SSRG International Journal of Civil Engineering
ISSN: 2348 – 8352 /doi:10.14445/23488352/IJCE-V7I4P103

Volume 7 Issue 4, 14-18, April 2020

Reinforced Concrete Shear Wall System and its Effectiveness in High rise Buildings

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Received Date: 28 February 2020
Revised Date: 21 April 2020
Accepted Date: 22 April 2020

Abstract

A shear wall has been the most common structure system used to stabilize building structures against horizontal forces caused by wind or earthquake. With the advent of reinforced concrete, shear wall systems have become widely used to stabilized efficiently, even the tallest building structures, by gaining concrete strength over 130MPa. A common shear wall system used for tall office buildings groups shear walls around the service core, elevator shafts and stairwells to form a stiff box structure. In contrast with office buildings, high-rise residential buildings have fewer demands for elevators, lobbies, and services. Hence, they do not usually have large stiff concrete shear wall boxes to resist horizontal forces. A more common system will incorporate a small box structure around a smaller number of elevators and stairwells and include discrete shear walls between apartments. To design shear wall arranged service core, the bending, shear, and warping stresses due to wind or earthquake loads are combined with stresses due to gravity loads. The box system's walls can then be designed as unit length wall spanning either floor to floor and between return walls.

Keywords — *Shear wall, High rise building, Box structure, Earthquake, Horizontal forces.*

I. INTRODUCTION

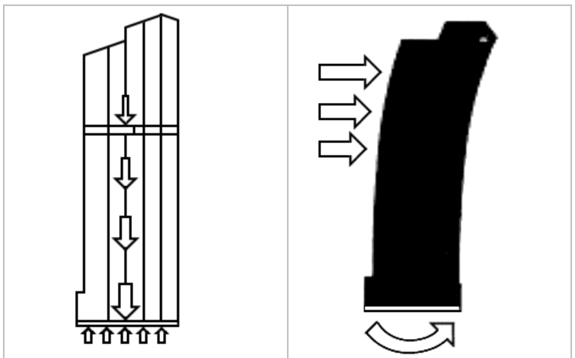
Reinforced cement concrete (R.C.C.) structures constitute various concrete elements like columns, beams and slabs, etc., reinforced with steel reinforcement bars. The concrete part of any member is known to undertake the compressive loads, and the reinforcement bars provide the necessary tensile strength to the structure and thus improve the strength of the structure on the whole. An R.C.C. framed structure is an assembly of slabs, beams, columns and foundations inter-connected to each other as a unit. The load transfer in such a structure takes place from the slabs to the beams, from the beams to the columns and then to the lower columns and finally to the foundation, which transfers it to the soil. The floor area of an R.C.C. framed structure building is 10 to 12 percent more than that of a load-bearing walled building. Also, R.C.C. structures offer a more flexible planning area.

These R.C.C. frames are used to build various structures ranging from single storey bungalows to multi-storey buildings. Multi-storey buildings may be classified as low-rise buildings, high rise buildings and skyscrapers. Buildings with a total height of fewer than 75 feet are termed as low-rise buildings or simply multi-storey buildings. Buildings with a total height between 75 feet and 500 feet are categorized as high-rise buildings. Buildings more than 500 feet high are categorized as skyscrapers. These high-rise structures and skyscrapers have higher vertical loads and higher lateral loads compared to low rise structures.

A. Loads acting on high rise buildings

The loads acting upon high rise buildings can be broadly classified as vertical loads and horizontal loads.

Vertical loads, as shown in figure 1. A includes the loading due to the dead weight of the structure. It arises from their individual construction members' weight like slabs, beams, columns, etc., along with the finishing loads. Live loads also come under the category of vertical loads. Such load depends on the purpose for which the structure is built. Also, it depends upon the number of serviceable storeys in the structure.



A-Vertical Loading | B-Horizontal Loading

Fig 1: Types of loading

As shown in figure 1.B, horizontal loads include loading due to wind forces, earthquake forces, and unexpected deflections. High rise buildings are susceptible to oscillations due to wind and must be investigated carefully for the sway behaviour by experiments such as wind tunnel test. This type of load increases proportionally with the building's height, as shown figure-2 The oscillations produced by wind can lead to a high lateral deflection and lateral acceleration for the occupants, thereby creating discomfort. As shown in figure-3, Earthquake loads originate at the time of tectonic movements or volcanic explosions. This load is transmitted to the structure at the foundation level of the structure. This load is directly proportional to the weight of the building. Any unexpected deflection caused either by a construction defect, or uneven settling of the foundation is also responsible for imparting lateral load to the structure.

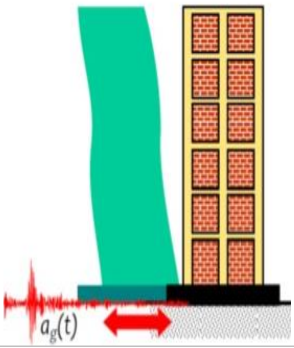


Fig 2: Earthquake Loading

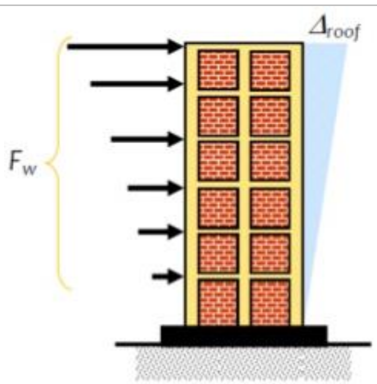


Fig 3: Wind Loading

II. TYPES OF HIGH-RISE STRUCTURES

A. Frame tube structure

It is a structure with closely spaced columns and deep spandrel beams that are rigidly connected, with the entire assemblage continuous along each façade. This arrangement approximates a tube cantilevered from the ground, as shown in figure 4.A.

B. Braced tube structure

Such structures are formed by introducing a minimum number of diagonals on each façade, which intersect at the column corners. An effective braced tube action may be achieved by replacing closely spaced columns with diagonal truss members. The John Hancock Centre, Chicago is an example of a braced tune structure. It is well known for its huge external X-bracing, as shown in figure 4.B.

A-Frame tube structure | B-Braced tube structure

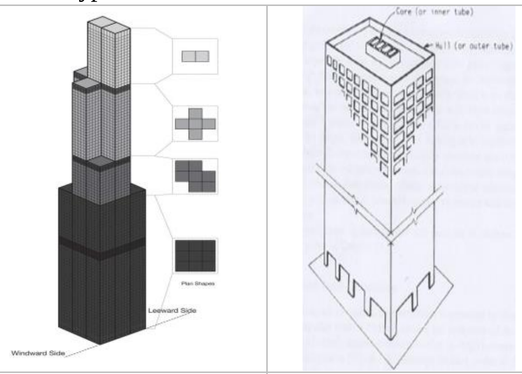
Fig 4: A- World Trade Centre, Washington DC, B. John Hancock Centre, Chicago

C. Bundled tube structure

Such structures are configured with multiple cells and provide vertical offsets without much loss inefficiency. The principle behind the bundled tube concept is that the interior rows of columns and spandrels act as interior webs minimizing shear lag effects. Torsional loads are readily resisted, and greater spacing of columns is possible. Sears Tower, as shown in figure 5. A situated in Chicago is the best example of a bundled tube structure.

D. Tube in the tube structure

It is a frame tube consisting of an outer framed tube together with an internal core. The outer tube plays a dominant role and has a greater structural depth. Such structures tend to have increased lateral stiffness. Figure 5.B shows an example of a tube in the tube type of structure.



A-Bundled tube structure | B-Tube in tube Structure

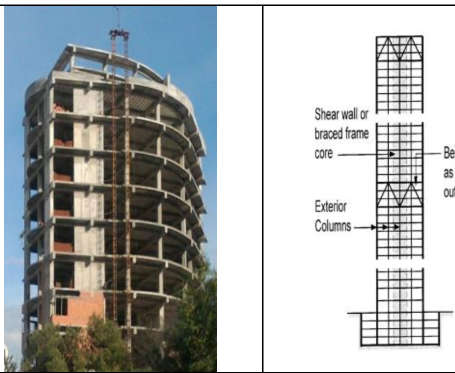
Fig 5: A- Sears Tower, Chicago, B- Tube in Tube Structure

E. Shear wall structure

As the name suggests, these structures comprise of shear walls. The vertical concrete shear walls may serve as architectural partitions and structural components to carry the vertical and lateral loads. The use of shear walls is suitable for high rise buildings because of their high in-plane stiffness and strength. Figure 6. A shows a building with a shear wall.

F. Outrigger braced structure

The central Core in such structures comprises a braced frame or shear walls with horizontal cantilever with outrigger trusses or girders connecting the Core to the outer columns. The effective structural depth of such structures is highly increased, thereby decreasing the lateral deflection and moment. Figure 6.B shows the key components of an outrigger braced structure.



A-Shear wall structure | B-Outrigger braced structure

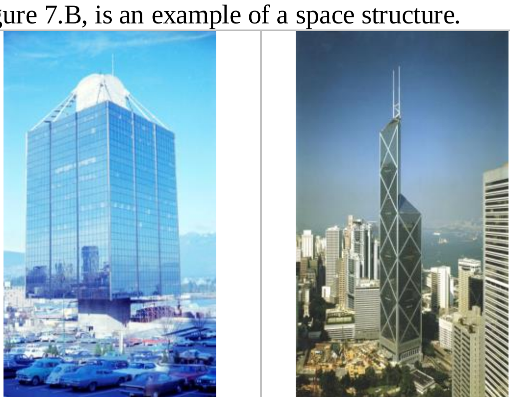
Fig 6: A- Shear wall structure, B- Outrigger braced

G. Suspended structure

These structures consist of Core or cores with horizontal cantilever at roof levels to which vertical hangers of steel cable, rods or plates are attached. The floor slabs are suspended from these hangers. These are often restricted to lesser heights when open space is desired at the ground level. As shown in figure 7.A, the Skyline Westcoast building is situated in Vancouver is an example of a suspended structure.

H. Space structure

Such structures consist of 3D triangulated frames that resist both gravity and lateral loads. Though these have complex geometries, they have relatively lightweight and can be erected for greater heights. Bank of China tower of Hong Kong, as shown in figure 7.B, is an example of a space structure.



A-Suspended structure | B-Space structure

Fig 7: A-Skyline Westcoast building, B- Bank of China, Hong Kong

I. Hybrid structure

Such structures are formed by combining two or more above mentioned structural forms either by direct combination or by adopting different forms in different parts of the structure, as shown in Fig 8. A.

A-Hybrid Structure

Fig 8: New Plans for Project Terrace House by Shigeru Ban, Japan.

III. SHEAR WALL

The lateral deflection in any one storey of a multi-storey or a high-rise building must not be more than the total building height divided by 480. This is necessary to avoid a limitation of the building, discomfort to occupants, degradation in the building's aesthetics, etc. This can be achieved by increasing the dimensions of the structural members, but this cannot be adopted for high rise buildings because it will increase the cost of construction, time taken for construction, and increase the height of individual storeys. Providing shear walls in such structures can prove to be fruitful.

Shear walls may be defined as the vertical plate-like reinforced concrete walls beginning from the foundation itself that are often constructed in high rise buildings to counter the horizontal loads which may act upon the structure. Most importantly, these horizontal or lateral loads include the earthquake and wind load that act upon the structure. The thickness of shear walls may vary from 150 mm to 400 mm depending on the height and type of the structure and lateral loading intensity. These may also be defined as vertically-oriented wide beams that carry the earthquake load to the foundation. Shear walls are known for providing large strength and stiffness to buildings in the direction of their orientation, which significantly reduces the building's sway and thereby reduces damage to the structure and its components. Provision of openings for doors and windows is possible in shear walls, but their size must be small and symmetrically located. In the last two decades, shear walls have become an important part of mid and high-rise residential buildings. These shear walls are known for reducing the lateral displacements under earthquake loads.

A. *SHEAR WALL TYPES AND CONFIGURATIONS*

Depending on the height and width of monolithic shear walls, they can be classified as short, squat or cantilever. When the height to width ratio of a shear wall is less than unity, it is termed a short shear wall. When the ratio mentioned above is greater than one but less than three, it is termed a squat shear wall. And when the height to width ratio of shear wall is more than three, it is termed as cantilever shear wall. Depending on the shear wall's shape as seen in the structure's plan, shear walls may be categorized as plane, flanged, channel or Core.

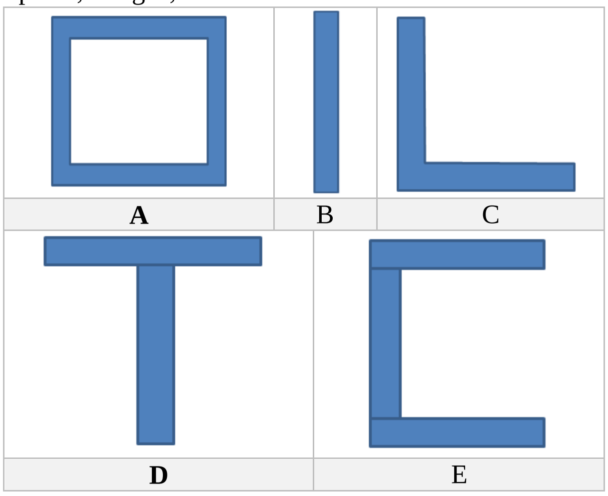


Fig 9: Shear wall configurations. A- Core shaped, B- Planar, C- L shaped, D- Flanged, E- Channel shear wall.

The plan position of the shear wall may be termed as a shear wall configuration. This configuration influences the behaviour of the structure considerably. Some of the common shear wall configurations are shown in figure-9. The choice of shear wall configuration is important because it is responsible for providing flexural stiffness to the structure. These shear walls may often require openings for doors and windows, which are necessary for functional consideration.

IV. LITERATURE REVIEW

Some of the work done by a few scholars has been mentioned below.

I.S. 13290:2016 specified various provisions for the design of shear walls. Some of the basic general requirements include: minimum wall thickness of 150 mm, reinforcements are to be provided in both longitudinal and transverse direction with a minimum reinforcement of 0.0025 of the gross area in each direction, reinforcement must be provided in two curtains when the thickness of the wall is more than 200 mm, the diameter of bars in any part of the wall shall not exceed 1/10th of the thickness of that part and the maximum spacing of reinforcements in either direction shall not be more than 450 mm in any case. It also specifies that the shear strength of shear walls with openings must be checked along the critical planes that pass through the openings.

A. Kumbhare and Saoji (2012)

Analyzed a G+11 RCC structure with different location of shear walls to check their effectiveness. The results indicated that a significant change is observed in the values of shear strength and bending moments of columns at different building levels with the change in shear wall location. Placing shear wall away from the centre of gravity increased most of the member's forces. It was concluded that shear walls should be coinciding with the centroid of the building.

B. Firoozabad et al. (2012)

Studied the seismic behaviour for a 25storey building with different shear wall configurations. The criteria for structural performance of shear wall were represented by the deformation demand inherent in the structure and the top storey drift. They showed how different shear wall configurations behaved differently with up to a 100% decrease in top story drift. They elaborated that the maximum drift limitation of 0.004has per I.S.- 1893-2016 was satisfied using EL CENTRO earthquake but not TABAS earthquake. Their study's major conclusion was that the quantity of shear wall could not guarantee the building's seismic behaviour.

C. Lakshmi et al. (2014)

Compared seven different shear wall configurations of a sixteen storey G+15 RC building with the model with no shear wall. The equivalent static method, response spectrum, and static pushover analysis were done to study the lateral displacement and storey drift of the various models. Their study concluded that the particular model showed the best results when the shear walls were placed at the building plan's central Core and exterior columns. It was observed that the lateral displacement was reduced by up to 52% in this case. It was also observed that maximum reduction in the drift values was obtained when the shear walls were placed at the building's corners. They also concluded that response spectrum analysis produced more realistic results as compared to equivalent static analysis.

D. Hiremath and Hussain (2014)

Concluded that provision of shear walls at adequate locations reduced the displacement due to earthquake substantially. Also, the lateral displacement and storey drift varied with the thickness and location of the shear wall. The 25 storey building models have a uniform and varying shear wall thickness at different storey levels. It was concluded that models with varying shear wall thickness offered lesser storey drift than the model with uniform shear wall thickness. It was also observed that a very low storey drift ratio is found in the bottom storeys, very high in the middle storeys and finally decreases towards the top storeys.

E. Suresh and Yadav (2015)

Studied a G+20 RCC building for the optimum shear wall location under lateral loading. They analyzed their structure for earthquake loads for area lying in zones II and V. They also studied the effect of lateral loading by the wind. The irregular building model was analyzed for buildings without the shear wall, with central shear wall core and with shear walls at the corners. Their study concluded that the plan without shear walls gave much more displacements and storey drift than the shear wall model. They concluded that shear walls along four edges were the most optimum shear wall location**.**

V. CONCLUSIONS

From the above, it is very clear that the R.C.C. shear wall system can be the best solution for high-rise buildings because it seems more economical and easier in construction than any other system. By different modelling and analysis with any soft-ware like E-Tabs, we can optimize a shear wall system, which can be the most economical resist effectively the forces coming on it. It is also seen that a boxed shear wall system is also an efficient means for resisting torsions due to irregular building. Even multiple shear walls throughout the tall building may be coupled to provide additional frame action and hence increase overall building stiffness coupling can be realized by relatively shallow header or linked beams within the ceiling cavity at each level utilizing one-two storey high shear coupling walls even by adding coupling shear wall at a single level reverse curvature is induced in the Core above the coupling shear wall, significantly reducing lateral drift by increasing the overall building stiffness. Centre core wall boxes can also be coupled via stiffed beams or trusses at a discrete level to external shear walls or columns to achieve a similar and more pronounced effect than that noted in another system. Thus, the concrete shear wall becomes the central component in a core and outrigger system. It can also use slip form or jump form technique dur to high strength concrete availability, enabling the wall thickness to a minimum and maximizing rentable floor area. The need for complex bolted, or side welded steel connection can also be avoided, and well detailed reinforced concrete can also develop about twice damping as structural steel. This is an advantage where acceleration serviceability is a critical limit state or ultimate limit state design in earthquake-prone areas.

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