Review on lateral load resisting system for different geometric shapes of high-rise buildings

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Abstract - **Recently there has been an enormous increase in the use of high rise buildings, especially in metro cities. The cities are getting compacted and populated. To address such a problem the effective solution is to grow vertically. But as the structure extends vertically it becomes slender and responsive to lateral loads. The lateral loads are mainly in the form of seismic load & wind load. So, it is essential to protect these buildings from lateral loads. Lateral load resisting systems play a vital role in high rise buildings. As name indicate that lateral load resisting system it reduces lateral loads and make the building safe. The lateral load resisting system effectively controls the excessive drift due to wind and earthquake and thus minimizes the risk of damage to building. This paper presents an overview of research work done regarding the seismic & wind analysis of high rise buildings with different geometric shapes. The summery and research gaps are discussed in this paper.**

keywords - **Lateral load resisting system, High-rise buildings, geometric shape.**

I. INTRODUCTION

A. General

Modern tall buildings have well-organized and well-designed structural system. High-rise buildings are made up of high-strength materials, resulting in reduced structural members size, thus, the building becomes more slender and flexible. These flexible building are very sensitive to lateral loads such as wind load and earthquake load. In such high rise buildings as height of building increases, the lateral load becomes more dominant than gravity load or vertical load of the building. Therefore, in order to reduce such vibrations and to achieve better performance against the wind loads and earthquake loads, there are various lateral load resisting systems adopted for high rise buildings. (Baikerikar et al, 2014). Understandably, a suitable choice of buildings shape and architectural modifications are also extremely significant and effective design approaches to reduce wind and earthquake-induced motion by altering the flow pattern approximately, hence for this research work different shape of buildings are generally studied. In this literature survey, the concept and classification of various lateral load resisting systems are reviewed in detail for high rise structure. The aim of the study is to determine the most effective lateral load resisting system by considering various geometrical shapes of buildings.

B. Development of High Rise Structural System

Efficient high-rise buildings cannot be designed without considering the factors that affect the selection of a structural system for high-rise buildings. In modern tall buildings, generally, shear walls are used to resist lateral loads developed by wind or earthquake. But when the building increases in height say 90m, the stiffness of the structure becomes more important and incorporation of lateral load resisting system is necessary to provide sufficient lateral stiffness to the structure. The lateral load resisting system effectively control the excessive drift due to lateral load which is induced by wind or earthquake, so that, the risk of structural and non-structural damage can be minimized. For high-rise structures, particularly in seismic prone zone like north-east states of India and west India, the lateral load resisting systems can be used to develop the high-rise building.

Lateral Load Resisting Systems

Following are the lateral load resisting system which can be used in high-rise building,

1. Shear wall system
2. Braced system.
3. Outrigger system.
4. Rigid frame system
5. Frame tube system.
6. Bundle tube system.
7. Trussed tube system.
8. Diagrid system.

1. SHEAR WALL SYSTEM

In structural engineering, a shear wall is a vertical element of a lateral force-resisting system that is designed to resist in-plane lateral forces, typically wind and seismic forces. The shear wall serve both architecturally as partitions and structurally to carry gravity and lateral loads. Shear wall generally starts at foundation level and are continued throughout the building height. It has very effective stiffness as well as strength which make them ideal for high rise buildings. In a shear wall structure, such walls are entirely responsible for the lateral load resistance of the building. They act as vertical cantilevers in the form of separate planar walls and as non-planar assemblies of connected walls around elevator, stair and service shafts. Because they are much stiffer horizontally than rigid frames, shear wall structures can be economical up to about 35 stories. In low to medium-rise structures shear walls are combined with frames, it is reasonable to assume that shear walls attract all the lateral loading so that the frame may be designed for only gravity loading. Shear wall structures have been shown to perform well in an earthquake for which ductility becomes an important consideration in their design.

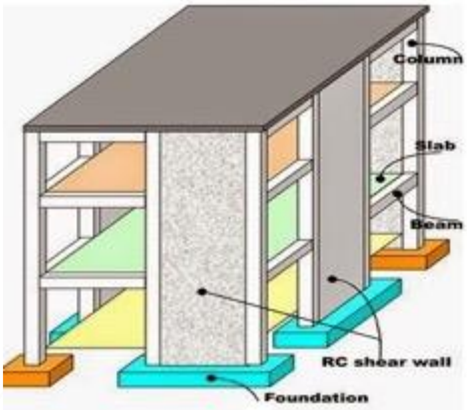

Fig. 1 Shear wall system

2. Bracing System

Steel bracing systems can be used effectively for seismic retrofitting of existing RC buildings as well as for seismic design of new buildings. In braced frames, the lateral resistance of the structure is provided by diagonal members that together with the beams form the web of the vertical truss with the columns acting as chords. Because the horizontal shear on the building is resisted by the horizontal components of the axial tensile and compressive actions in the web members bracing systems are highly efficient in resisting lateral loads. Bracing is generally regarded as an exclusive steel system but nowadays steel bracings are also used in reinforced concrete frames. The efficiency of bracing in being able to produce a laterally very stiff structure for a minimum of additional material makes it an economical structural form for any height of building, up to the very tallest. Generally, braces are of two types, concentric and eccentric. Concentric braces connect at the beam-column intersection, whereas eccentric braces connect to the beam at some distance away from the beam-column intersection. Also, bracings are categorized as vertical bracings and horizontal bracings system depending upon the path of transferring load. Vertical bracing is placed in the form of diagonals between column lines in vertical planes to transfer horizontal forces to ground level, whereas the horizontal bracing system is provided in horizontal planes at each floor level, to transfer horizontal forces to the vertical bracings.

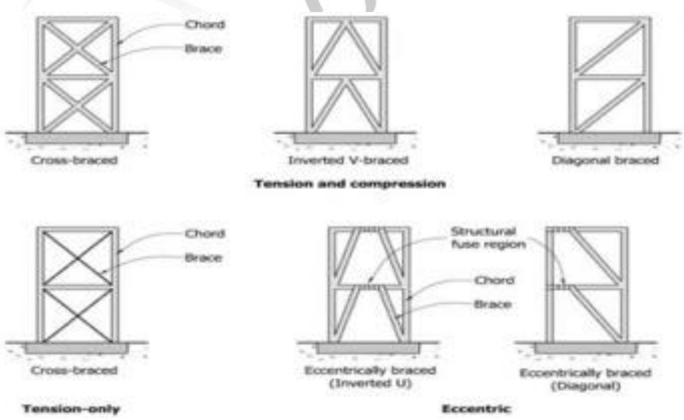

Fig. 2 Bracing system

3. Outrigger System

The outrigger structural system is one of the lateral load resisting systems. Outriggers are rigid horizontal structures designed to improve building overturning stiffness and strength by connecting the belt truss ties all the external columns on the periphery of the structure and the outriggers connect these belt trusses to the central core of the structure thus restraining the exterior columns from rotation. This system is functionally efficient as there is a free floor space between the central core and the exterior columns. Outrigger system can be incorporated into steel, concrete or composite structures. The outrigger system is commonly used as one of the structural system to effectively control the excessive drift due to lateral load, so that, during small or medium lateral load due to either wind or earthquake load, the risk of structural and non-structural damage can be minimized. For high-rise buildings, particularly in seismic active zone or wind load dominant, this system can be chosen as an appropriate structure. On the basis of connectivity to the core, there are two types of outrigger truss conventional outrigger system and virtual outrigger system. In the conventional outrigger system, the outrigger trusses or girders are connected directly to shear walls or braced frames at the core and to columns located outboard of the core. In the virtual outrigger concept, the same transfer of overturning moment from the core to elements outboard of the core is achieved, but without a direct connection between the outrigger trusses and the core.

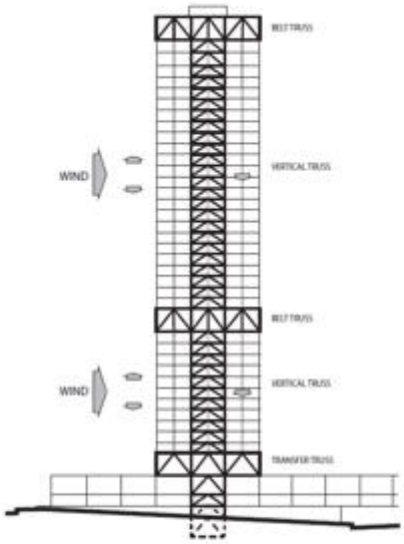

Fig. 3 Outrigger system

4. RIGID FRAME STRUCTURE

A rigid frame is the load-resisting framework constructed with straight or curved members connected by essentially rigid connections which resist movements induced at the joints of members. Rigid frame also called as moment-resisting frames. Its members can take bending moment, shear, and axial loads. A rigid-frame high-rise structure typically comprises of parallel or orthogonally arranged bents consisting of columns and girders with moment-resistant joints. The continuity of the frame also increases resistance to gravity loading by reducing the positive moments in the girders. The advantages of a rigid frame are the simplicity and convenience of its rectangular form. Rigid frames are considered economical for buildings of up to about 25 stories, above which their drift resistance is costly to control.

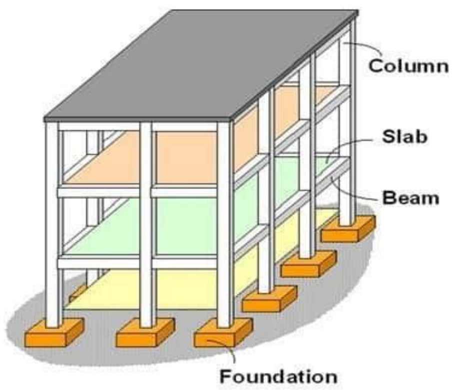

Fig. 4 Rigid frame system

5. DIAGRID SYSTEM

Diagrid System is nothing but the grids of RCC or Steel provided in structure diagonally with the specific geometry. Also, it is a structural system of triangulated beams, straight or curved and horizontal ring that together make up a structural system for a high-rise building. In short, it is made up of intersecting diagonal and horizontal components. The configuration and efficiency of a diagrid system reduce the number of structural element required on the façade of the buildings, therefore less obstruction to the outside view. Diagrid has good appearance and it is easily recognized. The diagrid members can carry gravity loads as well as lateral forces due to triangulated configuration. Diagrid structures are more effective in minimizing shear deformation because they carry lateral shear by axial action of diagrid member. It provides an alternate load path in the event of a structural failure and also reduce the weight of the superstructure can translate into a reduced load on foundation.

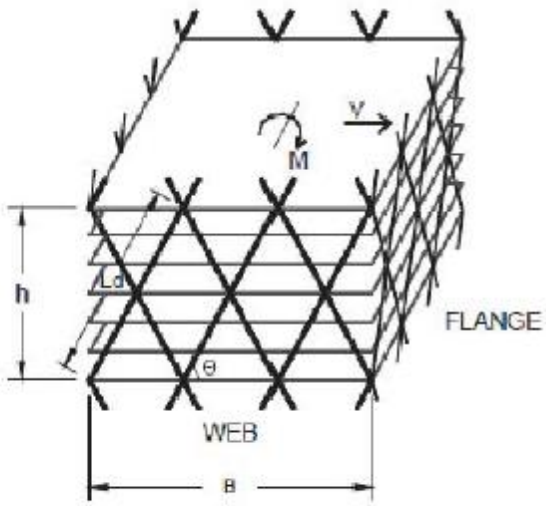

Fig. 5 Diagrid frame system

II. Literature Review

In this section, the present theories and practices related to in different geometrical shapes of high rise building by using various lateral loads resisting technique and their behavior is studied by referring to published literature in various journals, books and conferences.

S. Made et al (2019) have carried out research on analysis of steel structure by considering different lateral load resisting system namely diagrid, conventional moment and bracing. In the diagrid system, lateral and vertical load resisted effectively by diagonal member and this system now become more popular due to its aesthetic appearance. In this study, the author consider three buildings of G+10 steel tower by incorporating diagrid frame, moment-resisting and brace frame. All three types of buildings are modelled in finite element software ETABS and induced seismic loading. The response spectrum analysis has been carried out. According to AISC 360-10 and ASCE/SEI 7-10 codes. Then to determine efficiency structural steel weight of all models is compared. The author concluded that diagrid system is more efficient against the seismic loading than brace frame and moment frames. The stiffness of diagrid system is more than other systems. Also, the structural weight of diagrid system is minimum. In addition, the results show that moment frame has the longest natural period so it is more flexible than other systems.

J. Shaligram and K.B Parikh (2018) have investigated the lateral load has great significance in design. As the height of the building increases, the lateral load becomes more dominant than the gravity load of the building. Lateral loads such as Wind load and Seismic Load are act on the high rise building. These loads are resisted by various lateral load resisting systems. In this paper, the comparison of different types of lateral load resisting systems is studied. The prime focus of this paper is to suggest effective lateral load resisting system for high-rise building with considering the seismic zone of that building. The author concludes that the various lateral load resisting systems are applied for different height of the building. The steel bracing system can be used for low rise buildings whereas the shear wall can be used for medium-rise buildings. Due to high in structural weight shear wall is uneconomical as compare to steel bracing. Diagrid system is effective and economical for the high rise building. From this paper, diagrid system is most suitable lateral load resisting system for high rise building.

A Potnuru and Y Shaik (2017) have worked on the wind analysis of different plan configuration comparatively. In this paper different shapes of building is taken for analysis such as L shape, I shape, C shape and rectangular. For the analysis of buildings finite element software ETABS is used. The different load conditions are considered as per IS 456. For the analysis of gravity load, live load and wind load is considered as per IS 875 part-1, part-2, part-3 respectively. The basic wind speed is 50 m/s considered.

Author concludes that lateral displacement is more in L shape as compare to rectangular plan. Basically, lateral displacement is higher in the asymmetric shape of building as compared to the symmetric shape of the building. The interesting part is base shear and torsion is remained unchanged regardless of plans. The overturning moment is high in case of L shape plan as compared to rectangular plan. The maximum shear force in beam and column is increased exceedingly in L shape plan as compare to rectangular plan. It shows in results that by using shear wall in L shape building the lateral displacement effectively decreases. This paper concludes that the shape of the building largely affects the wind load; Symmetric buildings are safer as compare to asymmetric buildings.

Anes Babu et al (2017) have worked on the effect of steel bracing RC framed structure. As the earthquake is inevitable so there is need to resist the effect of it on structure. Author consider RC frame structure for modelling and analysis, the three structures are analyzed firstly without shear wall and bracing. Secondly, with bracing system and thirdly with shear wall. All three types of buildings are modelled in finite element software ETABS. For choosing the effective system, the parameter as lateral displacement, story drift and story shear are studied. Author concluded that X bracing having less story displacement but story shear is comparatively higher. Steel bracing is superior for the retrofitting of the existing structure. For weakest seismic zone X bracing is most suggested. Steel braced building effectively reduces the lateral drift as compared with shear wall building. The storey drift of steel braced building is less as compared to the normal building ultimately the overall response of the building decreases. The story shear of braced building high as compared to the normal building, which is results in an increase in stiffness of building. Steel bracing significantly reduces the lateral drift as compare to the shear wall.

D. A. Narkhede et al. (2017) have carried out research work on the comparison of seismic behaviour of shear wall and bracing system in RC frame structure. Shear wall and bracing systems are generally used in medium to high rise building according to their need. This system gives stiffness, strength and energy dissipation to resist lateral loads induced due to earthquake. In paper author consider G+10 building which is analyzed by using STAAD-Pro V8i software. The comparison reaction of shear wall and bracing system by using the response spectrum method. The author concludes that shear wall and bracing are very effective to reduce lateral displacement and deflection of building. As compare to bracing system the shear wall gives more stiffness to the building. The concrete bracing is very useful to existing structures for retrofitting and strengthening of structure. by using X bracing very effectively reduces lateral displacement in building. The use of shear wall at the centre of is most suitable as compare to other location to reduce lateral displacement in building. Shear wall is most preferred to medium high rise building to further improve the quality of structure against seismic load. Also, X bracing is most suitable to reduce lateral displacement, story shear, defection.

S. P. Dhoke et al. (2017) have presented an analysis of various lateral load resisting systems comparatively. Such that, frame tube system and diagrid system. For the modelling and analysis purpose finite element software ETABS is used. The comparative analysis of lateral load resisting system is carried out by the method of response spectrum. On the basis of lateral displacement, story drift, modal time period and story shear forces. Author conclude that the diagrid system which better stiffness than frame tube system and beam-column system. By refereeing the ETABS results and comparing it shows that diagrid system having better performance than other systems in case of displacement, storey forces, stiffness and time period. When overall comparison suggest that steel outrigger and belt truss system is more efficient than concrete outrigger and belt truss system

M. Kalra et al (**2016)** have carried out research work on the effect of wind load on different shapes of G+50 storied buildings. It is important to design structure such structure which aesthetically well as well as structurally stable at any adverse conditions. In this paper, seven different types of buildings are taken for analysis. The analysis was done by using STADD pro software. All the loads were taken as per IS 875:2000. Parameters are taken for assessment likely storey drift, joint displacement, bending moment. By the study, it is clear that the shape of building play vital part in resisting wind forces. The author concluded that as the height of the building increases the story drift and joint displacement is increased whereas shear force and bending moment is decreases. The results show that, the L shape and U shape of buildings having highest displacement as compare to other shape of buildings. Whereas Plus shape and non-uniform shape of building have the least displacement and high stiffness than other shapes of buildings. So the plus and non-uniform shapes of buildings are most stable buildings. For other shapes of buildings it possible to increase the stability by increasing the number of column and beams without changing original dimensions of building.

Shehata E. Abdel Raheem et al (2016) have carried out their work on seismic performance of L shaped multistoried buildings with moment-resisting frame. The earthquakes demonstrate the damage percentage of irregular shape of buildings as compare to regular shape of buildings. The structural design for irregular shape buildings are different pattern than regular shape of buildings. Also, sudden change in dimensions leads to torsion and affect the stiffness of the structure. The aim of this paper is to study the seismic performance of L-shaped irregular buildings with moment-resisting frames by an evaluation of the irregularity effects on measured seismic response demands. The author concludes that for storey shear force, overturning moment, inter-storey drift, torsion–moment responses at the base and along the building height, top-floor displacement and torsional irregularity coefficient prove that buildings with irregularity are more vulnerable than those with a regular configuration resulting from stress concentration and coupled lateral-torsional behaviour.

M. R. Sultan and D. G. Peera (2015) have worked on the dynamic analysis of multi-storied buildings for different shapes. As the irregular shapes of buildings are highly prone to seismic damage as compare to regular shapes of buildings. The seismic response of the structure is the main reason for the damage of the structure. so it is important to know seismic response to structure during seismic activity to minimize the damage. In this paper, there are four different shapes of buildings of G+15 are consider such as rectangular, C shape, H shape, L shape in severe earthquake region. The four models were analyzed by ETABS software. The author concludes that in high seismic zone irregular shapes of buildings are most affected than regular shape of buildings. As results show that L, C and H shape of buildings undergo high deformation than rectangular building. By using equivalent static method L shape of building having lowest base shear as compare to all other shapes of buildings but rectangular building has the highest base shear among all other buildings. From all parametric study it is clear that the C shape of building is unsafe than all other types of buildings. This paper suggests that regularity in planning of building is the most important factor for earthquake consideration point of view.

A. L. Gawate and J. P. Bhusari (2015) have research work on the behaviour of outrigger structural system for high rise building. It is observed that the outrigger system is one of the popular lateral load resisting system among the other lateral load resisting systems for high rise buildings in recent periods because it significantly reduces storey drift. Outrigger system drastically reduces the lateral drift and gives stability to structure. The outrigger and belt truss are used to control excessive drift of high-rise building. As per this paper, the economy depends on optimum location of outrigger system. The two types of outrigger are used at different locations on a trial basis to find optimum location. For analysis of high rise building the finite element software package, ETBS were used. The author concluded that the optimum location for the single outrigger is of 0.47H from bottom of building. When two outriggers provided then one outrigger is fixing at top and second outrigger is at 0.3H from bottom of building. When two outriggers are provided 0.333H away from each other than the optimum location of two outriggers are 0.333H and 0.667H from bottom of building. When one outrigger is provided at the top floor, it is less effective to control drift. Drift is drastically changing when two outriggers are provided. For the top sway there is addition outrigger is provided at top it results best to control sway and there is no soft-story formation.

III. Summary of Literature

1. The literature survey in the performance and behaviour of building structures when subjected to wind loads suggests that the requirement of establishing a methodology for studying the response of building structure to winded loads has become essential. Many researchers have performed work over various types of building. on the different types of buildings and find out the important parameter which is useful for understanding the behaviour of wind forces.

2. The researchers concluded that the steel bracings can be used as lateral load resisting system of multistory building up to 10 to 20 storey whereas Shear wall can be used for 20 to 35 storey building as lateral load resisting system. But shear wall has more structural weight compared to steel bracings which might be uneconomical for 10 to 15 storey.

3. Steel bracing system is an efficient and effective lateral load resisting system. Also used as the lateral load resistance system for reinforced concrete structure is an effective technique. Different types of bracing system reduce the storey drift and displacement of the structure. Out of various arrangements of bracing X bracing system is more effective in increasing lateral load capacity of the structure. Bracing system reduces bending moment and shear force in the column. Steel bracing transfer the lateral load through axial action. Steel bracing can be used to retrofit the existing structure.

4. By providing the shear wall to the high rise building, seismic behaviour will be affected to a greater extent and also the stiffness and strength of building will be increased. It is also observed that due to diagonal columns in periphery of the structure the diagrid structure is more effective in lateral load resisting system

5. The concrete outrigger is superior in reducing the lateral storey displacement as compared to the steel outrigger in the tall RCC building. Virtual outrigger system is more efficient than conventional outrigger in high-rise building which increases the strength and stiffness against the lateral load which is induced by earthquake.

6. The moment resisting frame with shear walls are very good in lateral force such as earthquake and wind force. The shear walls provide lateral load distribution by transferring the wind and earthquake loads to the foundation. Also, impact on the lateral stiffness of the system and also carry gravity loads.

7. When the high-rise building is subjected to different geometrical shapes such as regular and irregular. Then irregular shapes of buildings have feel more story drift, lateral displacement, deformation and less base shear as compare to regular shapes of buildings.

8. There will be an increase in the storey drift and displacement of joint with the height in high-rise buildings. It seen that L-shape and U-shape are the least stable of all the shapes. In case of Plus shape and non-uniform shape the stiffness was high as compared to the other cases, hence plus shape and non-uniform are the most stable.

IV. Gaps in Literature

Based on the literature review investigated with reference to lateral load resisting system for different geometric shapes of high-rise buildings, there are certain of research work which is not studied earlier, as mentioned below:

1. Looking at the present scenario of construction industry, there are various research and analysis done on the high rise buildings of different shapes, but there is need of research work to be done on suitability of lateral load resisting system for that particular shape of building.
2. Various researchers have carried out work on the only lateral load resisting for particular seismic zone, there will be large scope for future study in lateral load resisting system for different shapes of high rise buildings by considering all type of seismic zone with different soil interaction.
3. Researchers have carried out work on the few shapes of buildings with considering conventional lateral load resisting systems but there is more scope for the investigation of different lateral load resisting system for the various symmetrical and unsymmetrical shapes of high-rise buildings.
4. Lateral load resisting system can be used with a combination of energy dissipation device.

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