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REVIEW ON OPTIMIZATION OF STRUCTURAL DEVELOPMENTS FOR HIGH RISE- STEEL BUILDINGS: THE CASE OF DIAGRID

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Abstract - Advances in structural engineering and Technology, a significant growth has been widely increasing structural system of high rise steel buildings. In structural systems, Diagrid system in high rise buildings are very popular among engineers and architects. It is important to study diagrid structures under lateral loads such as wind load or seismic load. It has played a major role due to their inherent aesthetic quality, structural efficiency and geometrical versatility. Form the study it was analysed; all diagrid models had an exhibited problem concerning stability of interior columns and local flexibility. To overcome problem; this paper was review about diagrid configurations, geometrical patterns, design and construction methods for diagrid node under wind or seismic loading. This study was gives good indication on preliminary design of diagrid structural behaviour and efficiency under various parameters are presented.

Keywords: high rise steel building, diagrid structural system, lateral load resistance, geometrical patterns.

I. INTRODUCTION

Structural development of high rise steel buildings has been a continuously evolving process. Due to their several advantages such as the offsite prefabrication and the easy dismantling process, the high recycling rates of the material and components, etc. As the height of building increase, the lateral load resisting system becomes more important than the structural system that resists the gravitational loads. The lateral load resisting systems that are widely used are: rigid frame, shear wall, wall-frame, braced tube system, outrigger system and tubular system. Recently, the diagrid – Diagonal Grid – structural system is widely used for tall steel buildings due to its structural efficiency and aesthetic potential provided by the unique geometric configuration of the system. [7] The most commonly and popularly used material in the construction of diagrids is steel. The sections commonly used are rectangular HSS, rounded HSS and wide flanges. Diagrid is a particular form of space truss. The famous examples of diagrid structure all around the world are the Swiss Re in London, Hearst Tower in New York, Cyclone Tower in Asan (Korea), Capital Gate Tower in Abu Dhabi. It consists of perimeter grid made up of a series of triangulated truss system. Diagrid is formed by intersecting the diagonal and horizontal components. These diagonal members act as inclined column to carry gravity load and lateral load on periphery of building. [7] The configuration and efficiency of a diagrid system reduce the number of structural elements required on the façade of the buildings, therefore less obstruction to the outside view. The structural efficiency of diagrid system also helps in avoiding interior and corner columns, therefore allowing significant flexibility with the floor plan. Perimeter "diagrid" system saves approximately 20 percent of the structural steel weight when compared to a conventional moment-frame structure. [3] Diagrid structures are more effective in minimizing shear deformation because they carry lateral shear by axial action of diagonal members. Diagrid structures generally do not need high shear rigidity cores because lateral shear can be carried by the diagonal members located on the periphery. [6] The diagonal member of the diagrid carries both shear and moment. So, the optimal angle of placing of the diagonals is dependent of building height. The optimal angle of the columns for maximum bending rigidity in the normal building is 90 degree and for the diagonals for shear rigidity is 35 degree. [3] The nodes are the important part of the design of the diagrid system. All the diagonal sections are connected to each other by the help of nodes. These nodes are designed for two types of loads, vertical load and horizontal shear. These nodes are joined to the other sections by welding or bolting. It is made sure that very less amount of weld is to be used in the joining. The vertical load is transferred in the form of axial loads from the diagrid members that are placed above the nodes to the gusset plate and stiffeners, then to the diagrid members below the nodes. [10] The horizontal shear is also in the form of axial loads in the diagrid above the nodes, but here one is in compression and another is in tension. [10]

II. LITERATURE REVIEW

Following few researches of previous works which are based on,

K. Moon was carried out stiffness-based design methodology for diagrid structure and braced-frame buildings and the result obtained for displacement and required steel tonnage that braced-frame structure has more displacement and steel requirement as compared to diagrid structural system. Author also examined the geometric configuration of braced tube and diagrid structure in which it was found that optimal angle for diagrid structures it was between 60-70 degrees whereas for braced frame it was between 40-50 degrees. [1]

Kyoung Sun Moon, Jerome J. Connor And John E. Fernandez were presented a simple methodology for determining preliminary member sizes and applied to a set of building heights ranging from 20 to 60 stories, and parameters for the optimal values of the grid geometry are generated for representative design loadings. It was found that, for 60-story diagrid structures having an aspect ratio of about 7, the optimal range of diagrids 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 lateral displacement is reduced as the building height decreases. [2]

Kyong Sun Moon, presented stiffness-based preliminary design methodology of diagrid structures and applied to a set of diagrid structures, 40, 50, 60, 70, and 80 stories. Each storey height is designed with diagonals placed at various uniform angles as well as gradually changing angles. This design studies were provided for the optimal configuration of the diagrid structure grid geometry within a certain height range. It was observed that tall diagrid structure with aspect ratio ranging from 4 to 9 then optimal angle are ranging from 60° to 70°. [3]

Story Heights (Stories)	Height/Width	Optimal Angle (Degrees)	Optimal 's'
40	4.3	63	4
50	5.4	63	6
60	6.5	69	4
70	7.6	69	5
80	8.7	69	6

Table 1: Optimal Angles and 's' Values for Uniform Angle Diagrid structure [3]

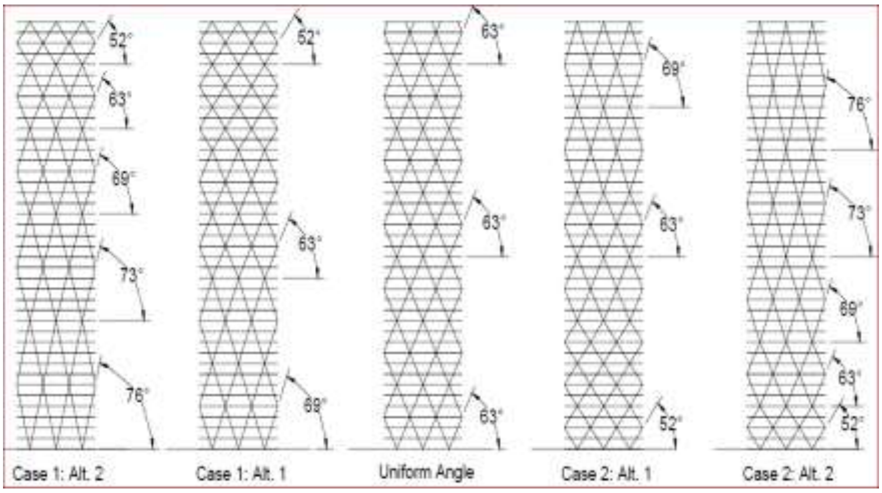

Figure 1: Variously configured 40-storey diagrids (H/B = 4.3) [3]

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	3820	Near Optimal
5 stories	73 degrees	4200	+5.3%
6 stories	76 degrees	4960	+30.5%

Table 2: Influence of Changing Angles for 60 Story Diagrid [3]

Case	Alt.	Angle Description	Optimal 's'	Steel Mass (tons)
1	2	79, 76, 73, 69, 63	0.9	1068
	1	73, 69, 63	2.7	1009
Uniform Angle		69	4.1	**883**
2	1	63, 69, 73	5.1	1906
	2	63, 69, 73, 76, 79	2.1	1597

Table 3: Diagrid Design Optimal 's' Values and Steel Masses for 40 story [3]

Giovanni Maria Montuori, Elena Mele, Giuseppe Brandonisio, Antonello De Luca were provided different diagrid geometry configuration for 90 story building. They were evaluated diagrid structure under wind loads, gravity loads and various performing parameters. Comparison in terms of structure weight and efficiency for different patterns. Here tall building model has different diagrid patterns. The building was 90 storeys with square plane 53m X 53m with central core 25.4m X 25.4m and height of building was 351m with 3.9m floor height. There were various loads applied like dead load, love load and also a lateral load like wind load and earthquake load as per ASCE-07 provision. There were different strategies had adopted for generating model. Strategy 1: regular diagrid has 3 patterns with constant angle and variation of height of 60,70 and 80m. Strategy 2: three patterns with various angle and constant height. Strategy 3: constant angle but variable size along height. Then analysis of that all patterns with various patterns like steel weight, lateral drift, stiffness etc. [4]

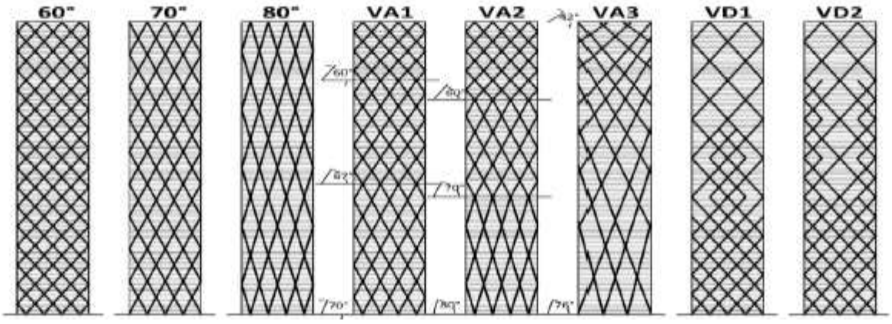

Figure 2: Different geometry patterns of diagrid structure [4]

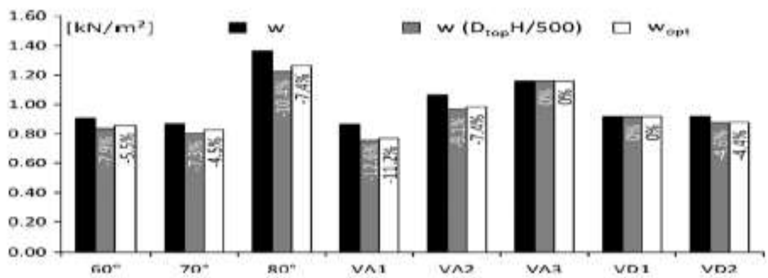

Figure 3: Unit steel weight of diagrid patterns [4]

Giovanni Maria Montuori, Elena Mele, Giuseppe Brandonisio, Antonello De were studied on design criteria for secondary bracing systems. Design criteria was applied to some 90 story building models, characterized by perimeter diagrid structures with different module height and diagonal cross sections. The outcomes of the proposed compared to the structural response of the diagrid building models, obtained without and with secondary bracing systems. It could be solved problems of stability of interior columns and local flexibility. But increase of structural weight (about 3%), any flexural engagements in the diagrid member is eliminated. [5]

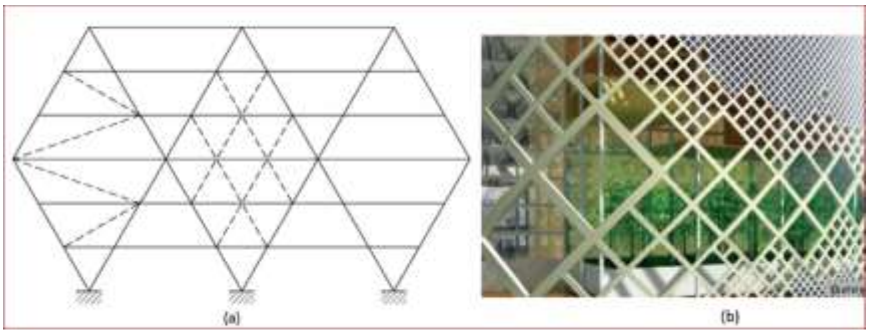

Figure 4: Secondary Bracing System in diagrid [5]

Jinkoo Kim1, and Young-Ho Lee studied the seismic performance of 36 storey diagrid structure with various brace angles using nonlinear static and dynamic analysis. The results were obtained with those of a tubular structure and a diagrid structure. According to the result the authors observed that as the slope of braces enlarged the shear lag effect increased and the lateral strength reduced. He was also observed that diagrid structure most effective in resisting lateral as well as gravity loads. They also deduce that the diagrid structure with circular plan showed higher strength than the diagrid structure with a square plan as a result of decrease in shear lag phenomenon. The diagrid structure showed higher strength than the tubular structure. The result also showed that the behaviours of diagrid under lateral load were highly brittle caused by buckling of braces and to overcome this they suggest to replace diagonal members with buckling restrained braces. [6]

Khushbu Jani, Paresh V. Patel, were analysis and designed of 36 storied building. There was regular floor plan of 36m x 36m size and Etabs software used for modelling and design. Design was done as per is-800:2007 with all load combination. Analysis and design were considered along wind and across wind for 50,60,70,80 story diagrid structure. The angle of inclination was uniform in diagrid structure through all height. Inclined column is provided 6m spacing along perimeter. The dynamic loading of wind was computes as per IS-875 (part3) and parameters of earthquake design was computed based IS-1893:2002. The analysis and design were done with Etabs software and analysis result shows various parameters like time period, story drift, top story displacement and load distribution. From study it is observed that exterior columns carry both lateral and gravity load effectively while internal columns carry only vertical load. [7]

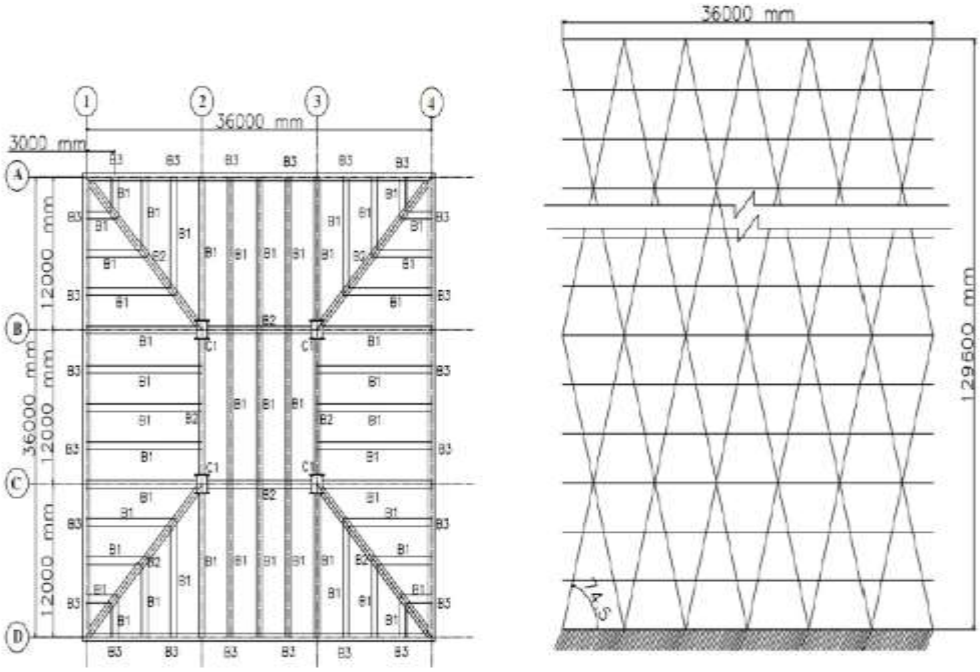

Figure 5: Typical Floor Plan Elevation of 36 Storey Buildings [7]

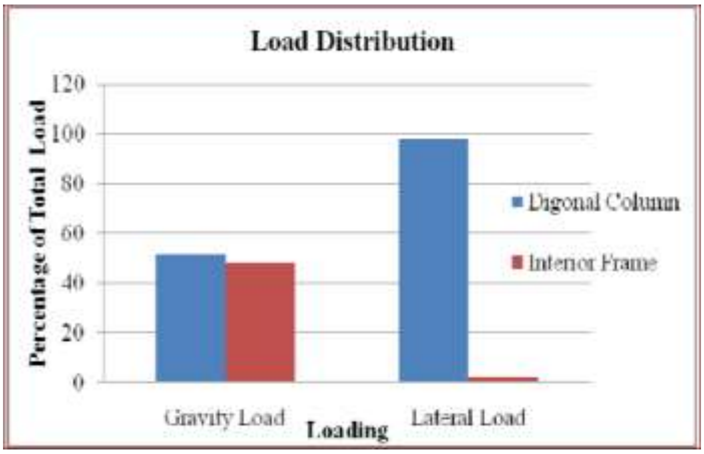

Figure 6: Load distribution in exterior and interior frame [7]

Roslida Abd. Samat, Fong Teng Chua, Nur Akmal Hayati Mohd Mustakim, Sariffuddin Saad and Suhaimi Abu Bakar were researched on the behaviour of the lateral displacement and shear lag effect due to wind load when the diagrid structure is constructed above a frame. Design of Models of 60-story buildings with a footprint of 36m x 36m were analysed by using Staad.Pro software. The level where the diagrid members started was altered. As result, the lateral displacement was reduced to 60.6 percent and 41 percent of the lateral displacement of a building with full frame system when the combination of frame-diagrid that had the diagrid started at Level 1 and Level 45, respectively were employed. Furthermore, the shear lag ratio was reduced from 1.7 to 1.3 when the level where the diagrid started was increased from Level 1 to Level 45. combination of diagrid and frame system is efficient in reducing the lateral displacement but not efficient in reducing the axial force in the external columns. [8]

Kyoung Sun Moona was carried out study on structural performance of diagrid systems employed for complex-shaped tall buildings such as twisted, tilted and freeform towers. It has investigated the impacts of variation of important geometric configurations of complex-shaped tall buildings, such as the rate of twisting and angle of tilting, parametric structural models taken to use for this study. It was deals with the structural design of diagrids to determine cross sectional area of typical web and flange. At top story they considered maximum deflection. SAP2000 software was used for analysis and design. [9]

Terri Meyer Boake was examined on variation in node design, understanding the linked dependence the modularity and choice to expose the steel in building, as well as on the actual fabrication of the node. As observed that some of most significant development in design of diagrid have laid on creation of the node as a key structural connection strategy. The majority node connection in diagrid structure to date have been constructed using custom plate steel fabrication, advance in casting application may soon see the adoption of this node technology to diagrid buildings. [10]

III. CONCLUSIONS

All the above review concluded that a stiffness- based methodology has been determined to design sizes of diagrid system. The optimal angle range of diagonal between 60° to 70°. It system has been characterized by variable angle, variable density which are shown more effective towards regular patterns. Secondary bracing system has been overcome to bucking mode and excessive inter story drift. Lateral load and gravity load resisted by axial forces on exterior frame of building, which make structure more effective. This system has less result in terms of top story displacement, story drift, shear lag effect, time period. Diagrid structure has complicated nodes due to their constructability can be enhanced by appropriate prefabrication methods. Structural steel tonnage has been 20% less than conventional frame system. It has unique compositional characteristic of the structure provided substantial aesthetic potential and efficiency in any existing urban context.

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