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DIAGRID STRUCTURES AT DIFFERENT GEOMETRY: INVESTIGATING SUSTAINABLE DESIGNS AT DIFFERENT DIAGRID ANGLES

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Abstract: **Engineers and architects prefer diagrid systems for tall buildings because of their inherent structural efficiency, decorative elements, and morphological adaptability. However, only a small amount of academic study has been conducted with an emphasis on performance, design requirements, and structural behavior. evaluation of this structural system; also, most of the scientific contributions in literature regular diagrids, or designs with recurring geometrical characteristics of the basic module (Scale, angle, width, and height). The initial step toward a systematic and thorough investigation of the geometrical patterns for diagrids is presented in this research. For this reason, diagrid buildings with recurring patterns are contrasted with other geometrical configurations that are created by varying the number and angle of diagonals along a building's height (variable-angle, VA, and variable-density, VD). Three distinct diagrid layouts are produced and created for a 40-story model building using methods either recommended by the researchers or available in the literature. On the basis of the analysis's findings, the resulting diagrid structures are evaluated under gravity and wind loads for various performance characteristics. Furthermore, the comparison of story drift, story displacement, and performances enables discussion of the potential for efficiency of the various patterns. The potential for diagrids in the construction of sustainable buildings is finally outlined.**

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

I. INTRODUCTION

The idea of a diagrid is nothing new; triangular constructions' innate stability has long been understood intuitively by people. The placement of diagonals in steel structures is the oldest and most natural solution. It has many applications and is very popular with engineers and architects. However, in the past, architects found diagonals to be highly obstructive and typically incorporated them into the building's interior cores. The Chocolate Factory Menier in Noisel, France (Fig. 1), a unique example of a structure with a trussed façade, was created in 1873 by architect Jules Saulnier[1].

Why does it say that "this is the moment of diagrid" if diagrid is based on an extremely ancient idea? Recent years have seen a startlingly innovative usage of triangulation that boldly characterizes the aesthetics of significant tall buildings (Fig. 3). The diagrid approach in the Swiss-Re Tower handles the unique geometry and shape, while the crystalline pattern in the Hearst Tower creates a beautiful structure "that plainly comes from rational thought."[2] A difficult building is encircled by the diagrid construction in the China Central Television (CCTV) headquarters a Moebius strip-like form; at the Guangzhou West Tower The diagrid lends a delicate firmness, depth, and personality to the building, according to the jury's verdict, which acknowledged the tower was named the 2011 CTBUH's "Best Tall Building Asia & Australasia." Awards Ceremony
Unquestionably, the structural effectiveness of the triangulated patterns is a major factor in the "diagrid craze," as it is said that "diagrid speaks a reassuring language of stability, a message qualified by its real physical economy and resilience... diagrid looks like it should work, and it does" [3]. The authors conducted a comparative analysis of the structural performance of a few recent tall buildings and found that diagrid structures combine a significant amount of lateral stiffness and strength capacity with a remarkable amount of material economy, resulting in extremely high structural efficiency[4]. Additionally, because of the practically limitless morphological possibilities of diagrid, it is possible to adapt it to almost any building shape and create beautiful façade designs by integrating structural and architectural elements.

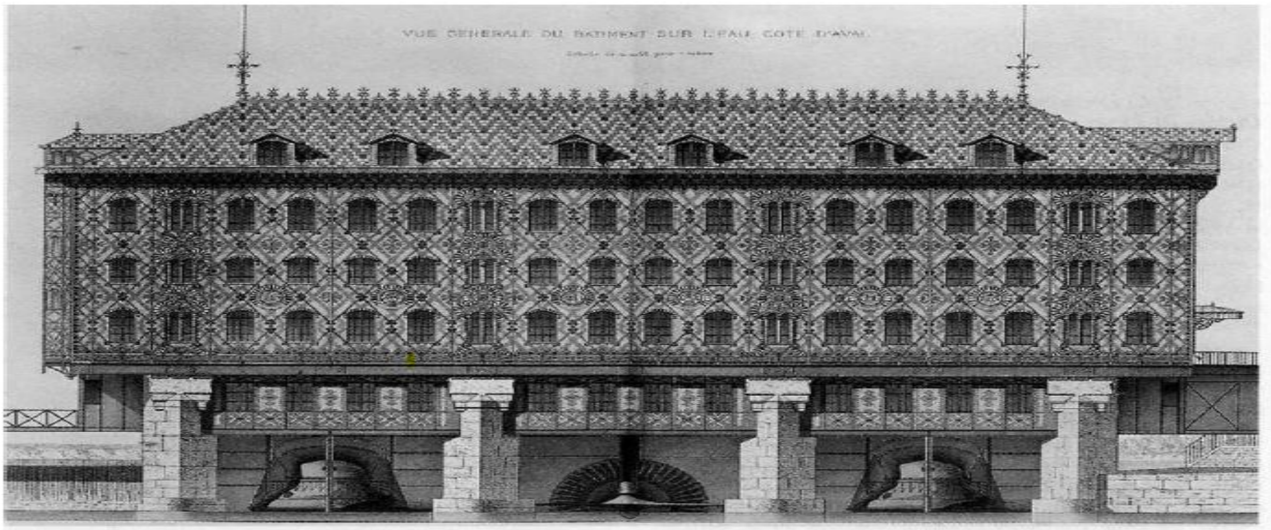


Fig 1 The trussed façade of the Chocolate Factory Menier at Noisel (from: [1])

The Orbit, a "twisted knot of steel masts" [3] that serves as both a sculpture and a tower and is "a piece of engineering and architecture and total artwork all integrated into one," is the best illustration of the extraordinary diagrid adaptability. Anish Kapoor and Cecil Belmond created [6] for the London 2012 Olympic Games (Fig. 4).

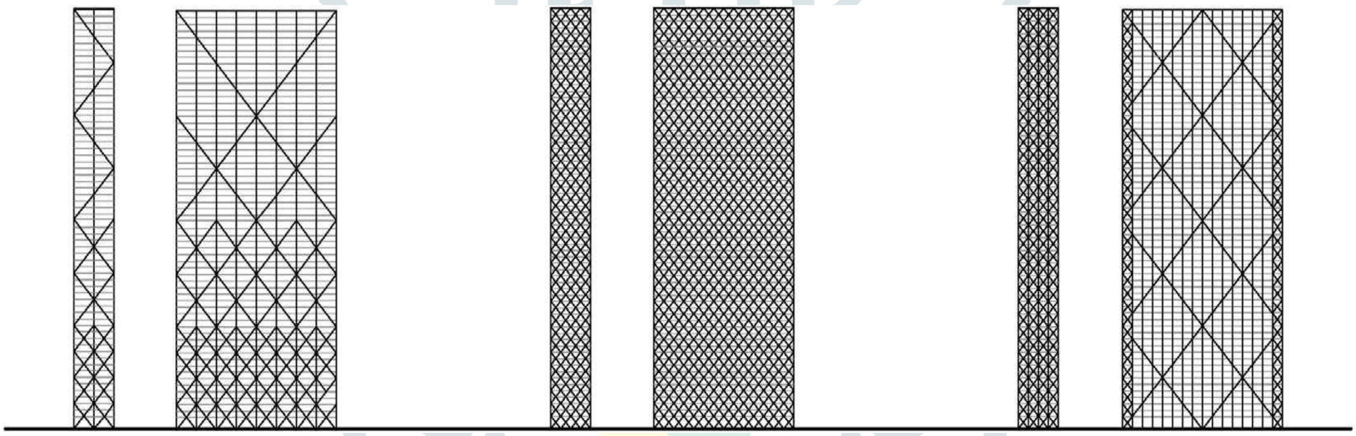


Fig. 2. Diagonalized structure solutions for tall buildings proposed by Goldsmith

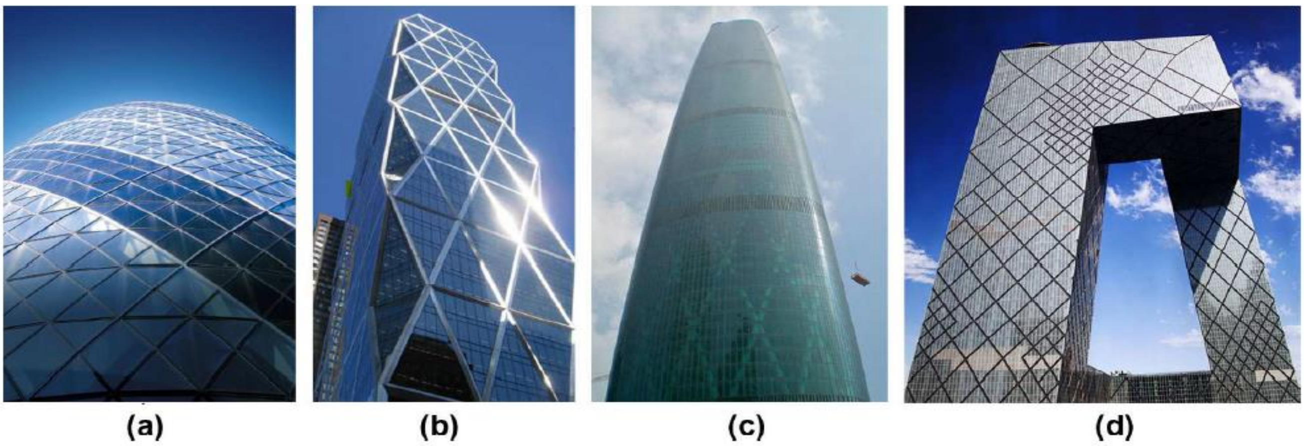


Fig. 3. (a) Swiss-Re Tower (from www.swisspacer.com), (b) Hearst Tower (from en.wikipedia.org), (c) China Central Television (CCTV) headquarters (from www.panoramio. com), and (d) Guangzhou West Tower (from www.worldarchitecturemap.org).

The possibility to create innovative and varied shapes, "each with unique expressions, feelings, and consequences," is explored starting with the diagrid base unit in [5], which provides a survey and classification of diagrid patterns from a geometric, formal, and "effective" point of view. There has never been a similar structural analysis of diagrid patterns with the ensuing devaluation of the pertinent structural efficiency. This work serves as the introduction to a systematic and thorough examination of geometrical patterns for tall building structural façades, with a focus on diagrids.

Fig.4.Arcelor Mittal Orbit(from www.anishkapoor.com

In order to achieve this, the geometrical properties and creation process of diagrid structures with both regular and variable patterns are examined. Design procedures are defined for the preliminary sizing of the diagonal members, and the resulting structures are then analyzed and compared in terms of structural weights and performance parameters with the ultimate goal of discussing the benefits and drawbacks of the various diagrid patterns.

Sustainability is a challenging, intricate, and elusive 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:

- Economic benefit;
- Resource management;
- Protection of the environment; and
- Social advancement.

A procedure created exclusively for economic and environmental issues is considered to be feasible; a procedure that is only intended for environmental and social issues is deemed tolerable, and a procedure created for social fairness and economical fairness is an issue. Consequently, a methodology that is sustainable and takes into account all three dimensions [7].

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. 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.

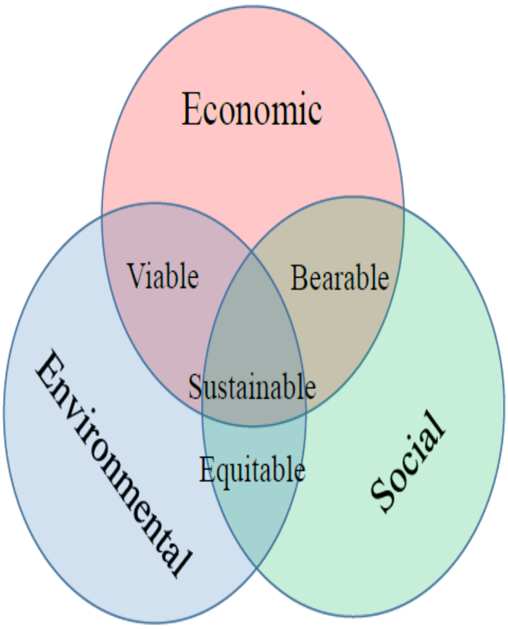


Fig 2 . Triple bottom line of sustainability - adapted from Adams, 2006

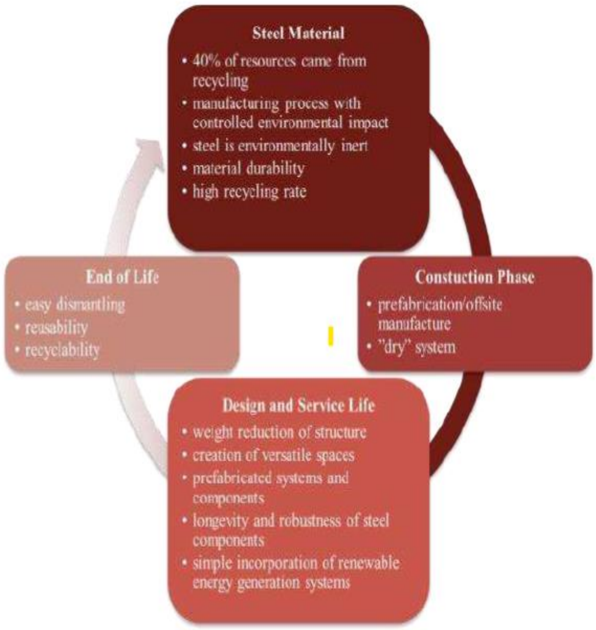


Fig 3 Environmental advantages of steel construction

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 [8].

II. OBJECTIVE OF THE PAPER

The main objectives of this paper are:

- To study Diagrid structures with different diagrid angles and geometry.
- To analyse and compare different diagrid structures.
- To find which geometrical shape in diagrid is most efficient among the 3 models.

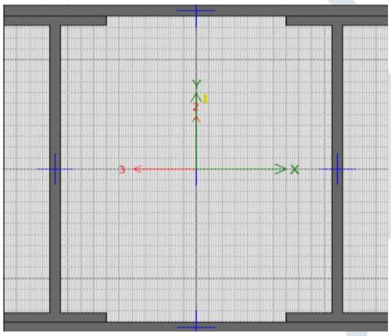
III. MODELLING AND ANALYSIS

TOTAL 3 MODELS ARE MADE IN E-TABS 2016, WITH DIFFERENT DIAGRID ANGLES IN THE MODEL.

MODEL	Description
MODEL 1	Diagrid columns at 74.47 Degree from 1-36 story and at 45 degrees from 37- 40 story
MODEL 2	Diagrid columns at 74.47 Degree from 1-27 story and at 50 degrees from 28- 40 story
MODEL 3	Diagrid Columns at 50 Degree from 1-30 story and 45 degrees from 31- 40 story

In the ETABS software, the gravitational load and the wind-induced lateral load are combined and given to the structure (according to IS 1893, 2016 - PART I). The design of diagonal members, floor beams, and interior columns is completed in accordance with IS:800-2007 based on the analytical results.

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, 3 different a taken into consideration in this study, compared to the wind load, the wind 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

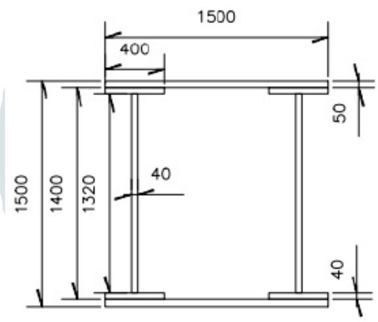
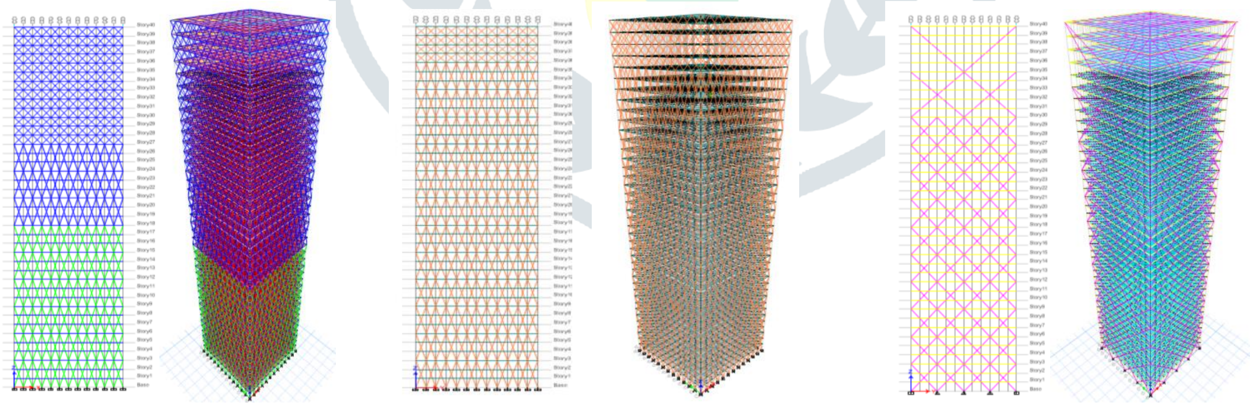


Fig 4. Built up section of Diagrid Structures



(a) (b) (c)

Fig 5. (a) Model 1 , (b) Model 2 and (c) Model

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

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 8 Size of typical member of Diagrid Steel structure

S. No.	Type	Values
1	Dead Load	3.75 kn/m2
2	Live Load	2.5 kn/m2
3	Wind Speed	44 m/s
4	Diagrid Angle	Model 1: - 74.5 Degree (1-27) & 50.19 Degree (27-40) Model 2: - 50.0 Degree (1-30) & 45.00 Degree (30-40) Model 3: - 74.5 Degree

Fig 9 Loading on Structure

1	Earthquake Zone	III IS 1893-2016(PART II)
2	Zone Factor()	0.16 (Table 3, clause 6.4.2) IS 1893-2016(PART II)
3	Type of soil	Medium soil (clause 6.4.2.1) IS 1893-2016(PART II)

Fig 10 Seismic Data

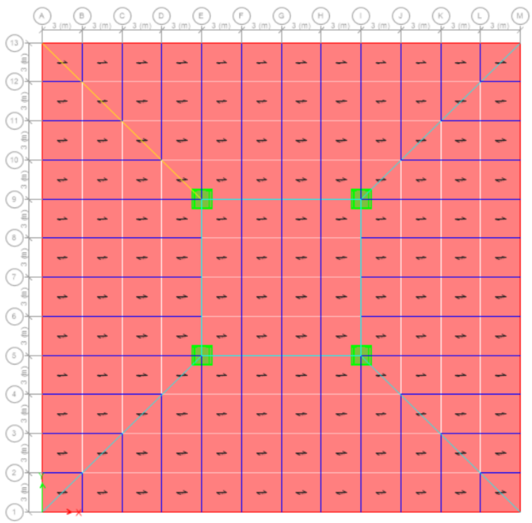


Fig 11. Typical Floor Plan of Diagrid Steel Structure

IV. RESULTS

A. Story Displacement

Comparative results for different structure Model 1, Model 2 and Model 3 Structure for Maximum story Displacement, Story drift are obtained in below Graphs , at earthquake loading

Story Displacement due to seismic load are given below: -

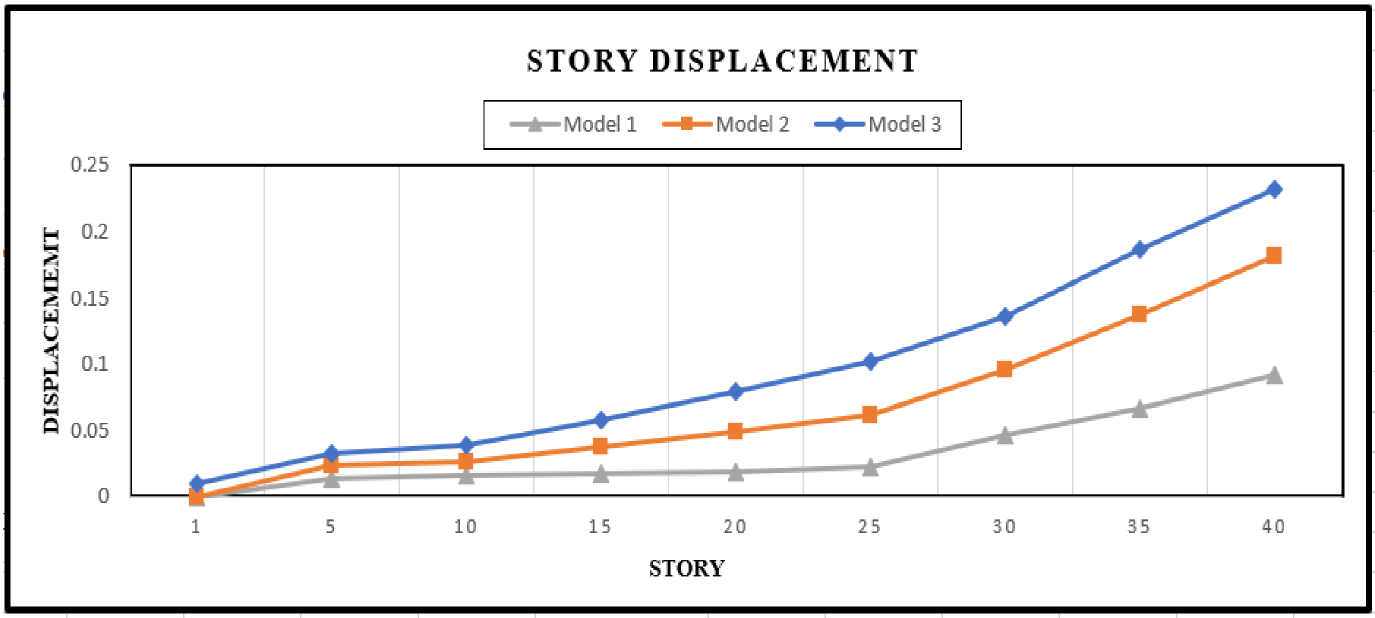


Fig 12 Comparison graphs of Story Displacement of Model 1 , Model 2 and Model 3 Structural System

As per IS code 1893(PART I) 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 Model 1(with overall 2 diagrid angle combination 74.5° & 50.19°)
the increase is respectively less as compared to Model 2 and Model 3. This graph shows how Diagrid Structures Model with combination of 74.5° and 50.19° work better to resisted the lateral forces.

B. Story Drift

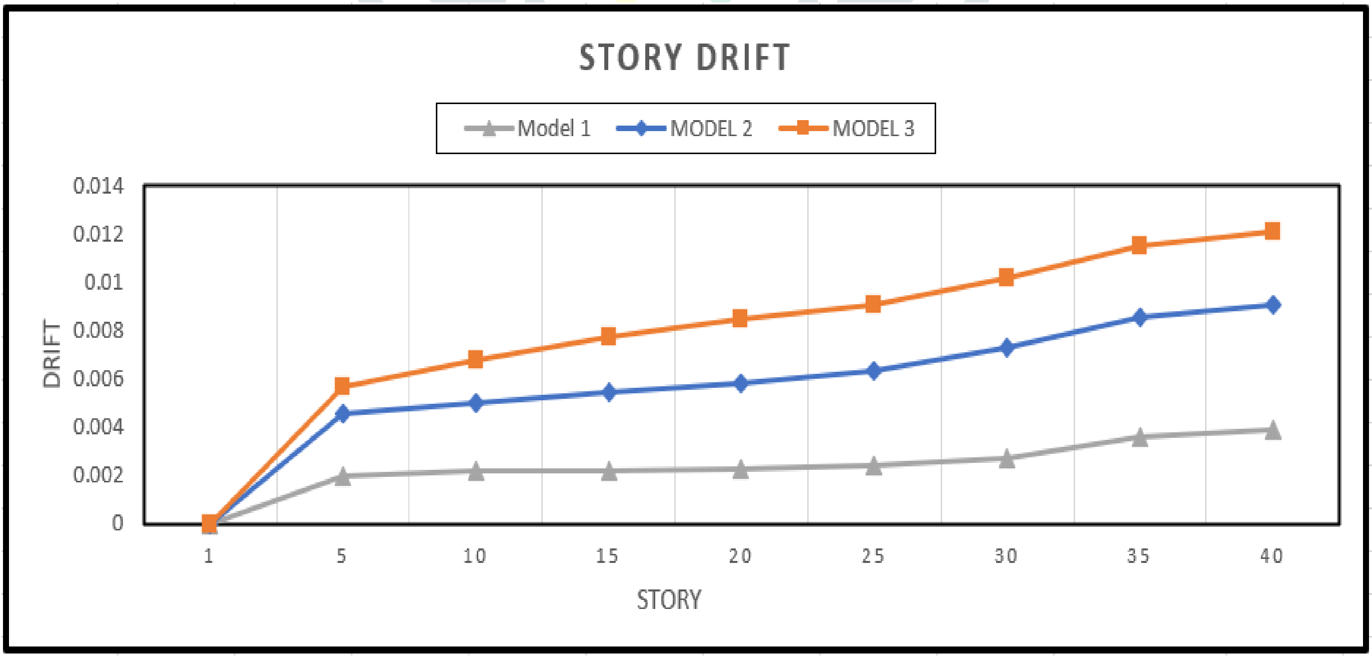


Fig 13 Comparison graphs of Story Drift of Model 1 , Model 2 and Model 3 Structural System

As per IS code 1893(PART I) 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 0.0144 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 Model 1 the increase is respectively very less (or constant at some points) as compared to Model 2 and Model 3. This graph shows how Diagrid Structures are able to withstand lateral loads to a greater extent than Model 2 and Model 3.

C. Load Distribution in 40 Storey Model 1 , Model 2 and Model 3 Diagrid Steel Structures

By comparing the results of analysis of Lateral and Gravity loads for columns and bracing in all 3 models (Model 1 , Model 2 and Model 3) we found that Model 1 Diagrid system resist more lateral loads from its exterior system (Diagonal columns) among all 3 system. So, the efficiency of Model 1 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:-

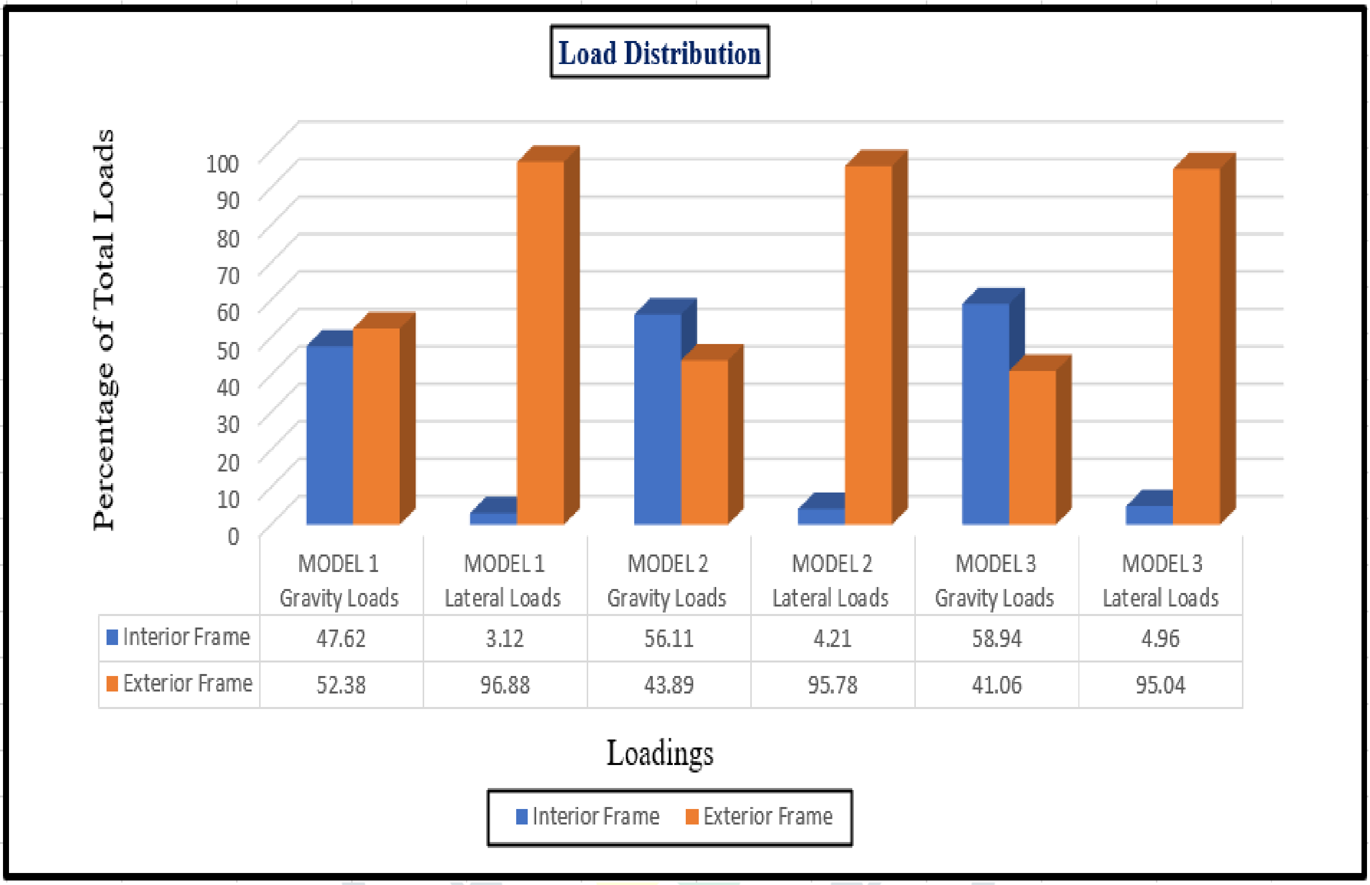


Fig 14 Comparison graphs of Load Distribution in Model 1 , Model 2 and Model 3 Structural System

It is noted from the above Fig. 12 Lateral loads resisted by Model 1 Diagrid External Frame is 96.88% which is maximum among all the system and the Gravity Loads resisted by Diagrid External Frame is 52.38% which is maximum among all system. From above Fig 16. We 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., at different arrangements of Diagrid angles. 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 Model 1 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. Model 1 structure results are much better for a High-Rise building because of its Diagrid angle combination of 74.5° and 50.19°, they improve the comfort conditions in the building, which decreases the cost of the building and construction.

Among the findings are that Model 1 is more efficient among the 3 Models, 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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