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Analysis of Diagrid Structural System

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Abstract

As in modern era population of metropolitan cities increased very rapidly. Due to which construction of high rise buildings is justified. High rise buildings require advance technologies in terms of structural material, vertical transportation and structural system. Mud bricks are used as structural material from ancient period. In late 19th century cast iron replace mud bricks. Structural material has developed from cast iron to reinforced concrete and steel to increase available strength. With the advancement, several types of structural system like framed structure, braced frames, shear wall, tubular structure, outrigger and diagrid were developed for high rise buildings which are the major requirement to accommodate large population of metropolitan cities. In the present study one of such structural system i.e. diagrid structural system has been studied. The high rise building having 40 storey with diagrid structural system with corner columns and without corner columns has been analysied in the present study. The objective of the study was to get the best configuration of diagrid structural system. Structural system is an important factor in the construction of high rise buildings. The aim of structural system is to transfer loads to ground efficiently. Lateral loads are dominating over gravity loads in high rise building. Hence structural system with high rigidity is required. Structural designers mainly increase the volume of structural components to increase the rigidity of structure, which reduces the usable floor area, increase dead loads and increase the cost of construction. Structural designers can reduce the volume of structural components for a required rigidity by using efficient structural system. Presently the Framed, tubular, space truss, super frame structural systems are used to construct high rise buildings. Nowadays a new system named diagrid system has been adopted as a replacement of framed structure. In diagrid system the diagonal members are designed as tress element. Diagrid structural system in unique as it resist lateral load by its axial action. Efficiency of diagrid structural system mainly depends upon angle of diagrid. In the present study the diagrid model with corner column and without corner column at various angles have been studied to find a better configuration. The analysis of diagrid structural system with corner columns and without corner columns was carried out by modeling a 40 storey building in SAP2000 at angles 30.96°, 50.19°, 60.95°, 67.38°,71.57° and 80.54° in terms of first time mode period and top storey displacement in the present study. A regular floor plan of 36m x 36m size with four inner columns at a distance of 12m from outer periphery is considered. SAP-2000 software is used for modeling and analysis. All structural members are designed as per IS 800:2007. Wind load is considered as per IS 875 (part III) for analysis of structure. From the analysis the first time mode period and top story displacement of building with corner column and without corner column has been optimized as 50° to 67° and 60° to 71° respectively. From the study, it was concluded that diagrid structural system with corner columns is better than diagrid structural system without corner columns.

Keywords: High Rise Building, SAP2000, Diagrid Structure

I. INTRODUCTION

High rise buildings become the major requirement of present time because of scarcity of land and increased population. Lots of high rise or tall buildings have been constructed in many parts of world. Before discussing the design criteria of tall and high rise buildings, it becomes important to define, what tall building is and what would be the criteria for declaring a high rise building. Various authors/agencies define this terminology in his way. Mujica defined the modern skyscraper, which is another term used for tall buildings, a building of great height constructed with a steel skeleton and provided with high-speed electric elevators. Taranath defined a tall building not in terms of its height or number of floors, but more on its appearance compared to neighboring building. Kowalczyk et al defined tall buildings from the structural point of view "A building whose height creates different conditions in the design and construction". But none of the above mentioned authors specified a particular height or number of floors.

The Council of Tall Buildings and Urban Habitat (CTBUH) offer the definition of a tall building from a more specific view point. The CTBUH, founded in 1969 and based in Chicago, is "an international not-for-profit organization supported by architecture, engineering, planning, development, and construction professionals, that has a mission to disseminate multi-disciplinary information on tall buildings and sustainable urban environments, to maximize the international interaction of professionals involved in creating the built environment. And to make the latest knowledge available to professionals in a useful form". It suggests that a tall building should follow one or more of the following criteria:

Building appear high relative to other buildings of the area/city in which it exists. Proportion of height of width to give the appearance of a tall building. Buildings require high-rise technologies like elevators and structural wind bracing. The Council also considers that 'tall building' is a building of 14 or more storeys (or over 50 meters/ 165 feet in height).

II. DIFFERENT GEOMETRIC FORMS OF HIGH-RISE BUILDINGS

A. *Twisted Structures*

The use of twisted forms for tall buildings has recently become an increasingly common architectural phenomenon in the world. The precursor of this type of construction is Santiago Calatrava, who designed the Turning Torso in Malmö (Sweden, Fig. 4)), the first twisted building in the world. When considering this geometrical form for optimum static work of a building, it is not advantageous compared to a straight rectangular body. For this geometrical form, diagrid, braced-tube and outrigger systems are used. For twisted tall buildings using the diagrid system, lateral stiffness decreases as the turn ratio increases. However, this system is much less sensitive to the turning ratio when compared to the braced-tube system. In the case of the outrigger system, the mechanism of the action determining the lateral strength of the building differs significantly from the two previous systems.

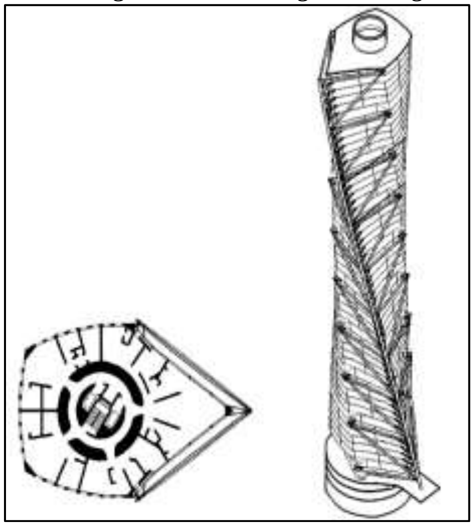

Fig. 4: The Turning Torso – Plan and cross-section

Lateral shear forces and the overturning moment in the diagrid and braced-tube systems are transmitted on the periphery. In an outrigger structural system with a braced core, the core carries lateral shear forces and part of the overturning moment. The perimeter mega columns connected to the rigidly braced core through outrigger trusses also have a significant share of bending stiffness in this system. As the outrigger structure is twisted, the perimeter mega columns wrap spirally around the building. The lateral stiffness of the outrigger system is substantially reduced as the twist ratio increases.

B. *Tilted structures*

Tilted tall buildings are designed to create a kind of dramatic architecture. An example of such a geometrical form is the Veer Towers in Las Vegas designed by Francisco Gonzalez-Pulido (Fig. 5). The static behavior of tall tilted buildings depends on the structural system and the tilt angle. Tilted buildings are subjected to a considerable initial horizontal deformation caused by non-centric gravitational loads. The induced gravitational horizontal displacements increase as the angle of inclination rises. Among the systems that can be used, the outrigger system produces the smallest gravitational horizontal deformation due to

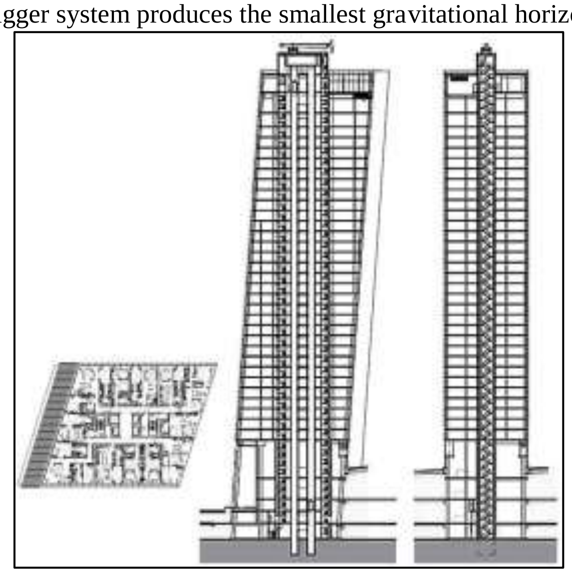

Fig. 5: The Veer Towers - Plan and cross-section

The triangularization of the major components of the structure. However, this system is exposed to dangerous impacts. As the tilt grows, high stresses are generated locally and there can be significant tensile forces.

C. Tapered structures

The geometric form of tapered buildings provides many favorable structural aspects for the design of very tall buildings. In addition, tapered high-rise buildings are more architecturally desirable due to the possibility of designing a mixed-use function. A model example of this type of building is the Shard in London, designed by Renzo Piano (Fig. 6). The most common characteristic of this form, due to its static and dynamic impact, is that the value of shear forces and overturning moments generated by lateral forces rises towards the base of the building. The value of lateral load, more than gravity, is critical when designing this type of structure. When analyzing the application of the diagrid, braced-tube, and outrigger systems, it can be stated that as the taper angle increases, their lateral stiffness increases. The effect of tapering on the reduction of lateral displacement is more significant as a building's height increases. When using an outrigger system, the rigidity of the lower level of the outrigger trusses that connect the mega columns and braced core is reduced because of their length.

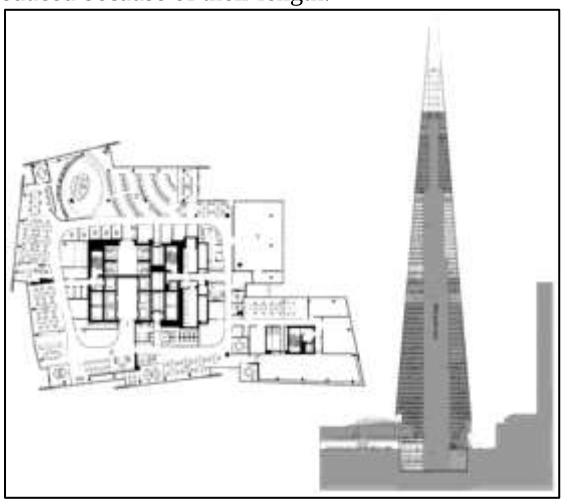

Fig. 6: The Shard Tower- Plan and cross-section

D. Free form Structures

In modern architecture, the number of tall buildings of free geometric form is increasing rapidly. Complex geometry is very often generated using sinusoidal curves with different amplitudes and frequencies. The most famous designers of this type of construction are Daniel Libeskind, Zaha Hadid, Frank Gehry, Norman Foster and Thom Mayne. A very interesting example of this type of building is Mode Gakuen Spiral Tower in Nagoya designed by Nikken Sekkei (Fig. 7). For these buildings, the most common support system is the diagrid system. In this system, lateral displacements increase as the geometrical form deviates from the classical rectangular cuboid shape. As the degree of oscillation of the form increases, the diagonal angle deviates from the optimal value, which in turn reduces the lateral stiffness of the building.

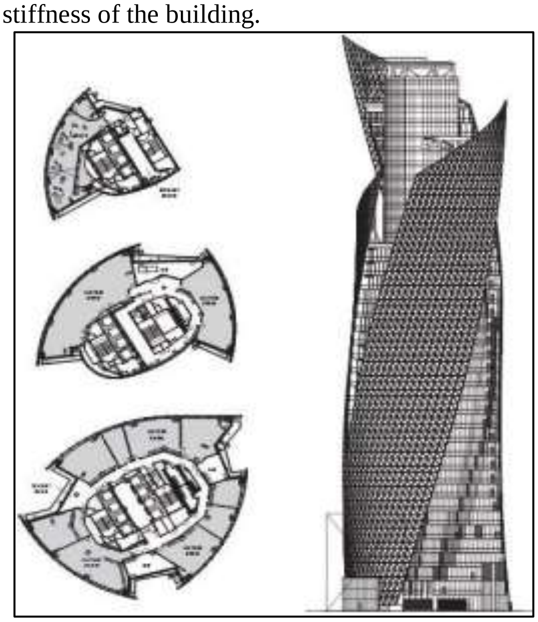

Fig. 7: The Mode Gakuen Spiral Tower - Plan and cross-section

III. CONCLUSION

Structural system is an important factor in the design of tall buildings. Use of suitable structural system reduces cost of material, time of construction and usable space area has also been increased. In the present study, without corner column and with corner column are two configuration of diagrid structural system studied at angle 30.96°, 50.19°, 60.95°, 67.38°, 71.57° and 80.54°. SAP2000 software is used for modeling and analysis. The various characteristics of high rise buildings e.g., first time mode period and top storey displacement has been analysied in this study. Comparison of results of two configurations has been done. The following conclusion has been made.

Optimum range of angle for 40 storey building without corner column is 60° to 71°. But when corner columns are provided the optimum range is 50° to 67°. Hence when corner column provided then optimum angle range is reduced. Building with corner column is more effective in resisting shear force and bending compared with building without corner column. Columns at corner reduce the displacement by 78.12 percent and at angle 30.96° and this reduction at angle 80.54° is 14.93 percent. Columns at corner reduce first time mode period by 54.41 percent at angle 30.96° and at 80.54° this reduction is 7.09 percent. Reduction in displacement is more than time period for all angles hence building with corner column is more comfortable for habitants. Diagrid structural system used with smaller angles should be provided with corner columns, since increase in stiffness is very high at smaller angles. The diagrid structural system with corner columns is stiffer at all angles. Hence diagrid with corner columns is always more economical. Diagrid structural system with corner column is reducing the requirement of steel ultimately reduce dead load. Hence diagrid structural system with corner column is more economical. Stiffness of diagrid with corner column is higher so we can use this system for higher building. Size of interior columns is reduced which results increase in usable floor area in diagrid with corner column. Interior columns are provided to reduce the span of beams only.

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