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REVIEW PAPER ON BEHAVIOR OF DIAGRID STRUCTURAL SYSTEM FOR HIGH RISE BUILDING

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Abstract— In recent days due to lake of availability of land the construction of tall buildings widely increasing, these buildings are affected by lateral loads due to wind and earthquake. There are many types of lateral load resisting structural systems for tall building such as rigid frame, shear wall, wall-frame, braced frame, dia-grid structure, tube system, outrigger, and core structure. Dia-grid structural system have emerged as one of the most innovative and adoptable approaches to structuring buildings in recent time. Dia-grid structural system is adopted for high-rise building because of its structural efficiency and flexibility for planning. Dia-grid stability systems hold great potential for future that wish to merge architecture and engineering in a compelling way as their execution. Dia-grid is structural system which resists the lateral forces by axial action of diagonal provided in periphery. The lateral displacement in X and Y direction for dia-grid structure is significantly less as compared to conventional structure, Hence the overall displacement of the structure can be effectively controlled by adopting dia-grid structure. Dia-grid structural system do not required any interior core to resist the lateral load because lateral load is resisted by the peripheral diagonal columns. Dia-grid structural system has emerged as a better solution for lateral load resisting system in terms of lateral displacements, steel weight, and stiffness. This paper represent the development and research work done on the seismic analysis, methodology of preliminary design, efficiency and effectiveness of dia-grid structural system.

Keywords— Tall Building, diagrid structural system, optimal angle, Stiffness based design, Seismic performance.

I. INTRODUCTION

In the late 19th century early design of tall buildings recognized the effectiveness of diagonal bracing members in resisting lateral forces. Most of the structural systems deployed for early tall buildings were steel frames with diagonal bracings of various configurations such as X, K and eccentric. However, while the structural importance of diagonals was well recognized, their aesthetic potential was not explicitly appreciated. Thus, diagonals were generally embedded within the building cores which were usually located in the interior of the building. Now-a-days, the diagrid system had been applied to several tall steel buildings because of its structural efficiency. Diagrid is particular form of space truss, which does not have any conventional column on the exterior periphery of the structure. Diagrid is formed by intersecting the diagonal columns and horizontal beams and is made up of the series of triangulated truss system. Diagrid structural system provides more flexibility in planning interior space and facade of the building. In recent years, diagrid structures have received increasing attention among both designers and researchers of tall buildings for creating one-of-a-kind signature structures. The term "diagrid" is a combination of the words "diagonal" and "grid" and achieves its structural integrity through the use of triangulation. Diagrid is a particular form of space truss. It consists of perimeter grid made up of a series of triangulated truss system. Diagrid is formed by intersecting the diagonal and horizontal components. Diagrid systems can be planar, crystalline or take on multiple curvatures. Diagrid structures consist of modules which are in diamond shape and lateral stiffness is provided more in diagrids than the other conventional type of structures. Diagrid structures are more effective in minimizing shear deformation because they carry lateral shear by axial action of diagonal members. For exterior structural systems the significant of diagrid system is identified for about 100 story buildings where frames, tubes or braced tubes are less efficient or uneconomical[3].The Structure should effectively bare the shear and bending due to these two a\factors. Diagrid are the array of triangles which has the combined ability to resist both gravity and lateral loads in a single action. The structures so got are stiffer and lighter than the conventional buildings. Due to the diagonal members the lateral loads are easily countered and it also resists the vertical loads and distributes it due to the triangulated arrangement.

II. LITERATURE REVIEW

A. Optimal Angle

In order to find the actual range of optimal angles: sets of 40, 50,60,70, and 80 story diagrid structure, with height to width aspect ration ranging from 4.3 to 8.7 and having various diagrid angles are optimally designed to meet the typical displacement design parameter of a five hundredth of the building height.

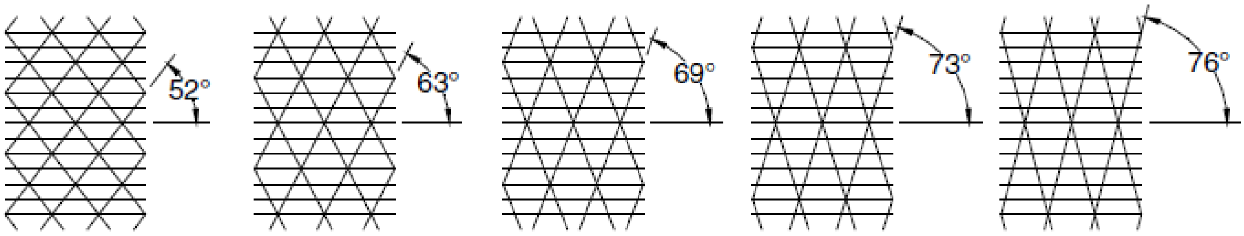

Figure 1 Diagrid of Various Angles

For 40 and 50 story diagrid structures, it was found that the buildings with an angle of 63 degrees meet the stiffness design parameter with the minimum amount of diagonal material. For 60, 70, and 80 story diagrid structures, the buildings with an angle of 69 degrees meet the design parameter most efficiently with the minimum amount of diagonal material. The influence of changing angles for 60 story diagrids is shown in Table 1. As can be seen in the table, at near optimal cases, the efficiency is not too sensitive to the change of angles.

Table 1 Influence of Changing Angles for 60 Story Diagrids [1]

Story Module	Diagrid Angle	Diagrid Steel Mass (Ton)	Percentile Difference
2 stories	52 degrees	5700	+50.0%
3 stories	63 degrees	3930	+3.4%
4 stories	69 degrees	3800	Near Optimal
5 stories	73 degrees	4200	+5.3%
6 stories	76 degrees	4960	+30.5%

It was found that the optimal uniform diagrid angle produces more economical design in terms of material usage than the gradually changing diagrid angles for diagrid structures, 40, 50, and 60 stories tall, with height-to-width aspect ratios ranging from 4.3 to 6.5, as is the case with the 48 story Hearst Building in New York. In the varying angle design, with angles varying from 63 degrees at the top to 73 degrees at the base of the building, in the 60 story structure for example, the structure is configured to better resist bending at the bottom and shear at the top. Thus, in terms of bending rigidity, the varying angle design is a more economical angle composition than the diagrid of uniform angle. A summary of these study results is shown in Table 2 for the 40, 60 and 80 story diagrid structures[1]. Optimal angle of 40,50, 60, 70 and 80 story diagrid structure ranges between 65 degree to 75 degree[2].it was found that, for 60-story diagrid structures having an aspect ratio of about 7, the optimal range of diagrid angle is from about 65˚ to 75˚. For 42- story buildings having an aspect ratio of about 5, the range is lower by around 10˚ because the importance of bending to the total displacement is reduced as the building height decreases[3].

Table 2 Efficiency of Uniform and Varying Angle Diagrids [1]

Diagrid Height	Height/Width	Angles (Bottom → Top)	Steel Mass (Ton)
40 Stories	4.3	52, 63, 69	1906
		63	**883**
		69, 63, 52	1009
60 Stories	6.5	63, 69, 73	4482
		69	**3820**
		73, 69, 63	4104
80 Stories	8.7	63, 69, 73	16627
		69	15611
		73, 69, 63	**11574**

B. Stiffness Based Preliminary Design

Two most important design requirements of any building structural design are strength and stiffness, and for very tall building with a large height-to-width aspect ration, the stiffness constraint generally governs the design. The strength of structural steel has increased with almost no change in its modulus of elasticity. Thus, the strength requirements can be met with smaller members, resulting in potential stiffness problems. One of the most important stiffness design parameters to consider in any tall building design is its maximum deflection, which is usually in the neighbourhood of a five hundredth of the building height[1]. Following the design methodology developed by Moon et al. (2007)[3], member sizes for the modules can be computed using Equations (1) and (2) customized for each design case.

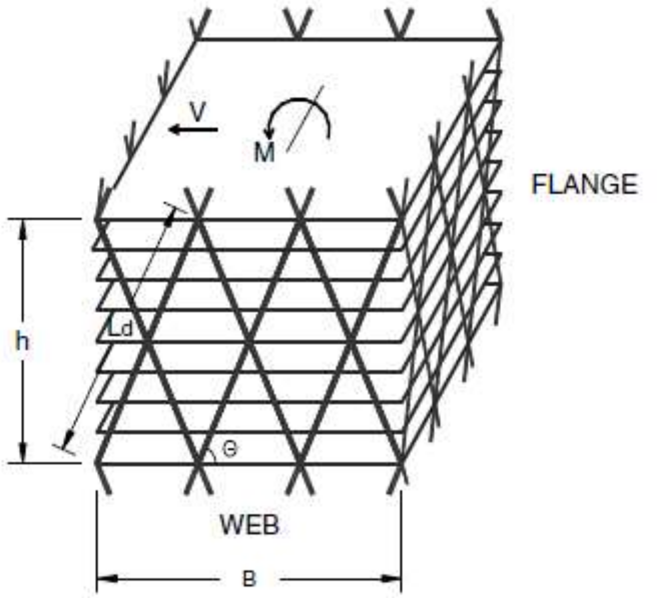

Figure 2 Typical Diagrid Module

$$A_{d,w} = \frac{VL_d}{2N_{d,w}E_d h\gamma\cos^2\theta} \tag{1}$$

$$A_{d,f} = \frac{2ML_d}{(N_{d,f}+\delta)B^2E_d\chi h\sin^2\theta} \tag{2}$$

$A_{d,w}$: Area of Each Diagonal on the Web
$A_{d,f}$: Area of Each Diagonal on the Flange
V: Shear Force
M: Moment
L_d: Length of Diagonal
E_d: Modulus of Elasticity of Steel
Θ: Angle of Diagonal Member
γ: Transverse Shear Strain
χ : Curvature
$N_{d,w}$: Number of Diagonals on Each Web Plane
$N_{d,f}$: Number of Diagonals on Each Flange Plane
δ: Contribution of Web Diagonals for Bending Rigidity
B: Building Width in the Direction of Applied Force

Optimal stiffness-based design corresponds to a state of uniform shear and bending deformation under the design loading. Uniform deformation states are possible only for statically determinate structures. Tall building structures can be modelled as vertical cantilever beams on the ground, and uniform deformation can be achieved for these structures(Connor, 2003)[4]. Then, the deflection at the top, u(H), is given by

$$u(H) = \gamma^* H + \frac{\chi^* H^2}{2} \quad (3)$$

H: Building Height
γ^* : Desired Uniform Transverse Shear Strain
χ^* : Desired Uniform Curvature

A stiffness based design methodology for diagrid structures was presented to help preliminary member sizing of diagrid structures with less iteration. Guidelines for selecting the bending to shear deformation ratio for optimal design was also presented. This design methodology will be very useful to both engineers and architects for preliminary design of tall buildings employing diagrid structural systems. Based on these guidelines, structural and architectural decisions at the early stage of design can be made in a more integrative and efficient way[1]. The optimal value of 'S' (ratio of the displacement at the top of the structure due to bending and the displacement due to shear) for 40, 50, 60, 70 and 80 storey is 2, 2, 3, 4 and 5 respectively. From the results, it can be seen that, bending mode is governing compared to the shear mode as building become taller. Stiffness based approach can be used for preliminary design of diagonal of diagrid structures [2].

C. Seismic Behaviour

From the study it is observed that most of the lateral load is resisted by diagrid columns on the periphery, while gravity load is resisted by both the internal columns and peripherial diagonal columns. So, internal columns need to be designed for vertical load only. Due to increase in lever arm of peripherial diagonal columns, diagrid structural system is more effective in lateral load resistance. Lateral and gravity load are resisted by axial force in diagonal members on periphery of structure, which make system more effective. Diagrid structural system provides more flexibility in planning interior space and façade of the building [5].

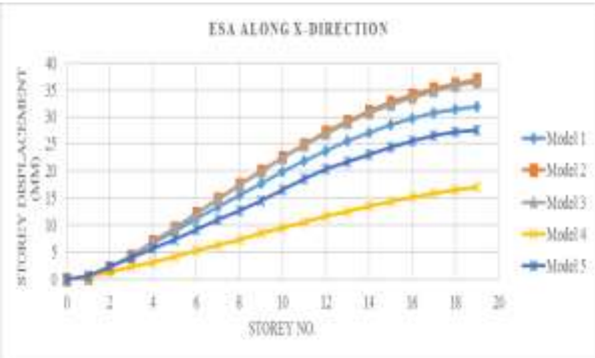

Figure 3 Equivalent Static Analysis of storey displacement along X-direction

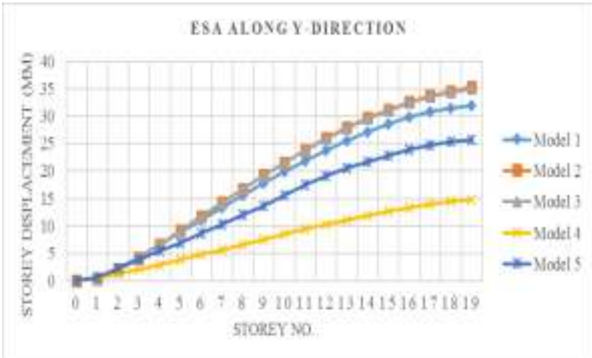

Figure 4 Equivalent Static Analysis of storey displacement in Y-direction

Figure 5 Response Spectrum Analysis of storey displacement along X-direction

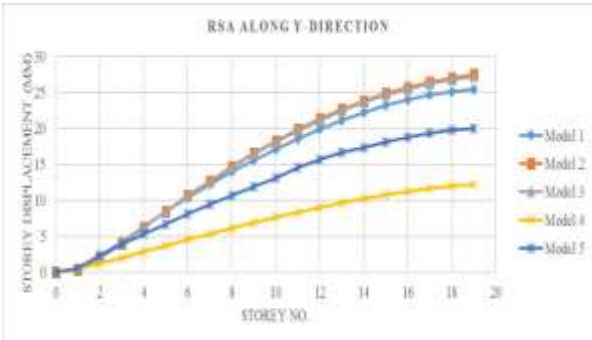

Figure 6 Response Spectrum Analysis of storey displacement in Y-direction

Where,
Model-1 is conventional frame structure,
Model-2 is core wall structure,
Model-3 shear wall structure,

Model-4 bracing structure and
Model-5 is diagrid structure.

Lateral displacement means total displacement of floor with respect to ground. It is caused due to lateral forces acting on building. the maximum displacements are shown from figure 3 to 6 which are obtained from equivalent static method (ESA) and response spectrum method (RSA). Comparatively the displacement of diagrid structure is better than conventional structure, core wall structure and shear wall structure [6]. Displacements on each storey and storey drifts are noticed to be less in diagrid systems when matched with conventional frame. Due to diagonal columns on its periphery, diagrid shows better resistance to lateral loads and due to this, inner columns get relaxed and carry only gravity loads. While in conventional building both inner area and elevation of the building [6]. Diagrid structural system has emerged as a better solution for lateral load resisting system in terms of lateral displacements, steel weight and stiffness. It is stiff enough to resist wind forces up-to higher heights. The diagrid structure provides high efficiency in terms of steel weight along with the aesthetic appearance. For 24 storey building, weight of conventional frame is 100% more than diagrid building. Displacements on each storey and storey drifts are observed to be less in diagrid systems as compared to conventional frame [7]. The lateral displacement in X and Y direction for diagrid structure is significantly less by 45.48% and 41.71% when considering Equivalent static analysis and 45.92%, 42.17% when considering Response spectrum analysis as compared to conventional structure. Hence the overall displacement and of the structure can be effectively controlled by adopting diagrid structure. For Wind Analysis, The lateral displacement in X and Y direction for diagrid structure is significantly less by 45.34% and 41.59% as compared to conventional structure [8].

III. CONCLUSIONS

From the above study it can be concluded that,

- It is also observed that most of the lateral load is resisted by diagrid columns on the periphery, while gravity load is resisted by both the internal columns and peripherial diagonal columns. So, internal columns need to be designed for vertical load only.
- Due to increase in lever arm of peripherial diagonal columns, diagrid structural system is more effective in lateral load resistance.
- Lateral load and gravity load are resisted by axial force in diagonal members on periphery of structure, which make system more effective. Diagrid structural system provides more flexibility in planning interior space and facade of building.
- Diagrid structural system has emerged as a better solution for lateral load resisting system in terms of lateral displacement.
- The time period are less in diagrid system. Lesser values of time period than conventional mode, core wall system and shear wall system are less flexible against seismic vibration.
- In comparison to conventional building, diagrid building are more aesthetic in look and becomes important for high rise buildings.
- Hence, from the above study, results and comparison with conventional building one can adopt diagrid structure for better lateral load resistance.

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