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Comparative analysis of diagrid structural system

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Abstract

Construction of multi-storey building is hastily growing in the course of the world. Advancement in construction technology, materials, structural systems, design and analysis software helped the growth of such buildings. Diagrid structures are rising as structurally efficient as well as architecturally significant for tall structures. Recently the diagrid structural system has been broadly used for tall structures due to its structural efficiency and aesthetic look. Generally, for tall buildings steel diagrid structural system is used. In this paper a regular G+9 storey steel building with plan of size 21.6 m × 21.6 m is considered, located in seismic zone III with zone factor 0.16. Modelling and analysis of structural members are done using Staad. Pro software. All structural members are designed considering IS 800:2007 and load combinations of seismic forces are considered as per IS 1893(Part 1): 2002. Three cases with 45º, 63.43º and varying angle for two storey module and three storey module for diagrid structural systems are considered. Comparison of analyzed results in terms of storey drift, storey displacement, and steel usage aspect is presented.
It is concluded that 45º diagrid system is most suitable from all aspects compared with the conventional system.

Keywords: Diagrid building, conventional building, storey drift, economy, seismic forces

Introduction

Construction of a multi-storey building is speedily increasing throughout the world. According to the data published in the 1980s, in all tall buildings in the world, 49% of them were located in North America. This distribution of tall buildings has changed entirely. Now Asia having the largest stake with 32%, and North America's having 24%. This data shows the accelerated growth of tall building construction in Asian countries during this era while North American construction has lagged. In fact, among the top ten tall buildings, eight are now in Asia and only two of them namely- the Sears Tower and the Empire State Building, are in North America. Generally, tall buildings are used as commercial office buildings. Other usages, such as residential, mixed-use, and hotel tower developments have since hastily increased. The development of tall building involves the various complex factors in which economy is the most important factor. For a very tall building, its structural design is generally guided by its lateral stiffness. Comparing conventional structural system for tall buildings with diagrid structural system as the diagrids can carry lateral loads much more efficiently than conventional structural system, because of their diagonal members called 'Diagrids'. The conventional building frames are not aesthetically elegant as diagrid building frames. A diagrid structural system provides great structural efficiency without vertical columns have also opened new aesthetic potential for tall building architecture. The configuration and efficiency of a diagrid system reduces the number of structural members required on the face of the buildings. The structural efficiency of diagrid system also helps in avoiding corner columns and therefore allowing significant flexibility with the floor plan. The diagonal members (Diagrid) in diagrid structural systems carry gravity loads as well as lateral forces due to their triangulated configuration. Diagrid can save up to 20% to 30% the amount of structural steel in a high-rise buildings. Diagrid buildings are rising as structurally efficient as well as architecturally significant for tall structures. Recently the diagrid structural system has been broadly used for tall buildings due to the structural efficiency and aesthetic potential provided by the unique geometric configuration of the system. Generally, for tall building steel diagrid structural system is used. Structural design of high rise buildings is governed by lateral loads due to wind or earthquake. Lateral load resistance of the structure is provided by interior structural system or exterior structural system.

Objectives

Safety and minimum damage level of a structure could be the major requirement of high rise buildings. To meet these requirements, the structure should have adequate lateral strength & sufficient ductility. The main objective of this work is to investigate the effectiveness of diagrid structural system in high rise steel building.

To attain the main aim following objectives are identified for this work:

a. To analyze the diagrid structural system
b. To get the optimum angle of diagrid frame
c. To compare the diagrid and conventional structural system
d. To investigate the effectiveness of diagrid structural system in high rise steel building

Literature Review

Many researchers have done the work in the field of diagrid structure. Here some important works are mentioned.

In [1] a stiffness-based design methodology for steel diagrid structural systems for tall buildings. The stiffness-based design methodology is applied to a set of diagrid structures, 40, 50, 60, 70 and 80 stories tall, with height-to-width aspect ratios ranging from 4.3 to 8.7.

In [2] there is comprehensive investigation into the nonlinear performance of steel diagrid structures using static, time-history dynamic and incremental dynamic analyses.

In [3] the comparative understanding of the design requirements and detailing of diagrid structures via an examination of significant recent examples which shows the diagrid as the new stability system is studied.

In [4] there is study of the analysis and design of 60 storey diagrid steel building. A regular floor plan of 24 m × 24 m size is considered. ETABS software is used for modeling and analysis of structural members.

In [5] there is analysis of regular five storey RCC building with plan size 15 m × 15 m located in seismic zone V is considered for analysis. Staad. Pro software is used for modelling and analysis of structural members.

In [6] the analysis and design of 36 storey diagrid steel building is studied. Load distribution in diagrid system is also studied for 36 storey building.

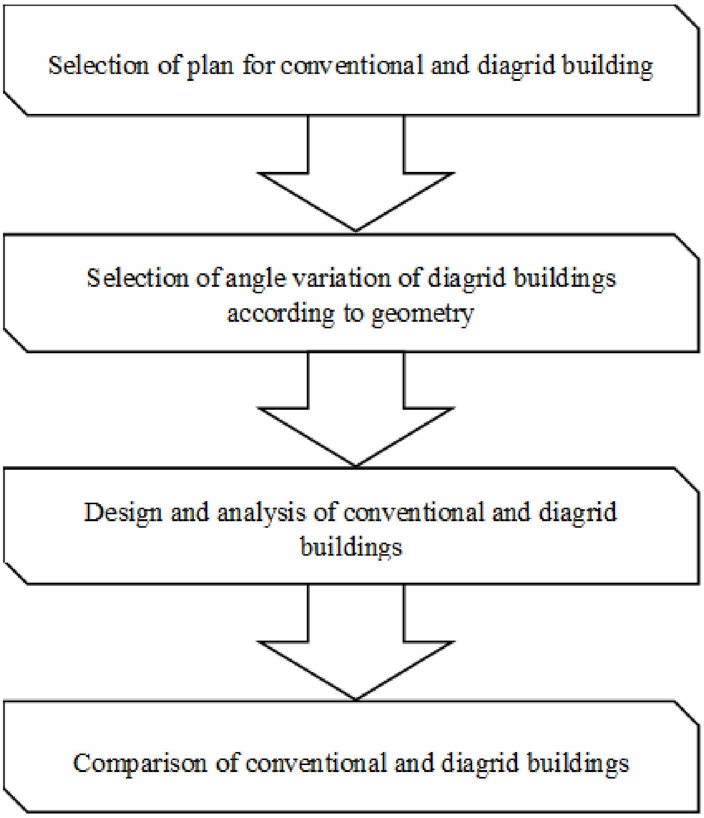
In [7] there is study of geometrical patterns for diagrids. The diagrid structures characterized by regular patterns are compared to alternative geometrical configurations, obtained by changing the angle of diagonals as well as by changing the number of diagonal along the building height.

In [8] there is comparison study of 24-storey, 36- storey, 48-storey and 60-storey of diagrid structural system with a diagrid angle 50.2°, 67.4°, 74.5° and 82.1°.

In [9] there is also the comparison of Storey Drift and Base Shear of 32-storey diagrid structural system with or without vertical column around periphery building and Simple frame building using E-TAB and SAP Software.

In [10] the seismic response of diagrid systems with comparison of storey drift and base shear of 32- storey diagrid structural system with or without vertical column around periphery building using E- TAB and SAP Software is done.

Methodology



1. A regular floor plan of 21.6m x 21.6m is considered for both diagrid and conventional buildings. Storey height is kept 3.6m.
2. The three angle variations are considered for diagrid building.
   I. 45^{o} diagrid building
   II. 63.43^{o} diagrid building
   III. Variable angle diagrid building

3. Both the building frames are analyzed for seismic zone III with zone factor 0.16. Seismic parameters are taken as per Indian code IS 1893(Part 1): 2002.
4. Dead load and live load are taken as per IS 875: 1987 Part 1 and Part 2 respectively and wind load is taken as per IS 875: 2015 Part 3
5. 27 load cases are considered for analysis and comparison on the basis of storey displacement, storey drift and steel usage.

Load Case No.	Load Case Details
1	EQx
2	EQz
3	Wx
4	Wz
5	DL
6	LL
7	1.5 (DL + LL)
8	1.2 (DL + LL + Wx)
9	1.2 (DL + LL + Wz)
10	1.2 (DL + LL - Wx)
11	1.2 (DL + LL - Wz)
12	1.2 (DL + LL + EQx)
13	1.2 (DL + LL + EQz)
14	1.2 (DL + LL - EQx)
15	1.2 (DL + LL - EQz)
16	1.5 (DL + Wx)
17	1.5 (DL + Wz)
18	1.5 (DL - Wx)
19	1.5 (DL - Wz)
20	1.5 (DL + EQx)
21	1.5 (DL + EQz)
22	1.5 (DL - EQx)
23	1.5 (DL - EQz)
24	0.9 DL + 1.5 EQx
25	0.9 DL +1.5 EQz
26	0.9 DL - 1.5 EQx
27	0.9 DL - 1.5 EQz

Plan of conventional and Diagrid Building

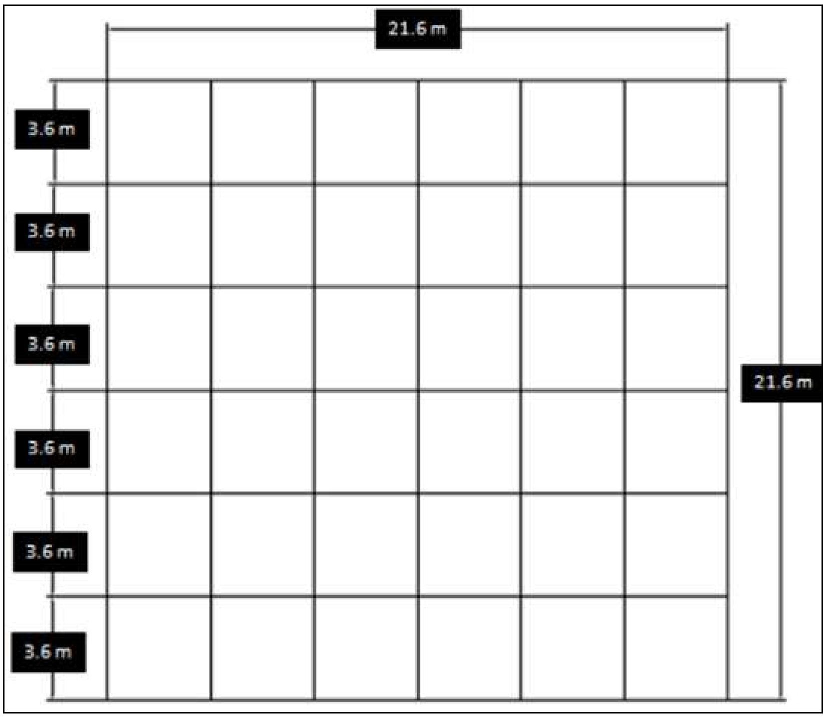


Fig 1: Plan of Conventional and Diagrid Building

Structural Models

Conventional Frame

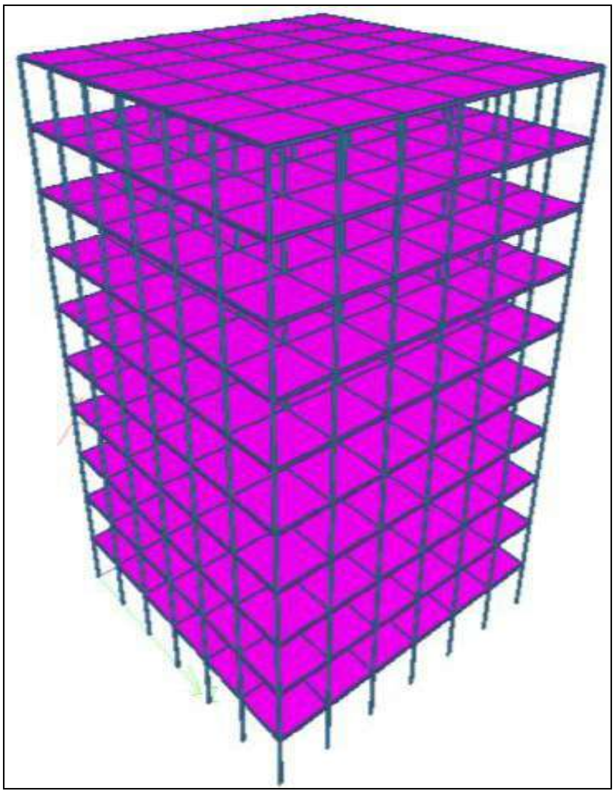


Fig 2: 3D Conventional Model

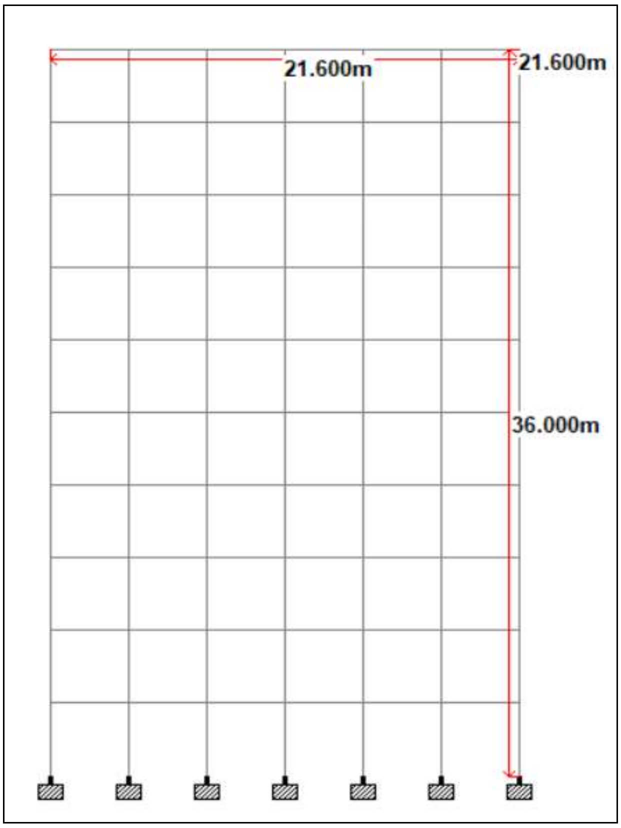


Fig 3: Front View of Conventional Model

45⁰ Diagrid Frame

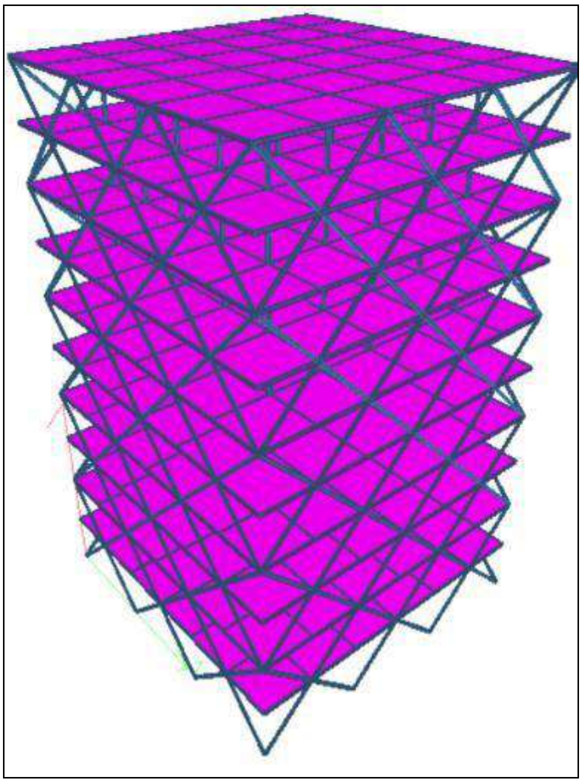


Fig 4” 3D 45⁰ Diagrid Model

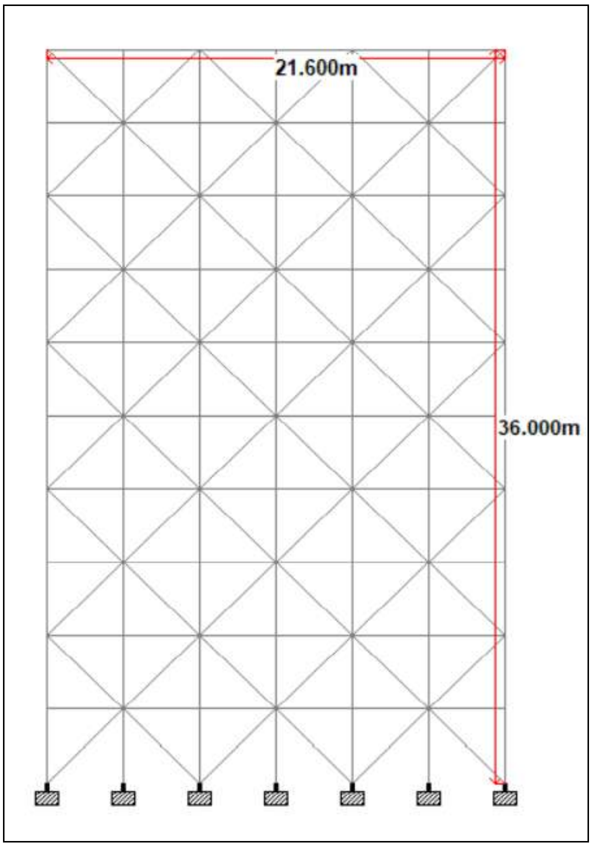


Fig 5: Front View of 45⁰ Diagrid Model

63.43⁰ Diagrid Frame

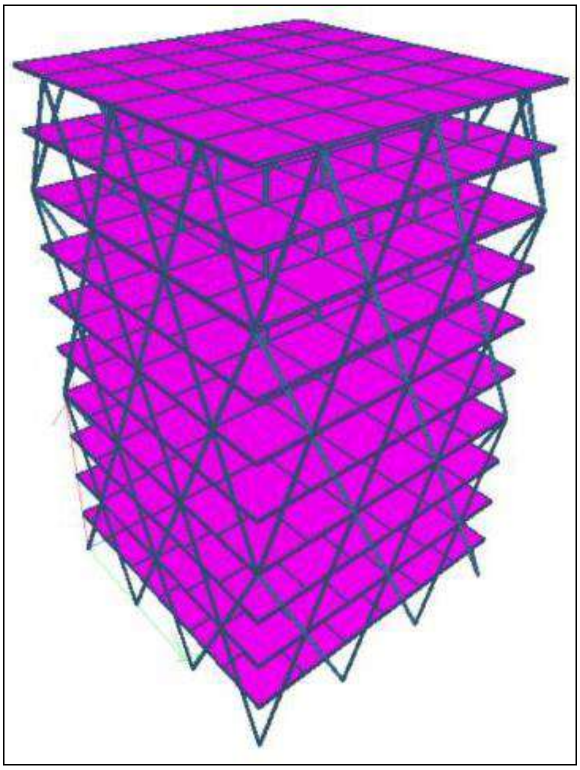


Fig 6: 3D 63.43⁰ Diagrid Model

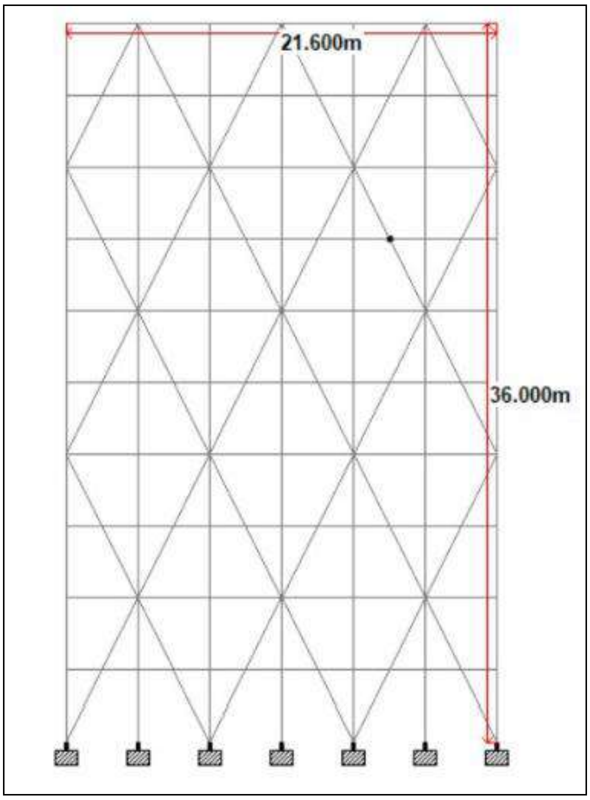


Fig 7: 3D Variable Angle Diagrid Model

Variable Angle Diagrid Frame

Storey	Angle
2 Storey Module	45⁰
3 Storey Module	56.30⁰

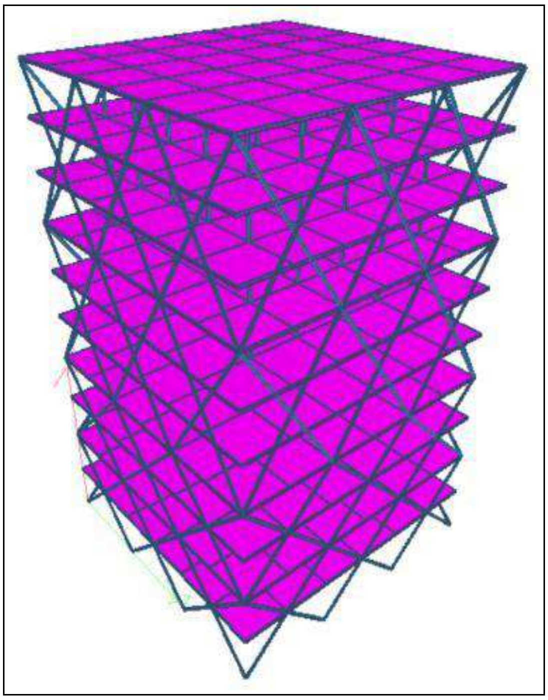


Fig 8: Rendered Variable Angle Diagrid Model

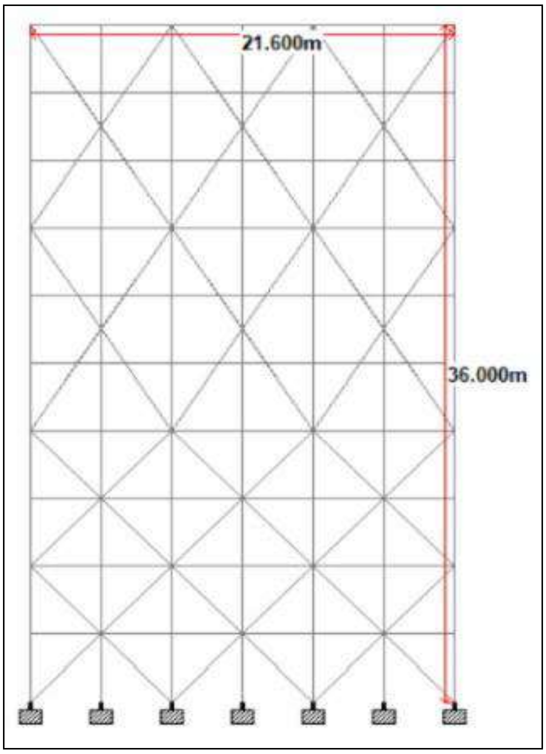


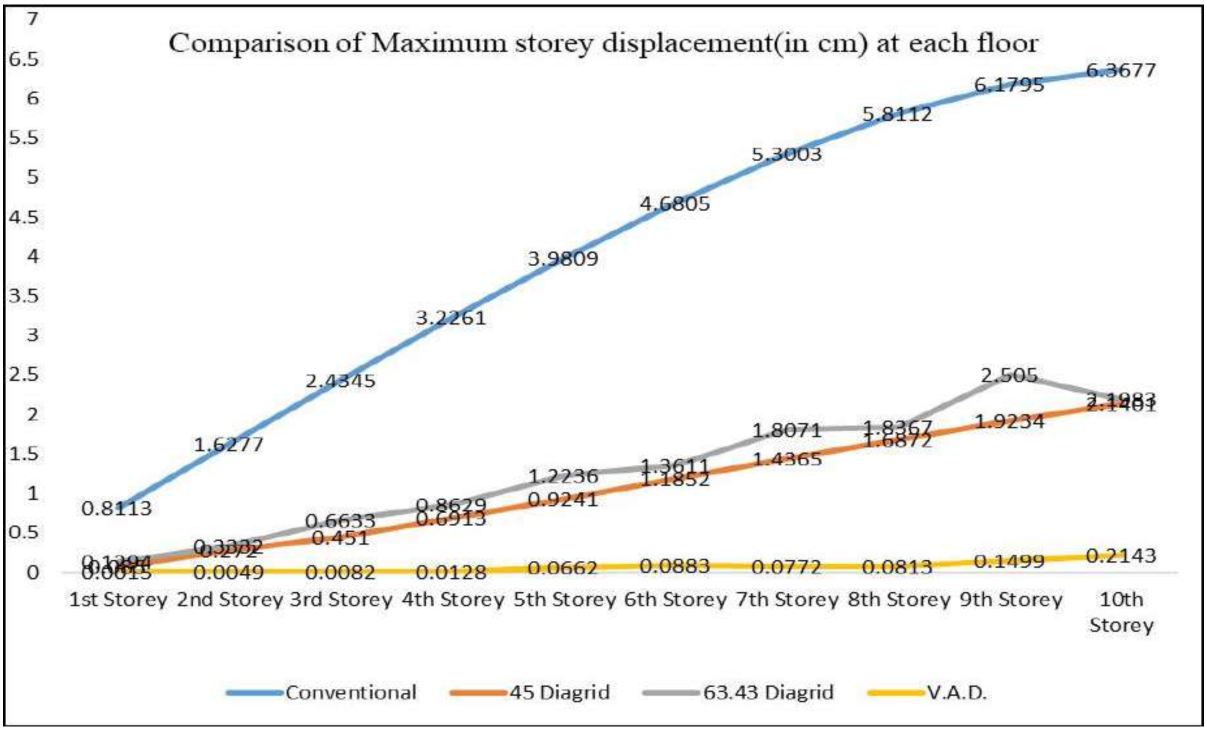
Fig 9: Front view Variable Angle Diagrid Model

Result and Discussion

Table 1: Comparison of Maximum Average Displacement (in cm) of each storey of conventional and diagrid buildings according to critical load case No. 13

Story	Conventional Building	45º Diagrid Building	63.43º Diagrid Building	Variable Angle Diagrid
1	0.8113	0.085	0.1294	0.0015
2	1.6277	0.272	0.3332	0.0049
3	2.4345	0.451	0.6633	0.0082
4	3.2261	0.6913	0.8629	0.0128
5	3.9809	0.9241	1.2236	0.0662
6	4.6805	1.1852	1.3611	0.0883
7	5.3003	1.4365	1.8071	0.0772
8	5.8112	1.6872	1.8367	0.0813
9	6.1795	1.9234	2.505	0.1499
10	6.3677	2.1401	2.1983	0.2143

From above results, conventional building shows the maximum storey displacement than all other diagrid buildings and variable angle diagrid building shows the least storey displacement. 45º diagrid building and 63.43º diagrid building shows the nearly same storey displacement.

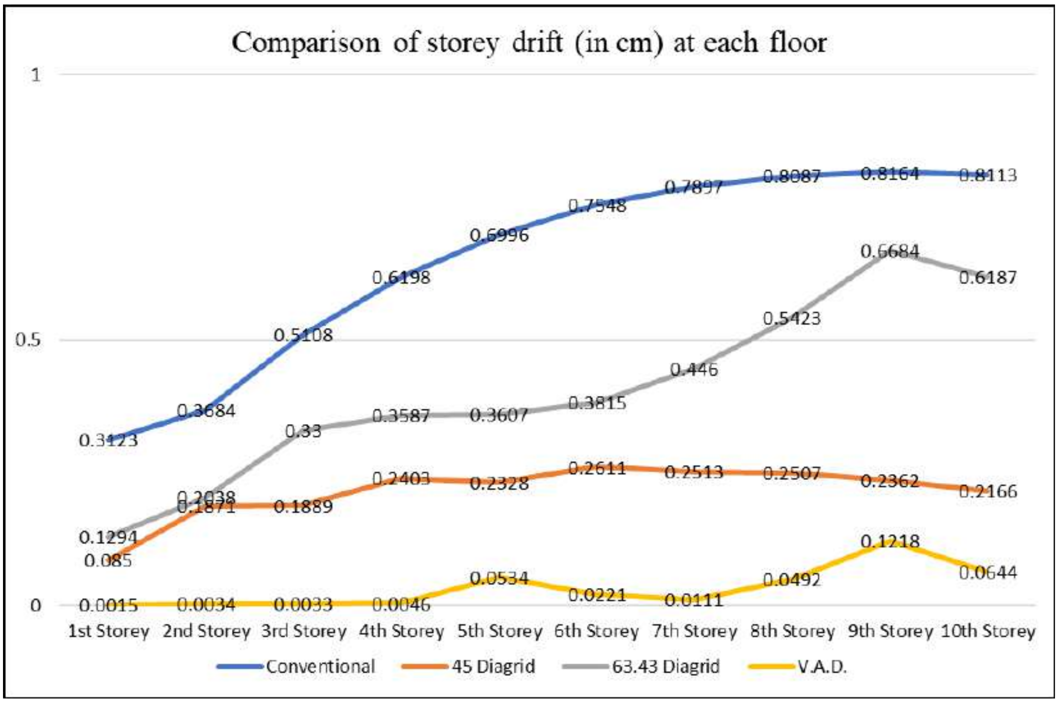


Graph 1: Comparison of Maximum Average Storey Displacement at each floor

Table 2: Comparison of Maximum Storey Drift (in cm) of each floor of conventional and diagrid buildings according to critical load case No. 13

Story	Conventional Building	45º Diagrid Building	63.43º Diagrid Building	Variable Angle Diagrid
1	0.3123	0.085	0.1294	0.0015
2	0.3684	0.1871	0.2038	0.0034
3	0.5108	0.1889	0.3300	0.0033
4	0.6198	0.2403	0.3587	0.0046
5	0.6996	0.2328	0.3607	0.0534
6	0.7548	0.2611	0.3815	0.0221
7	0.7897	0.2513	0.4460	0.0111
8	0.8087	0.2507	0.5423	0.0492
9	0.8164	0.2362	0.6684	0.1218
10	0.8113	0.2166	0.6187	0.0644

From above results, conventional building shows the maximum storey drift than all other diagrid buildings and variable angle diagrid building shows the least storey drift. 63.43º diagrid building shows the maximum storey drift after conventional building and 45º diagrid building shows the less storey drift than 63.43º diagrid building.



Graph 2: Comparison of storey Drift at each floor

According to IS 1893-2016, clause 7.11.1
"The storey drift shall not exceed 0.004 times the storey height."
Storey Height = 360 cm

0.04 x Storey height = 0.004 x 3600 = 1.44 cm

1. For 45 Diagrid
Max Storey Drift = 0.2611 cm < 1.44cm

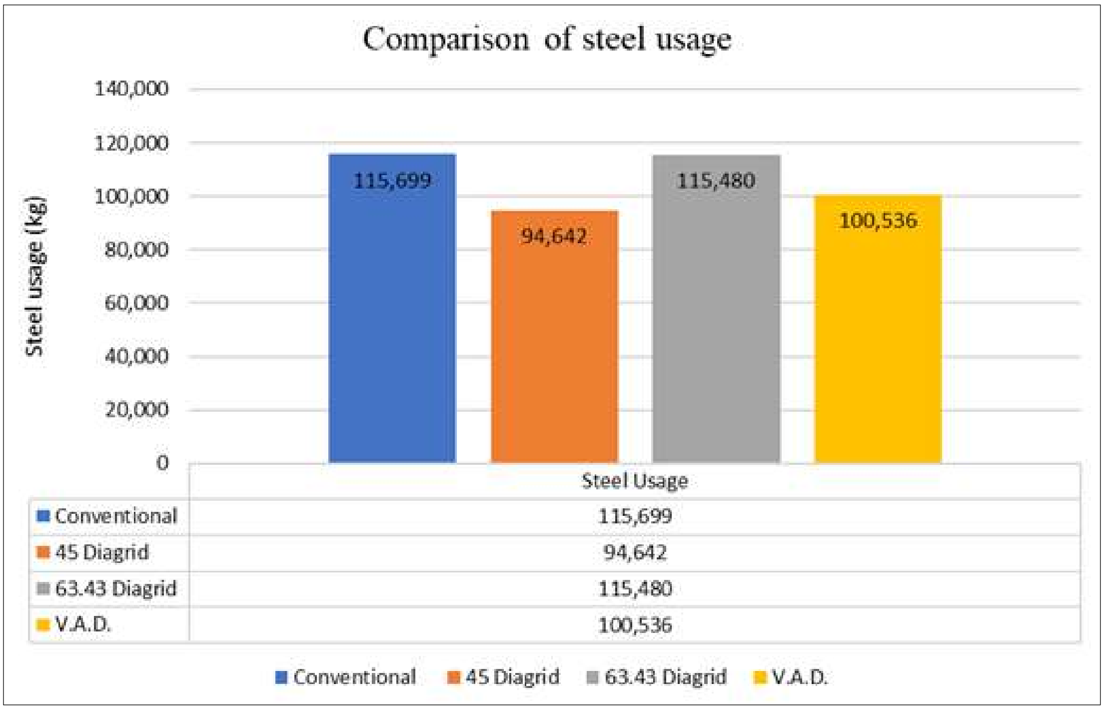
2. For 63.43 Diagrid
Max Storey Drift = 0.6688 cm < 1.44cm

3. For Variable angle Diagrid
Max Storey Drift = 0.0644 cm < 1.44cm

Hence, the storey drift result obtained for diagrid structure satisfied the clause 7.11.1 (IS 1893-2016)

Table 3: Comparison of Steel Usage (in kg) of conventional and diagrid buildings

Building	Steel Usage (in kg)
Conventional Building	115,699
45⁰ diagrid Building	94,642
63.43⁰ diagrid Building	115,480
Variable angle diagrid building	100536



Graph 3: Comparison of Steel Usage of Conventional and Diagrid Buildings

From above results, conventional building and 63.43º diagrid building shows the nearly same steel usage and then variable and both have maximum steel usage than all other cases. Variable angle diagrid building shows maximum steel usage after conventional building and 63.43º diagrid building. 45º diagrid building shows the least steel usage among all cases.

Table 8: Comparison of Maximum Average Displacement, Storey Drift and steel usage of top storey of conventional and diagrid buildings

Sr. No.	Result Parameter	Conventional Building	45º Diagrid Building	63.43º Diagrid Building	Variable Angle Diagrid
1	Max. Average Displacement (in cm)	6.3677	2.1401	2.1893	0.2143
2	Max. Storey Drift (in cm)	0.8113	0.2166	0.6187	0.0644
3	Steel Usage (in kg)	1,15,699	94,642	1,15,480	1,00,536

Conclusion
The following points are concluded from the above study about diagrid structure:
1. Maximum average displacement of top storey is reduced by 66.39% in 45º diagrid building, 65.61% in 63.43º diagrid building and 96.63% in variable angle diagrid building as compared to conventional building.
2. Storey drift of top storey is reduced by 13.15% in 45º diagrid building and 4% in variable diagrid building and 6.17% in 63.43º diagrid building as compared to conventional building.
3. Steel usage is reduced by 18.19% in 45º diagrid building, 0.18% in 63.43º diagrid building and 13.10% in variable angle diagrid building as compared to conventional building.
4. All three diagrid buildings show the better results than conventional building in storey displacement, storey shear and steel usage.
5. Variable angle diagrid shows the least storey displacement and storey shear than all other buildings.
6. 45º diagrid building shows the least steel usage than all other buildings and shows less storey drift and storey shear than conventional building, therefore 45º is optimum angle of diagrid to resist lateral loads and to achieve economy.

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