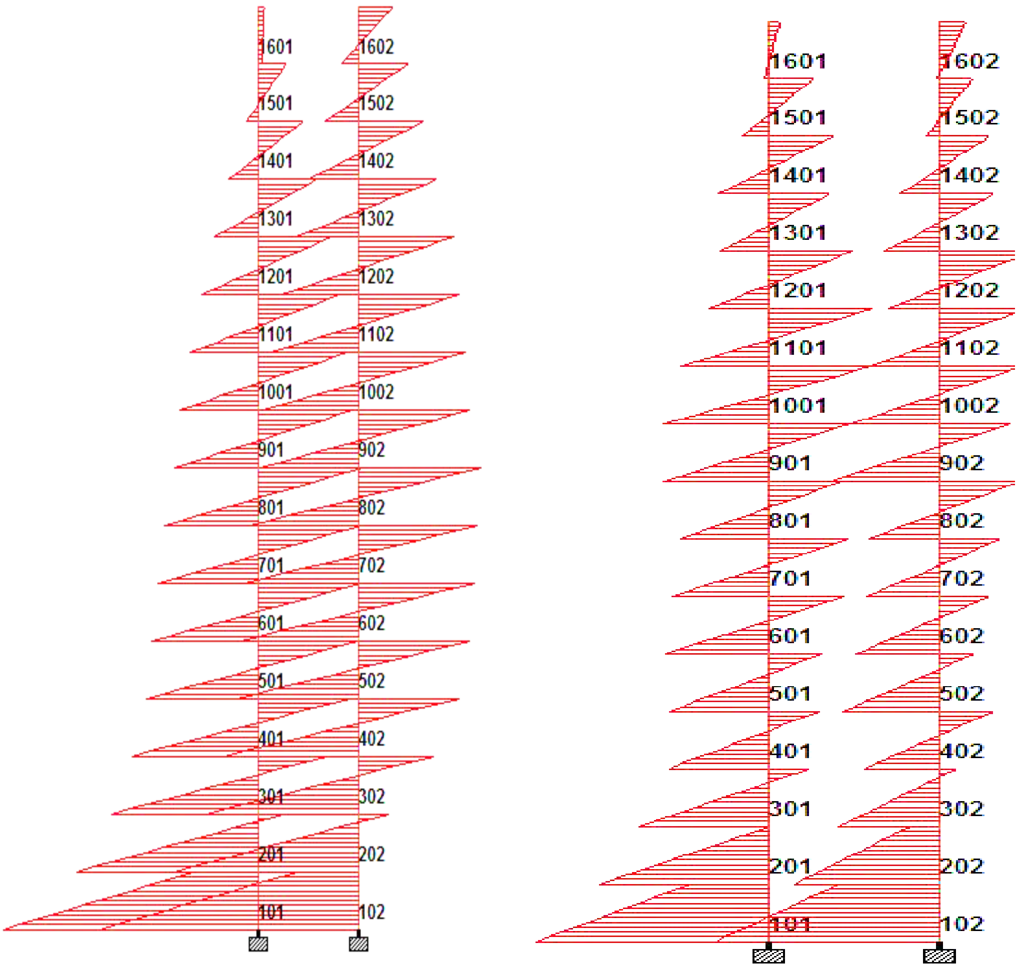
Although the axial force in interior columns of diagrid building increases in comparison to conventional building but there is a significant reduction in bending moment. This reduces the sectional requirement of columns in diagrid building.

4.2. Effect of Diagrid on Forces in Interior Beam:

The comparison of maximum shear forces and maximum bending moments in interior beams between conventional and diagrid building are shown in table 7.

It can be seen that the diagrid has effectively reduced the shear force in all the floors except the first floor. The ratio of shear force between the diagrid and the conventional building varies from 0.72 to 1.12. The maximum shear force in conventional building is found to be 212.59 kN in the beam of 7th floor, whereas the maximum shear force in diagrid building is found to be 177.07 kN in the beam of 1st floor.

It can also be seen that the diagrid has effectively reduced the bending moment in all the floors. The ratio of bending moment between the diagrid and the conventional building varies from 0.54 to 0.82. The maximum bending moment in conventional building is found to be 449.87 kN-m in the beam of 7th floor, whereas the maximum bending moment in the diagrid building is found to be 295.44 kN-m in the beam of 10th floor.



(a) Conventional building **(b) Diagrid building**

Fig – 6: Bending moment in interior column

Table - 3: Comparison of Axial force in Interior Column between Conventional and Diagrid building at location A

Member	Load Case no 7{1.5[DL+LL]}			Load Case no 8 {1.2[DL+LL+EQ(X)]}			Load Case no 12 {1.5[DL+EQ(X)]			Load Case no 16 {0.9DL+1.5EQ(X)}		
	Conventional	Diagrid	Ratio (Dia/Con)	Conventional	Diagrid	Ratio (Dia/Con)	Conventional	Diagrid	Ratio (Dia/Con)	Conventional	Diagrid	Ratio (Dia/Con)
101	7374.05	9617.89	1.30	5817.97	7335.12	1.26	4353.17	5570.71	1.28	2571.27	3162.83	1.23
201	6851.15	8963.46	1.31	5400.02	6826.51	1.26	4042.49	5182.41	1.28	2385.05	2937.32	1.23
301	6337.71	8303.76	1.31	4990.43	6321.67	1.27	3737.56	4799.95	1.28	2202.66	2719.30	1.23
401	5833.40	7649.94	1.31	4589.30	5825.15	1.27	3438.72	4425.52	1.29	2024.53	2507.91	1.24
501	5336.73	7076.68	1.33	4195.11	5371.92	1.28	3144.74	4067.81	1.29	1849.70	2295.97	1.24
601	4847.60	6432.67	1.33	3807.63	4888.74	1.28	2855.43	3707.46	1.30	1678.03	2095.78	1.25
701	4365.82	5783.70	1.32	3427.08	4404.35	1.29	2571.18	3346.72	1.30	1509.92	1896.73	1.26
801	3890.31	5141.77	1.32	3052.43	3925.98	1.29	2291.25	2990.83	1.31	1344.84	1700.78	1.26
901	3418.40	4589.56	1.34	2680.41	3489.21	1.30	2012.82	2644.19	1.31	1180.54	1495.29	1.27
1001	2950.13	3959.85	1.34	2310.70	3025.41	1.31	1735.46	2303.82	1.33	1016.57	1311.06	1.29
1101	2488.06	3324.95	1.34	1946.91	2557.70	1.31	1462.51	1959.96	1.34	855.74	1124.85	1.31
1201	2031.19	2697.03	1.33	1588.05	2090.91	1.32	1193.26	1614.49	1.35	697.51	935.33	1.34
1301	1575.42	2151.10	1.37	1229.82	1663.61	1.35	924.24	1278.62	1.38	539.29	738.53	1.37
1401	1119.04	1529.25	1.37	871.02	1190.95	1.37	654.78	924.14	1.41	380.77	538.26	1.41
1501	665.59	902.36	1.36	515.70	709.09	1.38	388.30	559.75	1.44	224.60	329.46	1.47
1601	211.92	282.25	1.33	161.45	224.88	1.39	123.23	189.90	1.54	69.90	113.48	1.62

Note: Ratio Dia/Con indicates ratio of member forces between Diagrid and Conventional building

Table - 4: Comparison of Axial force in Interior Column between Conventional and Diagrid building at location B

Member	Load Case no 7 {1.5[DL+LL]}			Load Case no 8 {1.2[DL+LL+EQ(X)]}			Load Case no 12 {1.5[DL+EQ(X)]			Load Case no 16 {0.9DL+1.5EQ(X)}		
	Conventional	Diagrid	Ratio (Dia/Con)	Conventional	Diagrid	Ratio (Dia/Con)	Conventional	Diagrid	Ratio (Dia/Con)	Conventional	Diagrid	Ratio (Dia/Con)
102	7374.05	9617.89	1.30	5984.85	8053.50	1.35	4561.76	6468.69	1.42	2777.69	4060.81	1.46
202	6851.15	8963.46	1.31	5566.20	7515.03	1.35	4250.22	6043.06	1.42	2590.58	3797.97	1.47
302	6337.71	8303.76	1.31	5154.38	6964.35	1.35	3942.49	5603.30	1.42	2405.36	3522.65	1.46
402	5833.40	7649.94	1.31	4743.25	6414.75	1.35	3631.16	5162.51	1.42	2217.41	3244.91	1.46
502	5336.73	7076.68	1.33	4342.90	5950.76	1.37	3329.48	4791.36	1.44	2034.83	3019.53	1.48
602	4847.60	6432.67	1.33	3947.88	5403.53	1.37	3030.74	4350.94	1.44	1853.67	2739.26	1.48
702	4365.82	5783.70	1.32	3557.67	4849.57	1.36	2734.43	3903.25	1.43	1673.45	2453.25	1.47
802	3890.31	5141.77	1.32	3171.58	4300.84	1.36	2440.20	3459.40	1.42	1494.03	2169.35	1.45
902	3418.40	4589.56	1.34	2788.63	3854.09	1.38	2148.10	3100.29	1.44	1316.02	1951.39	1.48
1002	2950.13	3959.85	1.34	2409.17	3310.35	1.37	1858.55	2660.01	1.43	1139.83	1667.24	1.46
1102	2488.06	3324.95	1.34	2033.72	2762.21	1.36	1571.02	2215.59	1.41	964.38	1380.48	1.43
1202	2031.19	2697.03	1.33	1661.63	2224.34	1.34	1285.23	1781.29	1.39	789.59	1102.13	1.40
1302	1575.42	2151.10	1.37	1290.68	1778.16	1.38	1000.32	1421.81	1.42	615.45	881.72	1.43
1402	1119.04	1529.25	1.37	919.31	1255.85	1.37	715.15	1005.27	1.41	441.19	619.39	1.40
1502	665.59	902.36	1.36	549.16	734.68	1.34	430.12	591.74	1.38	266.45	361.44	1.36
1602	211.92	282.25	1.33	177.58	226.72	1.28	143.39	192.19	1.34	90.08	115.77	1.29

Note: Ratio Dia/Con indicates ratio of member forces between Diagrid and Conventional building

Table - 5: Comparison of Bending moment in Interior Column between Conventional and Diagrid building at location A

Member	Load Case no 7{1.5[DL+LL]}			Load Case no 8{1.2[DL+LL+EQ(X)]}			Load Case no 12 {1.5[DL+EQ(X)]			Load Case no 16 {0.9DL+1.5EQ(X)}		
	Conventional	Diagrid	Ratio(Dia/con)	Conventional	Diagrid	Ratio(Dia/con)	Conventional	Diagrid	Ratio(Dia/con)	Conventional	Diagrid	Ratio(Dia/con)
101	-9.44	33.12	-3.51	608.63	330.08	0.54	764.19	408.22	0.53	765.83	405.37	0.53
201	-13.32	43.47	-3.26	433.36	247.05	0.57	544.38	295.68	0.54	545.48	287.54	0.53
301	-20.52	38.36	-1.87	344.38	191.89	0.56	438.08	226.41	0.52	441.47	216.45	0.49
401	-27.46	33.83	-1.23	295.23	149.82	0.51	379.75	175.32	0.46	384.55	166.57	0.43
501	-32.66	23.73	-0.73	259.44	137.03	0.53	337.38	174.99	0.52	343.35	173.69	0.51
601	-37.75	33.45	-0.89	242.81	152.62	0.63	319.69	183.09	0.57	326.99	175.87	0.54
701	-44.32	30.12	-0.68	232.46	142.80	0.61	311.33	170.47	0.55	320.75	161.64	0.50
801	-51.82	-23.33	0.45	231.92	127.46	0.55	314.25	154.57	0.49	325.24	148.12	0.46
901	-48.69	-15.63	0.32	208.97	139.36	0.67	284.01	185.62	0.65	294.37	187.30	0.64
1001	-52.17	21.03	-0.40	194.56	149.91	0.77	267.67	184.30	0.69	278.75	178.45	0.64
1101	-57.21	19.19	-0.34	174.21	147.82	0.85	244.54	183.26	0.75	256.71	177.66	0.69
1201	-63.83	-29.04	0.45	152.11	102.72	0.68	220.07	148.74	0.68	233.63	152.23	0.65
1301	-56.82	-18.25	0.32	118.67	81.84	0.69	174.95	107.38	0.61	187.04	105.43	0.56
1401	-58.41	11.46	-0.20	85.40	90.29	1.06	134.15	113.72	0.85	146.56	108.79	0.74
1501	-60.93	10.89	-0.18	44.17	62.42	1.41	83.63	79.19	0.95	96.63	75.23	0.78
1601	-82.31	-41.37	0.50	-17.29	-6.57	0.38	17.31	17.20	0.99	34.67	24.88	0.72

Note: Ratio Dia/Con indicates ratio of member forces between Diagrid and Conventional building

Table 6: Comparison of Bending moment in Interior Column between Conventional and Diagrid building at location B

Member	Load Case no 7{1.5[DL+LL]}			Load Case no 8{1.2[DL+LL+EQ(X)]}			Load Case no 12 {1.5[DL+EQ(X)]			Load Case no 16 {0.9DL+1.5EQ(X)}		
	Conventional	Diagrid	Ratio(Dia/con)	Conventional	Diagrid	Ratio(Dia/con)	Conventional	Diagrid	Ratio (Dia/con)	Conventional	Diagrid	Ratio (Dia/con)
102	9.44	-33.12	-3.48	620.65	311.67	0.50	772.42	393.96	0.51	770.78	396.81	0.51
202	13.32	-43.47	-3.27	441.93	193.49	0.44	549.74	254.99	0.46	548.70	263.13	0.48
302	20.52	-38.36	-2.21	369.97	130.52	0.35	454.85	176.60	0.39	451.54	186.56	0.41
402	27.46	-33.83	-1.24	329.12	95.70	0.29	400.69	131.58	0.33	397.12	140.33	0.35
502	32.66	-23.73	-0.73	304.22	137.76	0.45	367.21	168.50	0.46	361.24	169.80	0.47
602	37.75	-33.45	-0.89	297.94	111.45	0.37	356.24	147.00	0.41	348.92	154.22	0.44
702	44.32	-30.12	-0.68	303.33	94.61	0.31	358.42	126.30	0.35	349.01	135.13	0.39
802	51.82	23.33	0.45	314.79	129.76	0.41	369.13	145.31	0.39	358.17	142.73	0.40
902	48.69	15.63	0.32	286.84	164.36	0.57	335.74	194.02	0.58	325.40	192.34	0.59
1002	52.17	-21.03	-0.40	278.00	121.56	0.44	323.04	155.04	0.48	311.97	160.89	0.52
1102	57.21	-19.19	-0.34	265.71	94.32	0.35	305.36	155.27	0.51	293.20	160.87	0.55
1202	63.83	29.04	0.46	254.21	149.19	0.59	287.82	166.15	0.58	274.28	162.67	0.59
1302	56.82	18.25	0.32	209.56	87.51	0.42	235.33	97.64	0.41	223.26	99.59	0.45
1402	58.41	-11.46	-0.20	178.84	71.96	0.40	196.15	89.10	0.45	183.76	94.02	0.51
1502	60.93	-10.89	-0.18	141.64	48.43	0.34	148.64	59.36	0.40	135.64	63.33	0.47
1602	82.31	41.37	0.50	114.38	59.63	0.52	104.04	46.96	0.45	86.70	41.44	0.48

Note: Ratio Dia/Con indicates ratio of member forces between Diagrid and Conventional building

Table - 7: Comparison of maximum shear force and maximum bending moment in Interior Beams between the Conventional and Diagrid building

Internal beams at	Maximum Shear Force			Maximum Bending Moment		
	Conventional	Diagrid	Ratio (Dia/con)	Conventional	Diagrid	Ratio (Dia/con)
16th Floor	98.20	83.90	0.85	-166.88	-97.46	0.58
13th Floor	178.50	167.49	0.94	-342.63	-227.68	0.66
10th Floor	203.64	172.98	0.85	-419.97	-295.44	0.70
7th Floor	212.59	173.24	0.81	-449.87	-269.97	0.60
4th Floor	205.51	147.55	0.72	-438.52	-238.88	0.54
1st Floor	157.92	177.07	1.12	-280.52	-230.53	0.82

4.3. Effect of Diagrid on Forces in Perimeter Beam:

The comparison of maximum shear forces and maximum bending moments in perimeter beams between conventional and diagrid building are discussed as per table 8.

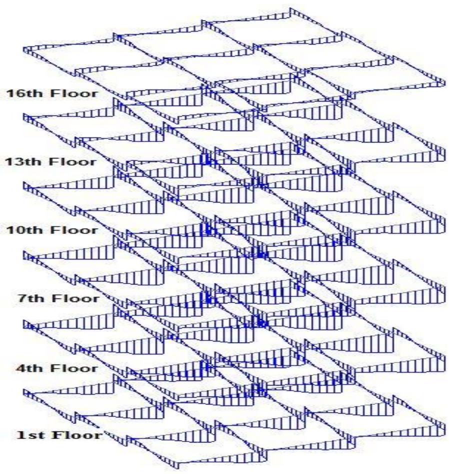
It can be seen that the shear force has been reduced significantly in the diagrid building. The ratio between the diagrid and the conventional building varies from 0.54 to 0.95. The maximum value of shear force in the conventional building is found to be 164.40 kN in the beam of 7th floor, where as the maximum value of shear force in the diagrid building is found to be 143.46 kN in the beam of 10th floor.

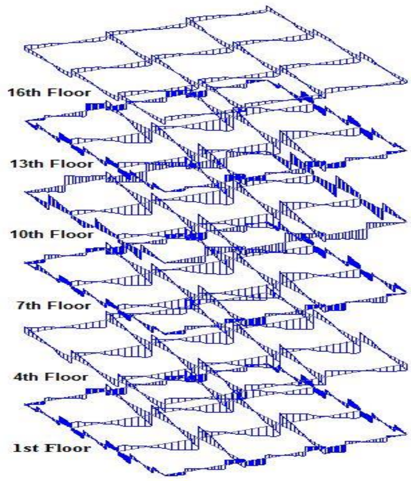
It can also be seen that the bending moment has been reduced significantly and effectively. The ratio between the diagrid and the conventional building varies from -0.23 to -0.54. The negative sign indicate the reversal of bending moment value in the diagrid building. The maximum value of bending moment in the conventional building is found to be -372.30 kN-m in the beam of 7th floor, where as the maximum bending moment in the diagrid building is found to be 151.17 kN-m in the beam of 10th floor.

Table - 8: Comparison of shear force and bending moment in Perimeter Beams between the Conventional and Diagrid building

Perimeter beams at	Maximum Shear Force			Maximum Bending Moment		
	Conventional	Diagrid	Ratio (Dia/con)	Conventional	Diagrid	Ratio (Dia/con)
16th Floor	62.21	54.49	0.88	-115.66	62.77	-0.54
13th Floor	128.60	92.67	0.72	-250.30	63.85	-0.26
10th Floor	150.49	143.46	0.95	-331.67	157.17	-0.47
7th Floor	164.40	87.98	0.54	-372.30	84.13	-0.23
4th Floor	162.79	92.75	0.57	-367.17	106.49	-0.29
1st Floor	116.72	88.43	0.76	-213.81	78.13	-0.37

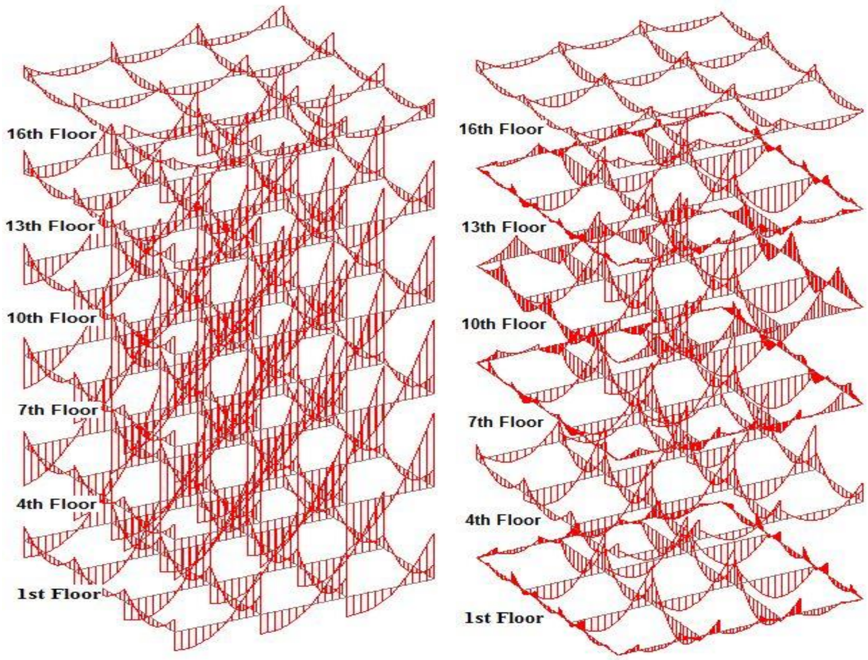
The shear force and bending moment pattern of interior and perimeter beams can be seen in figure 7 and figure 8 respectively.





(a) Conventional building **(b) Diagrid building**

Figure 7: Shear force diagram of selected floor beams for conventional and diagrid building



(a) Conventional building **(b) Diagrid building**

Fig - 8: Bending moment diagram of selected floor beams for conventional and diagrid building

The diagrid configuration provide a reduction in the span of peripheral beams at alternate floors, however this span remains constant in conventional building. Hence a significant reduction in forces of peripheral beams is found at alternate floors.

4.4. Effect of Diagrid on Weight of the Building:

The comparison of weight of columns and weight of beams between conventional and diagrid building is shown in table 9 and table 10 respectively. In the diagrid building the sectional requirement of the members has been reduced when compared to the conventional building. A reduction of nearly 6% in column weight and 17% in beam weight is found in diagrid building compared to conventional building. An overall advantage of approximately 12% in weight is seen in the diagrid building.

Table 9: Comparison of Weight of Columns between Conventional and Diagrid building

Type of Structural Member		**Conventional Building**		**Diagrid Building**	
		Section	**Weight (kN)**	**Section**	**Weight (kN)**
Columns 1^{st}- 4^{th} Floor	Vertical	Steel tube 850x850x20 mm	979.36	Steel tube 850x850x20 mm	244.84
	Diagonal	-	-	Steel Tube 650x650x10 mm	633.23
Columns 5^{th}- 8^{th} Floor	Vertical	Steel tube 750x750x20 mm	861.36	Steel tube 675x675x20 mm	193.22
	Diagonal	-	-	Steel Tube 650x650x10 mm	633.23
Columns 9^{th}- 12^{th} Floor	Vertical	Steel tube 650x650x15 mm	561.95	Steel tube 575x575x15 mm	123.90
	Diagonal	-	-	Steel Tube 400x400x10 mm	385.88
Columns 13^{th}- 16^{th} Floor	Vertical	Steel tube 550x550x15 mm	473.45	Steel tube 475x475x15 mm	101.77
	Diagonal	-	-	Steel Tube 400x400x10 mm	385.88
		Total Weight (kN)	**2876.12**		**2701.95**

Table 10: Comparison of Weight of Beams between Conventional and Diagrid building

Type of Structural Member	Conventional		Diagrid	
	Section	Weight (kN)	Section	Weight (kN)
Internal Beams	ISWB550 with Cover Plate of 250x10 mm TB	1710.63	ISWB500 with Cover Plate of 250x10 mm TB	1515.05
Perimeter Beams 1 { Floors: 1, 3, 5, 7, 9, 11, 13, 15}	ISWB600	753.99	ISWB550	634.07
Perimeter Beams 2 { Floors: 2, 4, 6, 8, 10, 12, 14, 16}	ISWB600	753.99	ISWB500	536.29
	Total Weight (kN)	**3218.61**		**2685.41**

5. CONCLUSION

In the present study G+15 storey conventional and diagrid building is analysed under gravity and seismic loading. The results are compared to evaluate the utility of diagrids. The following conclusions are made on the basis of present work:

- A significant decrease of bending moment in interior columns of diagrid building is found in comparison to conventional building.
- The use of diagrids significantly decreases the maximum shear force and maximum bending moment in internal and perimeter beams. The sign of maximum bending moment also changes in perimeter beams of diagrid building.
- The diagrid configuration provides a reduction in the span of perimeter beams at alternate floors, hence reducing the beam forces at alternate floors.
- The sectional requirement of the members has been reduced in diagrid building when compared to the conventional building. This results in an advantage of approximately 12% in weight for diagrid building.

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