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Diagrid and Bracing System Comparative Structural Performance and Sustainability Concept

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Abstract: One of the intriguing structural design concepts for robust tall structures is the diagrid (diagonal grid) structural design. Due to its attractiveness and structural efficiency, Diagrid, a new design trend for tall, complicated structures, has arisen. Using a compact grid of diagonal members, Diagrid's façade structural system resists both lateral loads and gravity loads. As opposed to a traditional steel frame, it employs less structural steel, resulting in a more environmentally friendly building. This research uses ETABS to examine the structural performance of tall structures made of Diagrid steel and tall buildings with various bracing systems. Therefore, the purpose of this study is to contrast the lateral displacement brought on by wind and earthquake load between high-rise structures (buildings) using the diagrid system and those using other bracing systems. The use of diagrid and other bracing systems in relation to the natural frequency of high-rise structures (buildings) is also investigated in this study. A 40-story building model has been taken for analysis in E-Tabs 2016, with a plan area of 1296m^2(36-meters x 36-meters) and 144 meters tall.

Keywords: Diagrid Structure, High rise building, Lateral Loads, Story Displacement, Story Drift

I. INTRODUCTION

High-rise building design is most often guided by lateral serviceability factors rather than ultimate strength needs. The impacts of wind become more prominent as structures get taller and thinner, and the number of structural elements required to provide to resist lateral loads increases significantly [1]. By installing bracing that is connected with pinned connections, frames' structural strength may be increased. Extra vertical steel trusses that are added to braced frames are particularly effective in resisting lateral stresses[2]. Bracing improves the overall stiffness and strength of steel and composite frames, making it a particularly effective worldwide upgrading method[3]. However, the location of bracing might be difficult because it might restrict the positioning of openings and façade design. Braces can be unappealing when they modify the building's original architectural styles, braces can be unappealing[4,5]. There are several different forms of bracing, including eccentric bracing, chevron bracing, cross bracing, K-bracing, and single diagonal bracing (Figure 1). The most recent high-rise structure (building) to be constructed would be the diagonal design known as diagrid. Diagrid is a small grid of diagonal elements that give buildings the strength to withstand lateral and gravity loads[7].

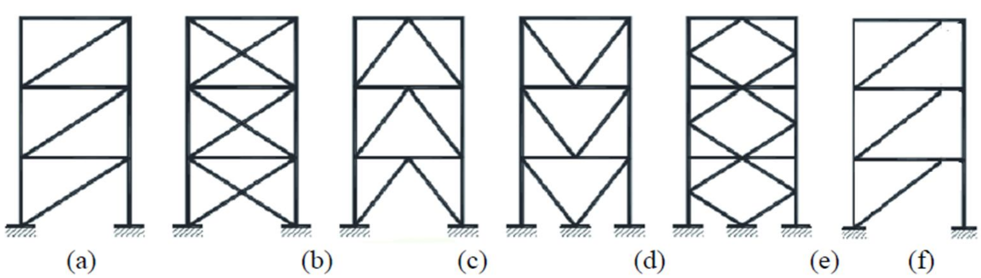

Figure 1. (a) Single diagonal (b) cross (c) chevron (d) V-bracing (e) K-bracing (f) eccentric bracing.

Conventional vertical columns are not used in the structural design of Diagrid[8]. Diagrid transmits shear by the axial action of the diagonal elements as opposed to traditional framed tubular constructions, which carry shear via the bending of the vertical columns, thereby decreasing shear deformation[9–11]. The majority of the lateral stress is resisted by the structure's perimeter diagonal columns, while the interior and perimeter diagonal columns both resist gravity load[12].

Other features of diagrid include its stunning looks and design, which reduces obstructions and allows for more natural light, which reduces the need for artificial lighting. In addition to saving floor space, diagrid's ability to eliminate interior, perimeter, and corner columns give architects more choice when designing a building's interior and exterior[12]. The geometric flexibility of the diagrid also allows for the construction of towering structures with complicated shapes like twisted, tilted, and tapering towers. Complex-shaped tall structure's structural performance is impacted by their geometric arrangements, such as the rate of twisting and tilting.

(a) (b) (c) (d)

Fig.1 (a) The 44-story Al Bidda Tower in Doha, Qatar (b) The Capital Gate, Abu Dhabi (c) The Bow tower, Calgary, Canada (d) Hearst Headquarters, New York

Sustainability is a challenging, intricate, and illusive topic. Since it has to do with the likelihood that humans will survive on our planet, it is of utmost importance. The future of civilization, at least as we currently perceive it, looks to be dubious unless steps are done now - and if there is still time - given the rate at which the human race is utilizing restricted and scarce resources. It improves the quality of life for the current generation and increases the likelihood that future generations will survive, improving their capacity to deal with the world they will inherit.

According to the present state of knowledge, sustainability includes the following components:
1) Economic benefit;
2) Resource management;
3) Protection of the environment; and
4) Social advancement.

A procedure created exclusively for economic and environmental issues are considered to be feasible; a procedure that is only intended for environmental and social issues are deemed tolerable, and a procedure created for social fairness and economical fairness and is an issue. Consequently, a methodology that is sustainable and takes into account all three dimensions [13].
Although there are many different sustainability concerns, the building sector is primarily concerned with reducing energy use during construction and use. Even while there is a trend toward so-called "Net Zero Energy Buildings," which create a balance between energy flow and renewable supply sources, the path to achieving this goal is still quite long.

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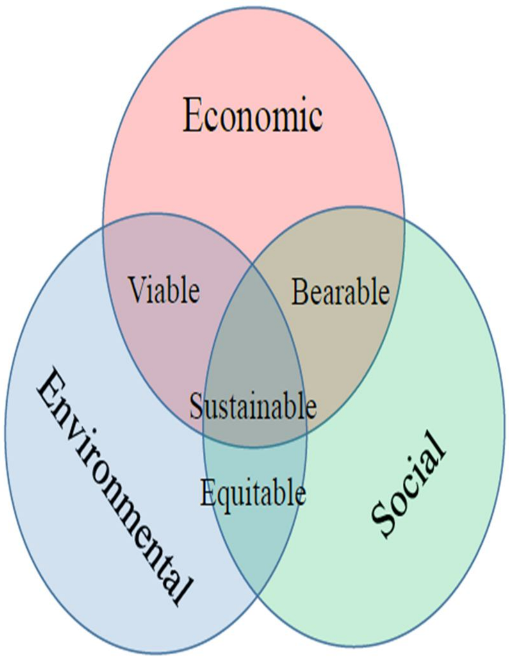
Due to a number of advantages, such as off-site prefabrication and the resulting decrease in waste and impacts on the construction site, the straightforward dismantling process, and the high costs of material and component recycling, steel structures have also been recognized for their sustainable strategy for development, etc. The steel construction industry is increasingly paying more attention to topics like the robustness, ecology, life-cycle costs, and sustainability of steel material and services.



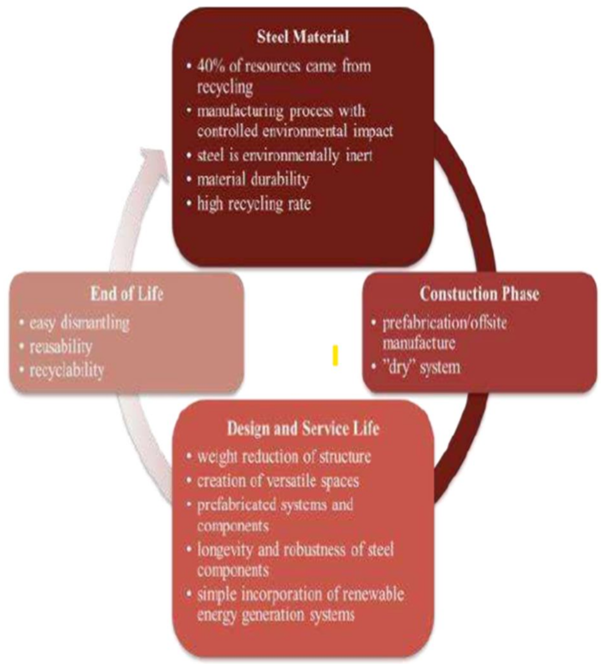


Fig 2 . Triple bottom line of sustainability - Fig 3 Environmental advantages of steel construction adapted from Adams, 2006

Diagrid systems have gained tremendous popularity in complicated constructions like curved shapes. The usage of diagonal components is fast expanding as a result of the use of diagrid, which replaces traditional vertical columns. To provide the structure greater optimization, several diagrid system characteristics must be determined, such as the ideal diagonal member angle[16]. Additionally, a significant quantity of structural material is conserved and the project becomes more cost-effective by removing everything but the core columns from the design. In fact, the effectiveness of the diagonal members reduces the overall number of internal columns, giving the architect more room to create the objects. Architects and designers much prefer this strategy to a braced frame structure[16].

II. OBJECTIVE OF THE PAPER

The main objectives in this paper are:

1) To study different type of bracings.
2) To analyze and compare bracing frame and diagrid structure.
3) To find which system among bracing and diagrid is sustainable and economical.

III.MODELLING AND ANALYSIS

Total 3 number of models are made in E-tabs , Diagrid Structure, X bracing system and Y bracing system with different position of bracing in the model. Modelling analysis is performed in E-tabs 2016 and response spectrum method is used for dynamic analysis.
In the ETABS software, the gravitational load and the wind-induced lateral load are combined and given to the structure. The design of diagonal members, floor beams, and interior columns is completed in accordance with IS:800-2007 based on the analytical results.

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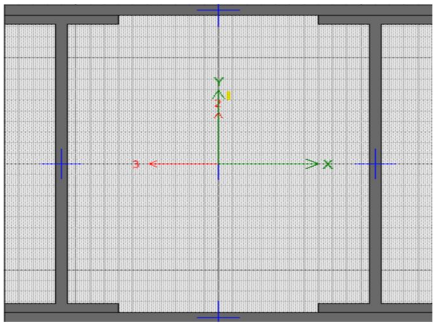
Steel is regarded as having a 345 N/mm^2 yield strength. Gravity load and lateral load brought on by an earthquake or wind are the two main forms of loading that affect a building. For the 40 story diagrid ,X-Bracing and V-Bracing structure taken into consideration in this study, compared to the wind load, the earthquake load's base shear is greater. As a result, the design of the structure is determined by the seismic load.



The best choice we have to adhere to the structure within limitations is to employ built-up sections since it takes a lot of strength to retain the structure within the limits allowed for diagrid structures. Figure 12 illustrates an interior column that is primarily resisting gravity loads. The larger yield strength of structural steel allows for smaller member sizes. So we take Fe345

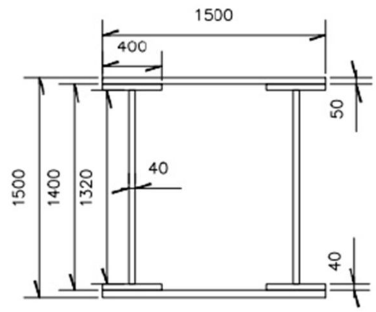
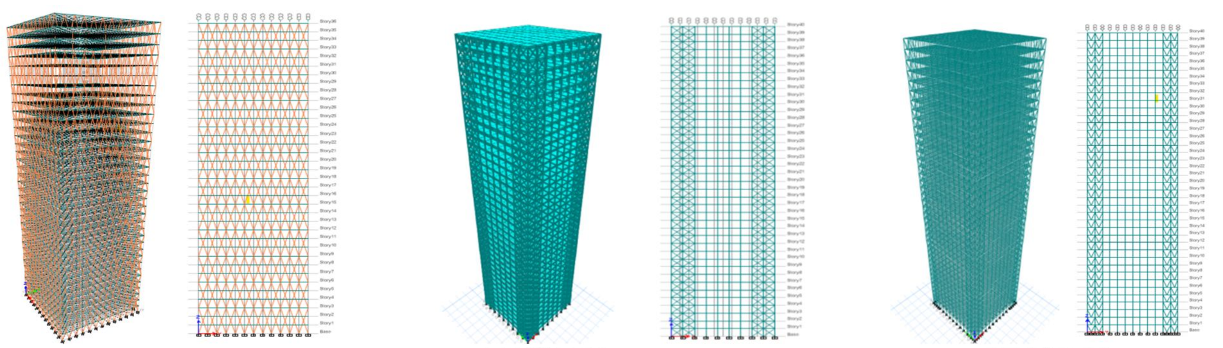


Fig 4. Built up section of Diagrid Structures



(a) (b) (c)

Fig 4. Isometric and elevation view of : (a) Diagrid Structure , (b) X- Bracing Structures and (c) Y-Bracing Structures

A. Model Description

S.No.	Structural System	Dimensions
1	Type of Building	Commercial(G+39)
2	Type of Structure	Steel structure
3	Length in X-direction	36m
4	Length in Y-direction	36m
5	No of bays in X-direction	13 No. @ 3m
6	No of bays in Y-directions	13 No. @ 3m
7	Floor to floor height	3.6m
8	Total height of buildings	144m

Fig 5 Description of Building

S.No.	Material	Grade
1	Concrete(Slab)	M30
2	Steel section(I-Shape)	Steel structure
3	Rebar	HYSD-415
4	Density of Steel	7850 kg/m^3
5	Young Modulus E	2.1x10^5 N/mm^2
6	No of bays in Y-directions	80000N/mm^2
7	Poisson's Ratio	0.3

Fig 6 Material Properties

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Type	Story	Diagonal Columns	Interior Columns	Beams (same for all story)
Diagrid	40	375 mm Pipe sections with 12 mm thickness (from 21st to 40th story) 450 mm Pipe sections with 25 mm thickness (from 1st to 20th story)	1500 mm × 1500 mm	B1 and B3 = ISMB550, B2 = ISWB 600 with top and bottom cover plate of 220 × 50 mm

Fig 7 Size of typical member of Diagrid Steel structure

S. No	Type of load	Values
1	Dead Load	3.75 kN/m^2
2	Live Load	2.5 kN/m^2
3	Wind Speed	44 m/sec
4	Diagrid Angle	67.5 Degree

Fig 9 Loading on Structure

1	Earthquake Zone	III
2	Zone Factor	0.16 (Table 3, clause 6.4.2)
3	Type of soil	Medium soil (clause 6.4.2.1)

Fig 10 Seismic Data

Type	Story	Column	Beam	Bracing	Secondary Beam
Steel Structures With X -Bracing	40	ISHB 400	ISMB 600	ISMB 300	ISLB 400

Fig 11 Size of typical member of Steel structural system with X and V bracing

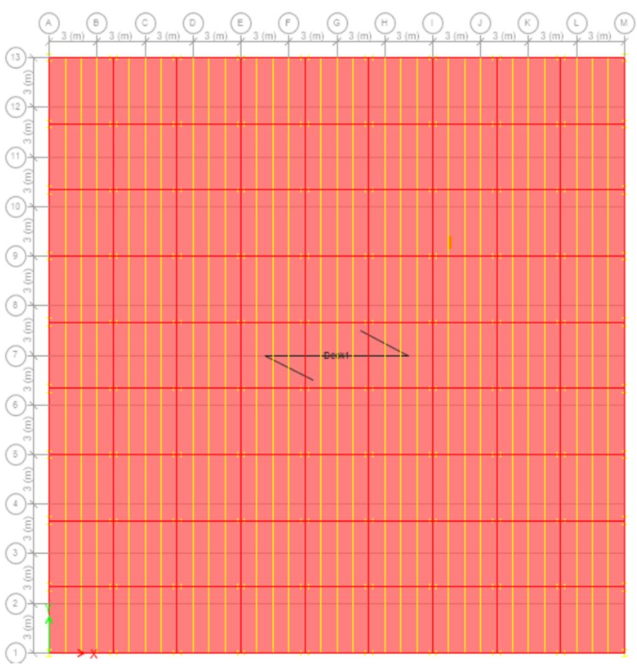

Fig 12 Typical Floor Plan Steel Structure with X-Bracings

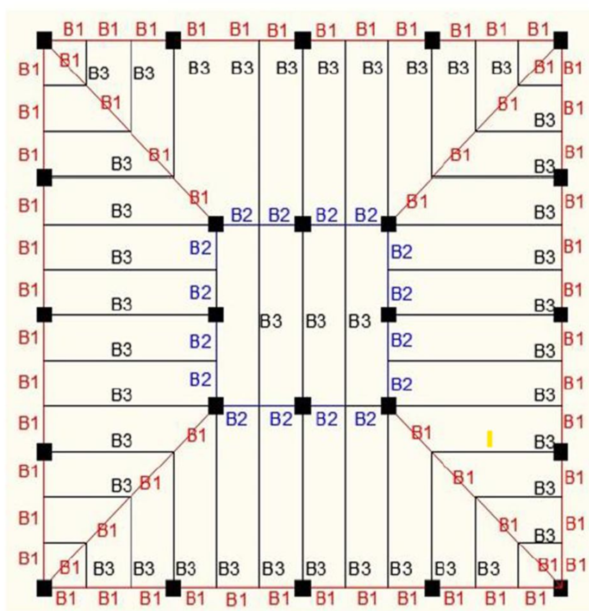

Fig 13 Typical Floor Plan of Diagrid Steel Structure

IV. RESULTS

A. Story Displacement

Comparative results for different structure Diagrid, X-bracing and V-bracing Structure for Maximum story Displacement , Story drift are obtained in below Graphs , at earthquake loading

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Story Displacement due to seismic load are given below: -

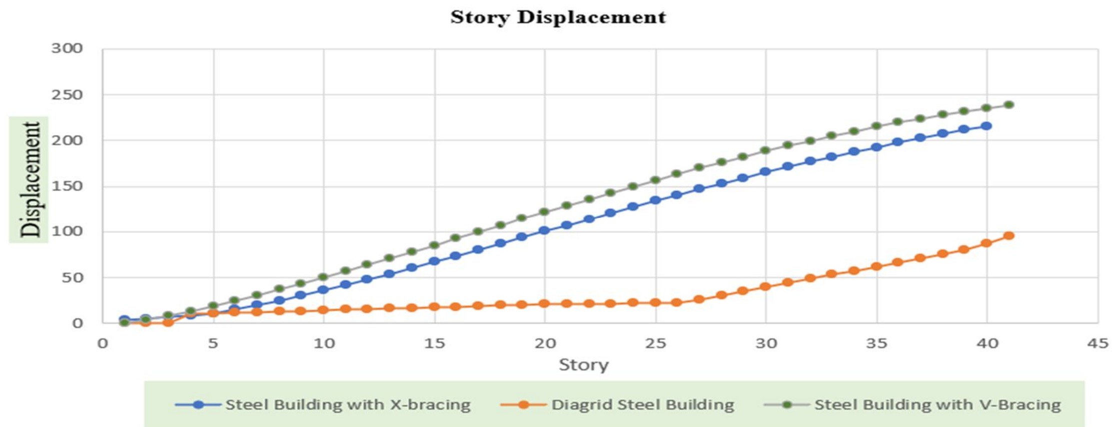

Fig 14 Comparison graphs of Story Displacement of Diagrid , X-bracing and V-bracing Structures

As per IS code 1893(PART II) 2016, Maximum Story Displacement is H/250. So, the maximum story displacement is 0.576 m OR 576 mm. Since the results of all 3 models are in limits. As the above graph shows as the height of the building increases the Story displacement also increases in all 3 models but in case of Diagrid Structure the increase is respectively less as compared to X-Bracing and V-Bracing. This graph shows how Diagrid Structures are able to withstand lateral loads to a greater extent than X-Bracing and V-Bracing.

B. Story Drift

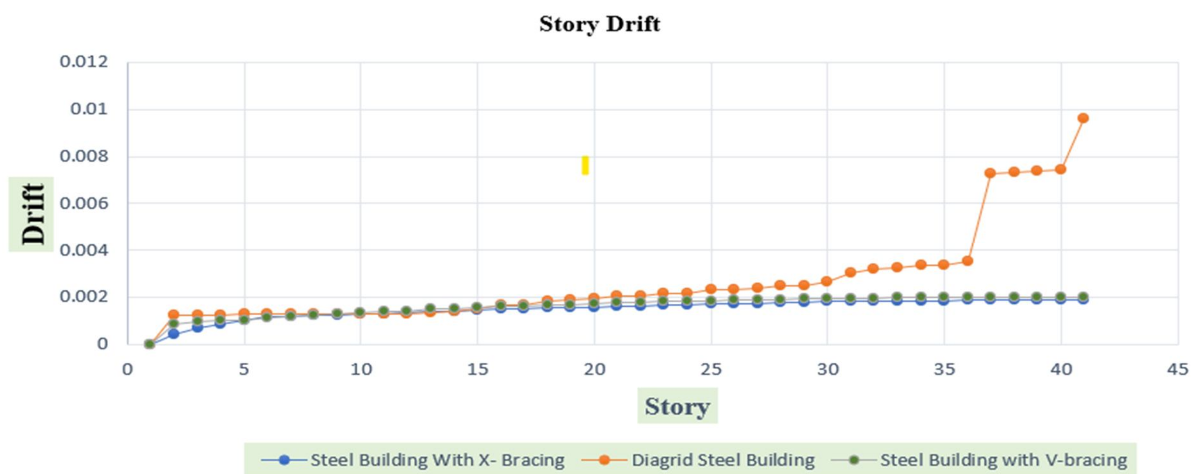

Fig 15 Comparison graphs of Story Drift of Diagrid , X-bracing and V-bracing Structures

As per IS code 1893(PART II) 2016, Story Drift is $0.004h_i$, where h_i is story height of the building, since story height of all model is same. So, Story Drift is 0.144 for all model. Since the results of all 3 models are in limits. As the above graph shows as the height of the building increases the Story Drift also increases in all 3 models but in case of Diagrid Structure the increase is respectively very less(or constant at some points) as compared to X-Bracing and V-Bracing. This graph shows how Diagrid Structures are able to withstand lateral loads to a greater extent than X-Bracing and V-Bracing.

C. Load Distribution in 40 Storey X-Bracing Structure, Diagrid Structure and V-Bracing Structures

By comparing the results of analysis of Lateral and Gravity loads for columns and bracing in all 3 models (X-Bracing, Diagrid and V-Bracing systems) we found that Diagrid system resist more lateral loads from its exterior system (Diagonal columns) than all 3 system. So, the efficiency of Diagrid Structure is comparatively better to resist lateral loads as well as gravity loads

Fig 12. shows the gravity loads and lateral loads on interior frames and exterior respectively :-

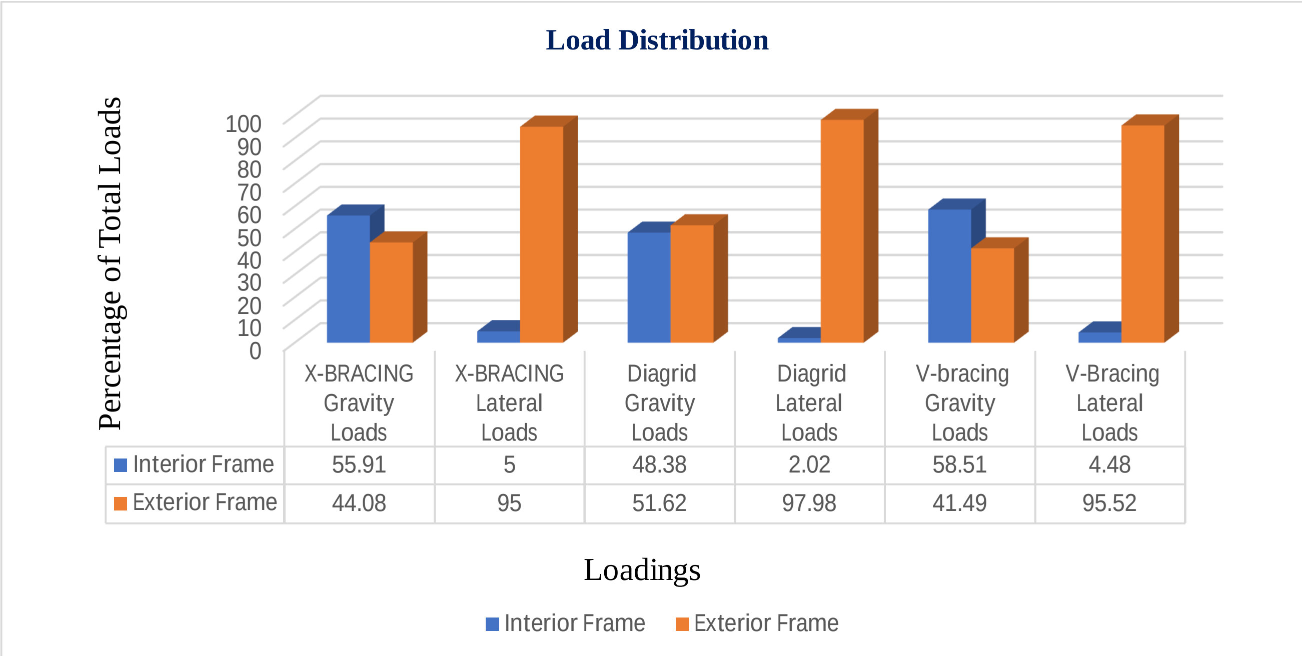

Fig 16 Comparison graphs of Load Distribution in X-Bracing, Diagrid and V-Bracing System

It is noted from the above Fig. 12 Lateral loads resisted by Diagrid External Frame is 97.98% which is maximum among all the system and the Gravity Loads resisted by Diagrid External Frame is 51.62% which is maximum among all system. From above Fig 16. Fee get to know in Diagrid system the interior frame is very less to be involve in resisting the Loads either be gravity or lateral loads.

V. CONCLUSION

In this paper we have done modelling and analysis of 40-Story structure on 3 different models i.e., X-Braced frame Structure, Diagrid Structure and V-Bracing frame Structures. From the results of Maximum Story displacement, Story drift and Load distribution on exterior and interior frames we get the best and economical results in Diagrid Structures. High-rise structures often use the diagrid structural system, which makes it easier to design and construct complicated structures in the modern era. Additionally, braced tube structures have proven to be extremely resilient to lateral displacements and storey changes. Even though the values of both structures are below the maximum allowable limits, braced frame structure results are much better for a luxury building because they will improve the comfort conditions in the building but require a lot of structural materials because it also includes cross bracing, which increases the cost of the building and construction ,whereas in diagrid structure, columns are only in the core of the building and bracing are in the periphery of the building, and building d remain economical along with values below the allowable limits.

Among the findings are that diagrid structures, as opposed to more traditional steel structural designs like braced frame structures, outrigger structures, etc., save a significant amount of (steel) weight. Additionally, the effectiveness of diagrid constructions has been evaluated in terms of safety, serviceability, and structural resilience in addition to material reduction.

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