Reinforced Concrete Shear Wall System and its Effectiveness in High-Arise Buildings

Rakesh Kumar[1], IshuSharma[2]
ResearchScholar[1],AssistantProfessor[2]
Structural Engineering,IIMTUniversity,
Meerut-250001, India

Abstract

The behaviour of shear wall structures for different loading conditions can be studied by using advanced theoretical analysis supplemented by model testing. This would help to determine the most suitable structural form and also to predict the behaviour of the structure at working and failure load. Thus the engineer can assess the true factor of safety. 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 wall arounds service core, elevator shafts and stairwells to form a stiff box structure. In contrast with office buildings, high rise residential buildings have less demands for elevators, lobbies and services and hence 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 elevator and stairwells and include discrete shear walls between apartments. During the initial design for adding damping, a BRB system had been considered. However, when comparing BRBs to the fluid damper arrangement, in order to achieve the same damping effect, the BRB cost was higher. Therefore, fluid dampers were selected.

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

INTRODUCTION

Reinforced cement concrete (RCC) structures constitutes of various concrete elements like columns, beams and slabs etc. which are 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 RCC framed structure is basically an assembly of slabs, beams, columns and foundation 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 in turn transfers it to the soil. The floor area of an RCC framed structure building is 10 to 12 percent more than that of a load bearing walled building. Also, RCC structures offer a more flexible planning area.

These RCC frames are used to build a variety of structures ranging from single storey bungalows to and sky scrapers. Buildings with total height less than 75 feet are termed as low-rise buildings or simply multi-storey buildings. Buildings with 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 as well as higher lateral loads as 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 include the loading due to the dead weight of the structure. It arises from the weight of them individual construction members 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.

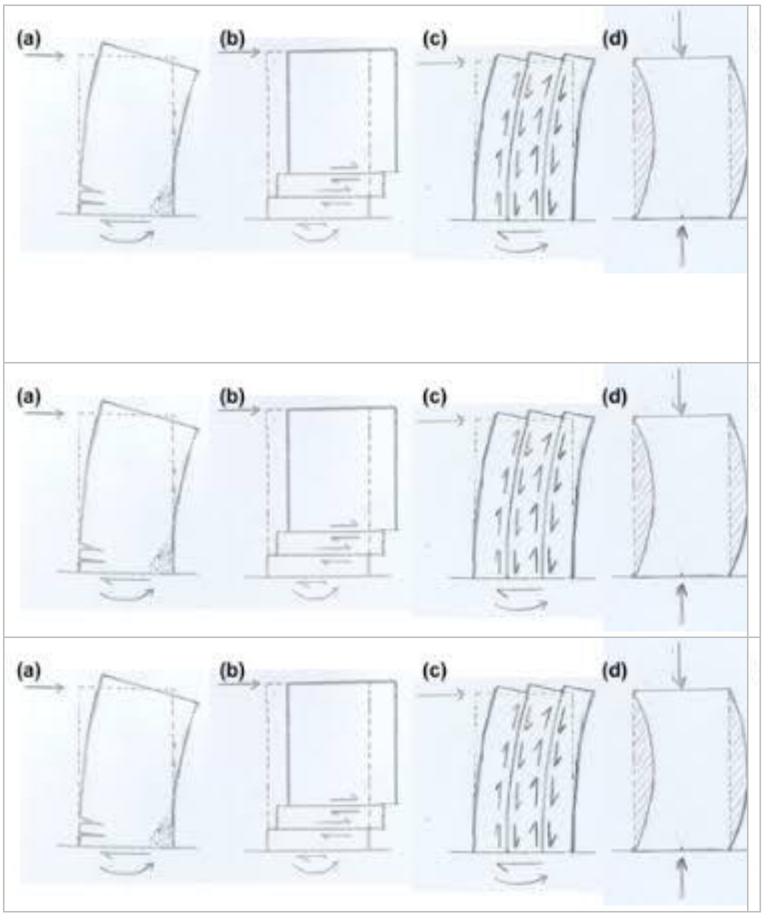


Fig 1: Types of loading

Horizontal loads as shown in figure 1.B include loading due to wind forces, earthquake forces and unexpected deflections. High rise buildings are susceptible to oscillations due to wind and thus must be investigated carefully for the sway behaviour by experiments such as wind tunnel test. This type of load increases proportionally with the height of the building as shown figure-2

The oscillations produced by wind can lead to a high lateral deflection along with lateral acceleration for the occupants, thereby creating discomfort. Earthquake loads as shown in figure-2 are originated 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 construction defect or uneven settling of foundation is also responsible for imparting lateral load on to the structure.

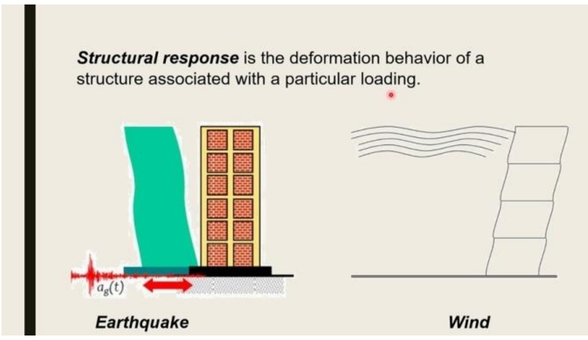


Fig 2: Earthquake Loading and Wind Loading

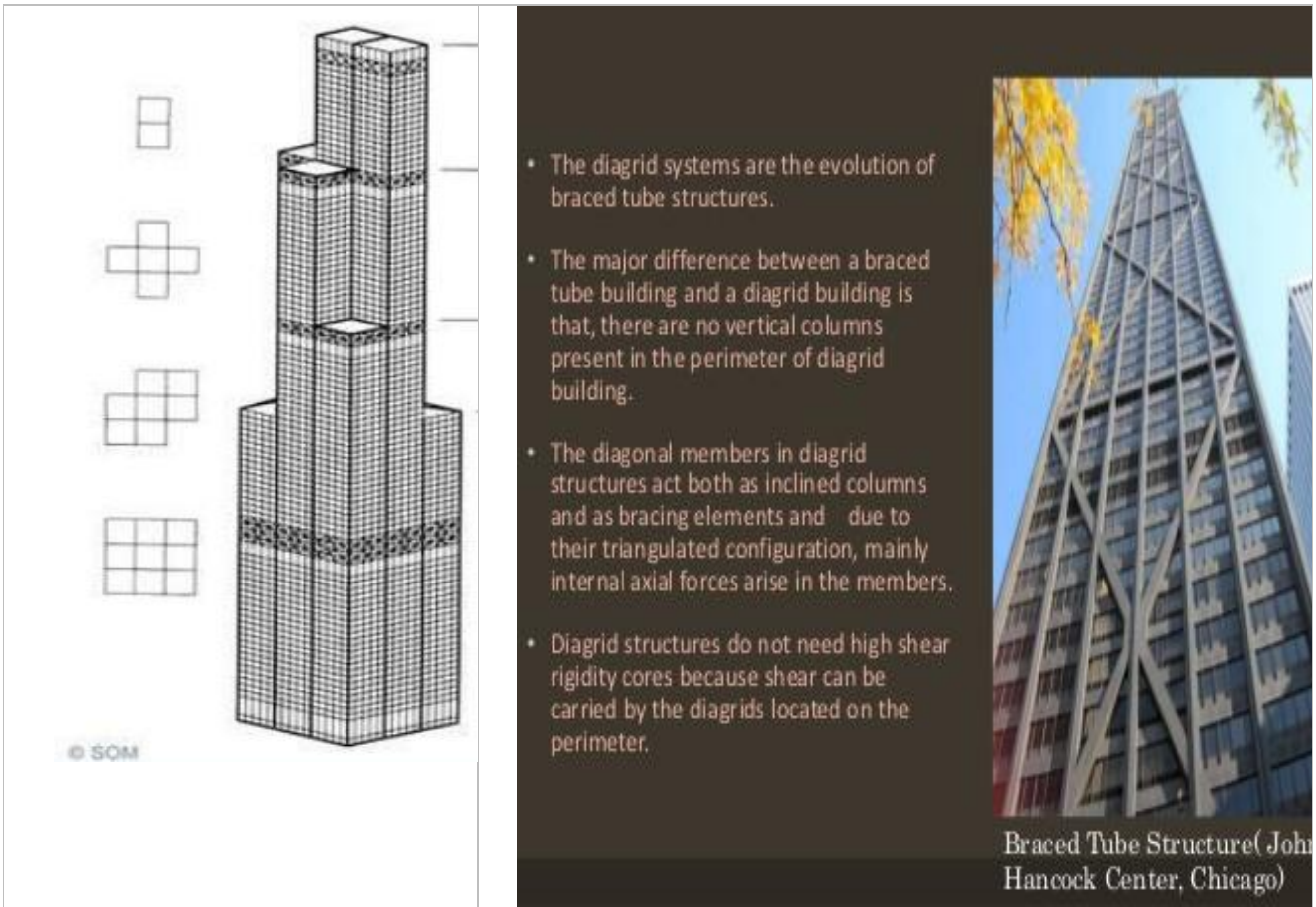
TYPES OF HIGH-RISESTRUCTURES

Frame tube structure

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

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 the replacement of closely spaced columns by diagonal truss members. The John Hancock Centre, Chicago is an example of 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

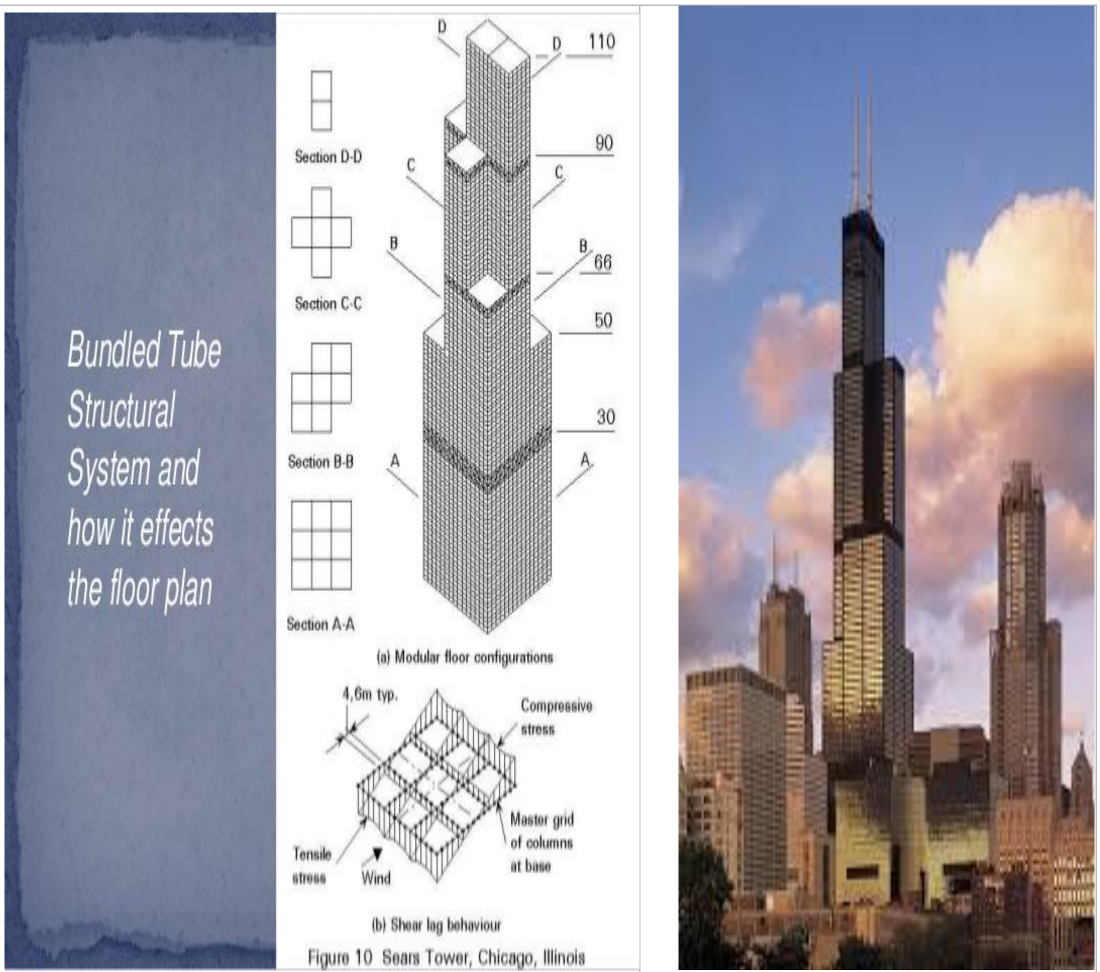
Fig 4: A

Bundled tube structure

Such structures are configured with multiple cells, and provide vertical offsets without much loss in efficiency. The principle behind the bundled tube concept is that the interior rows of columns and spandrels act as interior webs minimising 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 bundled tube structure.

Tube in tube structure

It is basically 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 tube in tube type of structure.



A - Bundled tube structure B-Tube in tube Structure

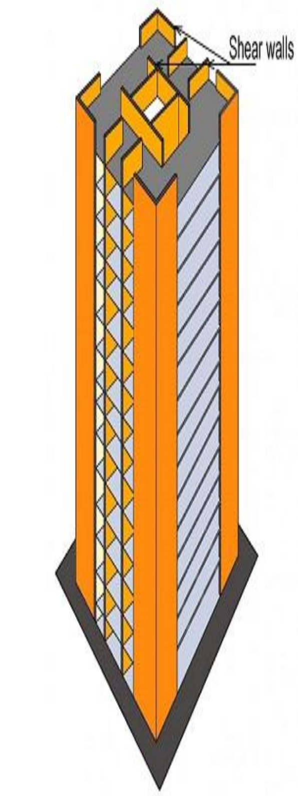
Fig 5: A- Sears Tower, Chicago, B- Tube in Tube Structure

Shear wall structure

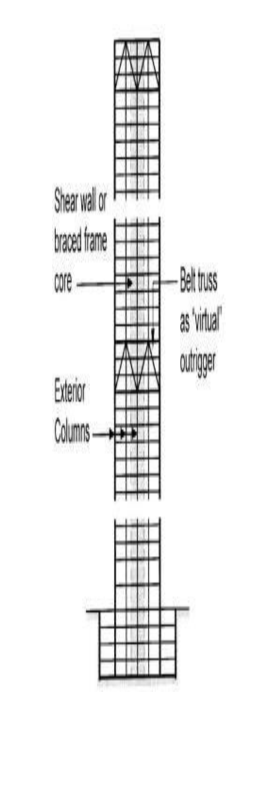
As the name suggests these structures comprise of shear walls. The vertical concrete shear walls may serve both as architectural partitions and structural components to carry the vertical and lateral loads. The use of shear walls is suitable for high rise buildings because of their high in-plane stiffness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

Outrigger braced structure

The central Core in such structures comprises of 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 there by decreasing the lateral deflection as well as 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

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. Skyline West coast building as shown in figure 7.A is situated in Vancouver is an example of suspended structure.

Space structure

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

	
A-Suspended structure	B-Space structure

Fig 7: A-Skyline West coast building, B- Bank of China, Hong Kon

Hybrid structure

Such structures are formed by the combination of 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:

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 limitation of use of building, discomfort to occupants, degradation in the aesthetics of the building 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 may also increase the height of individual storeys. Providing shear walls in such structures can prove to befruitful.

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. These horizontal or lateral loads most importantly 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 the intensity of lateral loading. 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 sway of the building 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 should be 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.

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 as short shear wall. When the above-mentioned ratio is greater than one but less than three, then it is termed as 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 shape of shear wall as seen in the plan of the structure, shear walls maybe categorised as plane, flanged, channel or core.

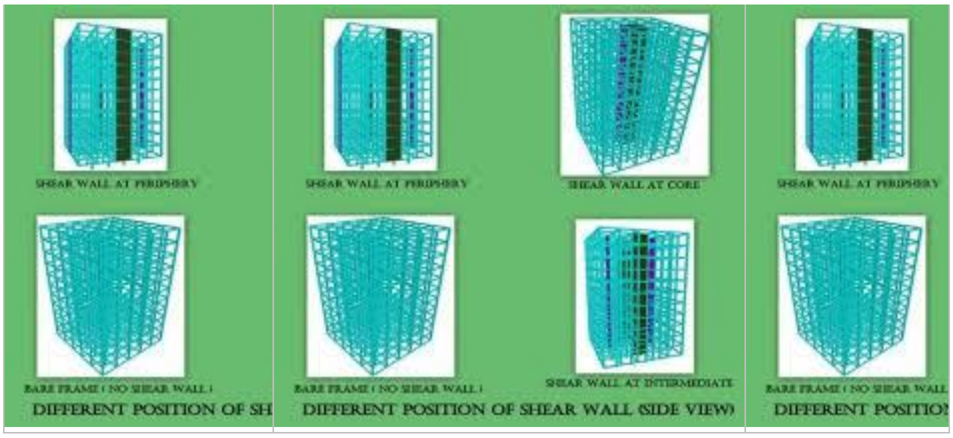


Fig 9: Shear wall configurations.

The plan position of shear wall may be termed as 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 of great importance 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.

LITERATURE REVIEW

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

IS 13290:2016 specified various provisions for the 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.

Kumbhare and Saoji(2012)

Analysed 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 levels of the building with the change in shear wall location. Placing shear wall away from centre of gravity resulted in increase in most of the members forces. It was concluded that shear walls should be coinciding with the centroid of the building.

Firozabad 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 configurations of shear wall behaved differently with up to 100% decrease in top story drift. They elaborated that maximum drift limitation of 0.004h as per IS- 1893-2016 was satisfied using ELCENTRO earthquake but not TABAS earthquake. A major conclusion from their study was that the quantity of shear wall cannot guarantee the seismic behaviour of the building.

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. Equivalent static method, response spectrum method and static pushover analysis was done to study the lateral displacement and storey drift of the various model. Their study concluded that the particular model showed best results when the shear walls were placed at the central core and exterior columns of the building plan. 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 corners of the building. They also concluded that response spectrum analysis produced more realistic results as compared to equivalent static analysis**.**

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 shear wall. The 25 storey building models have uniform and varying shear wall thickness at different storey levels. It was concluded that models with varying shear wall thickness offered lesser storey drift as compared to model with uniform shear wall thickness. Also, it was observed that very low storey drift ratio is found in the bottom storeys, very high in the middle storeys and finally decreases towards the top storeys.

Suresh and Yadav(2015)

Studied a G+20 RCC building for the optimum shear wall location under lateral loading. They analysed their structure for earthquake loads for area lying in zones II and V. They also studied the effect of lateral loading by wind. The irregular building model was analysed for building without 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 as compared to model with shear wall. They concluded that shear walls along four edges was found to be the most optimum location of shear wall**.**

CONCLUSIONS

From the above it is very clear that RCC 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 modeling and analysis with any soft-ware like E-Tabs we can optimize a shear wall system which can be the most economical system resist effectively the forces coming on it. It is also seen that boxed shear wall system is also efficient means for resisting torsions which is coming due to irregular building. Even multiple shear walls throughout 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 by means of 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 discrete level to external shear walls or column to achieve a similar and more pronounced effect than that noted in other system, thus the concrete shear wall becomes the centre component in a core and outrigged system also, which can used effectively using slip form or jump form technique dur to availability of high strength concrete as enabled the wall thickness to minimum and hence 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 much damping as structure steel. This is an advantage where acceleration serviceability is critical limit state or for ultimate limit state design in earthquake prone areas.

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