An Exploration of the Effect of Shear Walls in High-Rise Structures: A Review

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ABSTRACT

The provision of shear walls is crucial to the structural design of high-rise buildings subjected to seismic loading. Shear wall systems are the best solution for resisting lateral loads. Traditional reinforced concrete shear walls and steel plate shear walls are utilised around the world to withstand wind and seismic stresses. Composite construction methods have gained acceptance in the industry, and composite columns, beams, and slabs have lately begun to be used. The advantages of composite shear wall over reinforced concrete and steel shear walls have piqued the curiosity of researchers. Composite shear walls are a good method for earthquake resistant structures because they provide improved stiffness and ductility, reduced dead load and wall thickness, improved structural response, reduced cost and time of construction, and so on. This paper discusses the many methodologies used to investigate the seismic behavior of shear walls in multistory buildings. Researchers compared the performance of various types of composite shear walls to reinforced and steel plate shear walls. Experimental studies show that composite shear walls perform better under cyclic loading. The review finds that, while the majority of the literature is accessible on the seismic behaviour of shear walls, there is very little work on composite shear walls in high-rise buildings. According to the published research articles, the composite action is the key to the improved performance of composite shear walls. In terms of displacement, storey drift, storey shear, and other seismic parameters, this innovative technology outperforms conventional shear walls. Although it is established that there are various types of composite shear walls, the optimum solution for each seismic zone must be researched further. As a result, more study is required to quantify the design criteria and structural performance of the composite shear wall under seismic action. This highlights the need of researching composite shear walls using Indian design requirements in order to promote the use of such effective construction technology.

Keywords: *composite shear wall, seismic behavior, displacement, storey drift, storey shear.*

INTRODUCTION

Earthquakes are the most destructive natural hazards which causes damages to the manmade structures. Structural safety of building is the primary criteria that every designer considers during the design. Earthquake causes severe damages to the structures in terms of strength and stiffness. Shear walls are the most effective component used in multistory buildings to resist the lateral forces caused by earthquakes and wind. They are the structural vertical member that can resist shear, moment and axial load transferred to the wall from another structural member. Shear walls plays a key role in the energy dissipation, stiffness and seismic activity of tall buildings. Masonry buildings and multi storey buildings with RCC framed structure or steel structures were common in past years. Recently construction industry had shown interest towards composite structures.

Steel Concrete Composite construction has acquired acceptance worldwide as an alternative to RCC and steel construction. In composite construction technology, the composite action exhibit structural properties superior to individual material property. Steel-concrete composite beams, columns and slabs have been in

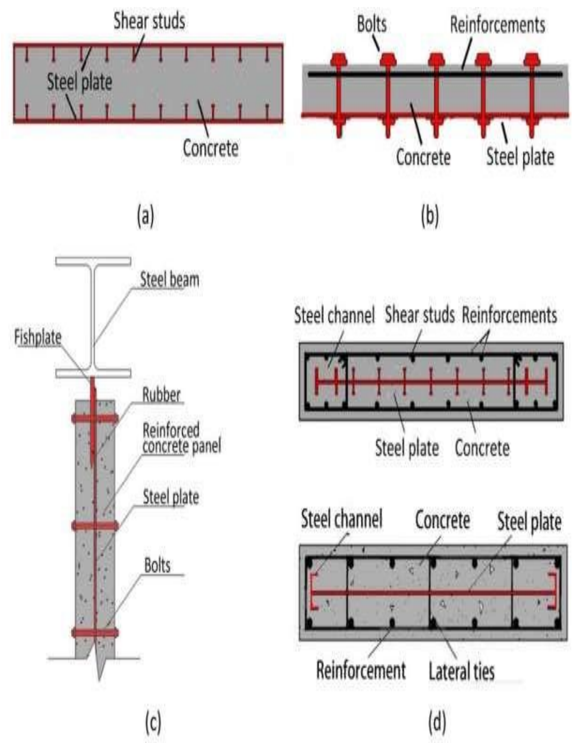

Figure 1: Different types of composite shear wall (a)double steel plate composite wall (b) single steel plate composite wall (c) infill plate shear wall (d)encased steel plate shear wall [16]

practice in many parts of the world. But very limited research works are carried out in composite shear walls.

WHY COMPOSITE SHEAR WALL

Reinforced concrete (RC) shear walls and steel plate shear walls are the common lateral load resisting system. Despite many economical and structural advantages, they have disadvantages also. Some of the severe problems noticed in RC shear wall is the development of tension cracks in the tension zones and compressive crushing in the wall corner and web areas during large cyclic loadings. There is reinforcement congestion localized at the end of the boundary element. In steel shear wall the buckling of the steel plate is visible and results in reduced shear capacity, stiffness, strength, and energy dissipation.

A better alternative to these problems is the use of composite steel concrete structural shear walls. Composite shear wall offers lateral stiffness, shear capacity, limit buckling and high bending resisting moment. For the same shear capacity, steel concrete composite shear wall will have less weight, larger shear stiffness and smaller cross section. Also, the steel plate used in composite structure acts as reinforcement and reduces dependence on conventional reinforcement and thus leads to considerable savings in construction time and cost.

TYPES OF COMPOSITE SHEAR WALL

The composite shear wall comprises of precast or cast in situ reinforced concrete wall, boundary beams and columns, one or two steel plates or steel tubes and mechanical shear studs or connectors. In composite wall, the steel plate is either attached on one or two sides of the precast or cast-in situ reinforced concrete wall or encased within the concrete. Composite shear wall can also construct as concrete infilled in steel tube. Shear connectors are welded to the steel plate in order to assure composite behavior. In figure 1, different types of composite shear walls are mentioned.

LITERATURE REVIEW

The term composite walling is introduced by H. D. Wright and S. C. Gallocher [1], which describes a vertical load- bearing system formed from two skins of light gauge profiled steel sheeting infilled with concrete that create composite section. The two stages of structural performance of the system have been studied in the work. The first is the construction stage during the erection, at which the profiled steel sheeting is first fixed to the steel frame and acts as a support for the wet concrete and gave temporary stability to the frame. The second is the service stage, during this stage when the concrete had hardened, the wall must take its final design load. A series of four tests was undertaken to investigate the behavior of the composite wall when subject to axial bending. In that 4 specimens 2 were short with length to thickness ratio is 12.7 and other 2 were slender with ratio 22.7.

The experimental study reported that as same as the composite slab performance, the proposed wall construction method is validated that it shows similar advantages over traditional construction. The model adopted by the author is in Figure 2. But the problem highlighted is that the value of ultimate resistance obtained from the experiment is less that the calculated value. It is also noted that structural response of composite walling is different from the conventional system under axial loads and moments. So when designing for axial resistance only concrete capacity may be considered for the walls with available decking. The construction stage of the walls showed an acceptable performance within the current CIRIA 11 recommendations.

Further, Amir Mirmiran and Mohsen Shahawy [2] reported the behavior of concrete columns confined by fibre composites. Florida Department of Transportation had sponsored study on the feasibility of hybrid FRP-concrete members. Both FRP-wrapped and FRP-encased columns are selected for the study. The uniaxial compression tests were performed for the experimental work in which a total of 30 cylindrical specimens were tested. It included six plain concrete and 24 concrete filled FRP tubes specimens. From the test results it is concluded that fibre composites increases strength and ductility of concrete by the effective confinement of concrete. It is also found out that dilation rate of concrete can be curtailed by FRP.

Then the lateral load resisting capacity of building with shear wall is demonstrated by P. P. Phadnis and Dr. D. K. Kulkarni.[3]. For the elastic time history analysis the author selected 5 models with shear walls at different positions and one with bare frame model, also in all the models infill brick wall is provided at the upper storey. Percentage of reinforcement in the column in bare frame is found to be more than with shear wall model. Fundamental natural period is decreased and lateral stiffness is increased for the models with shear wall. Lastly shear wall provided at all exterior corners shows better results.

However, the comparison between RCC building with and without shear wall was pointed out by P. V. Sumanth Chowdary and Senthil Pandian. M [4]. Finite element analysis is conducted on 4 different models of 8 storey building. 1st model was bare frame model. Core type at lift walls and rectangle type shear wall frame structure is other model. Next model is coupled type with openings and core type shear walls at lift walls. Last model is core type shear walls at the lift walls and four corners of framed type structure. When compared to other models it is understood that corner type shear wall shows less deflection. Core type shear wall

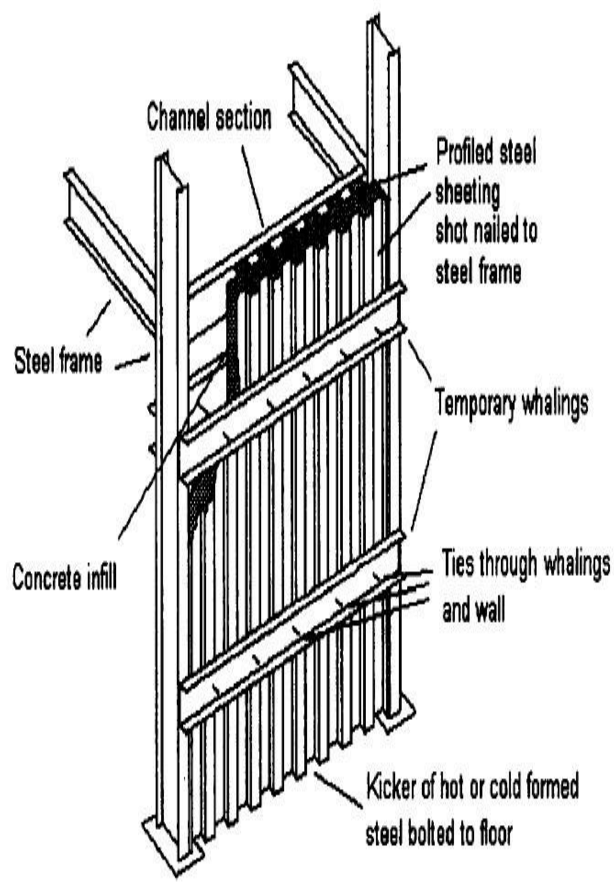

Figure 2: Diagram of composite wall adopted by H.D Wright

with shear at the corners is suitable for Zone IV and Zone V, Rectangle type is suitable for zone III and Coupled type shear wall with openings is allowable deflection in zone II.

Anamika Tedia and Dr. Savita Maru [5], further carried out the design and analysis of G+5 storey composite building consists of steel beam, steel encased column, profiled deck slab and foundation. In this study static and dynamic analysis is compared using STAAD PRO software and cost analysis is also done in comparison with RCC building. The direct cost of composite structure can be reduced by the faster erection process and that in turn make composite structure economical. The intrinsic ductile behaviour showed by the steel concrete composite structure during earthquakes enhances their seismic performance over RC structure.

The performance of composite shear wall (CSW) with L shaped folded steel plate at boundary element examined by S.Bahadir Yüksel and Alptug Ünal [6] experimentally. The elevation view of the test setup of composite shear wall with L shaped steel plate at boundary the region is shown in Fig:3. The specimen was tested under reversible repeatable loadings by means of a hydraulic cylinder loaded 500 KN compression, 500 KN tensile capacity in Selcuk University Earthquake Laboratory. The seismic behaviors of CSW test specimen were evaluated along with deformation and cracking patterns. From the test results, it was concluded that CSW displayed more ductile behaviour than reinforced shear walls. Loss of strength and adherence problem in reinforced concrete shear walls due to the concrete pouring at the intensive reinforcements present in shear wall boundary zones can overcome by this method of using steel plates. From the graphs its obtained that horizontal load bearing capacity of Composite shear wall reached a maximum when relative floor shift was about 1.5% and at 3% test was terminated. Strength, stiffness and energy consumption displayed similar behavior as RCC shear wall.

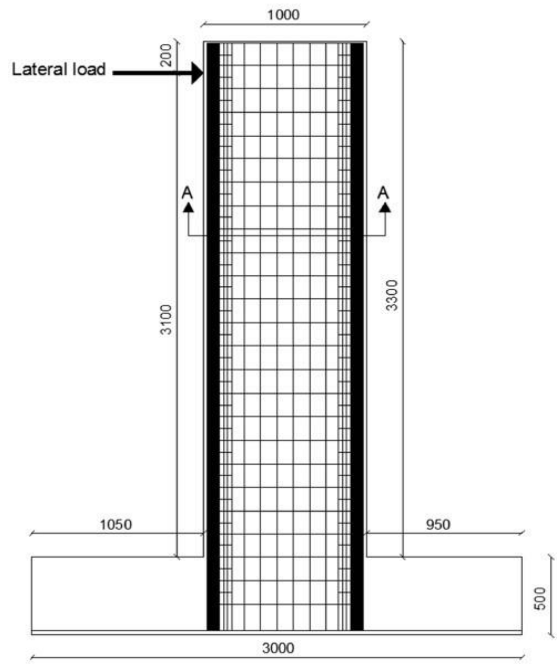

Figure :3 elevation view of the test setup of composite shear wall with L shaped steel plate at boundary the region. [6]

K. Sai Lakshmi *et al.*[7], proposed an experimental demonstration of the behaviour of composite shear wall system consisting of two skins of profiled steel sheeting and an infill light weight foam concrete core under in-plane monotonic shear loading. To generate composite action between steel sheet-concrete, mild steel intermediate fasteners are provided. To study the in-plane shear behaviour of CSW experimental studies were conducted under static loading. The result parameters on experimental investigations of composite shear wall panels are strength, stiffness, load deformation response, steel sheet concrete interaction, stress-strain characteristics and failure modes. The early elastic buckling of steel sheets and failure due to steel yielding can be prevented by the use of fasteners which are provided along the height and width of the specimen. Steel sheets with shear studs shows ductile behaviour after post peak with lateral deformation of the panel. Composite shear wall also showed higher shear resistance in static loading.

Later seismic damage caused in shear wall slab junction is taken into consideration by Snehal Kaushika and Kaustubh Dasgupta [8] with the help of ABACUS with different Peak Ground Acceleration values. Nonlinear Time history analysis is adopted for the analysis of three models such us one bay frame model, wall slab model, wall-sub assembly model. Reinforcement details are not considered in this research since seismic damage is governed by concrete behaviour. Concrete damaged Plasticity model is taken in software for the modelling. Based on the analytical study it is understood that the maximum stress concentration initially develops at the base of the shear wall and then propagates to the wall-slab junction. No significant damage was observed in sub assembly model due to the aspect ratio therefore squat wall behaviour was dominated. It is observed that from the damage caused at the slab junction a revised earthquake resistant design is required.

A review of seismic and wind analysis was performed by

A.A. Kale and S.A Rasal [9] in multistorey building. The concept of plan and vertical irregularities, regular and irregular configuration was taken into consideration. From the study it was concluded that wind effect is severe in 45 storey and seismic effect is severe in 30 and 15 storey buildings. Also it is interpreted that wind load is causes more impact than earthquake load for 30+ storey buildings.

Milan Sitapara *et al*. [10] carried out linear static pushover analysis for G+ 15 storey steel building with steel plate shear wall and composite shear wall. Composite shear wall (CSW) used in this study was with two 5 mm thick steel plate on both side of RCC core 70 mm thick wall and with shear connectors. The result parameters are studied for zone III and zone IV. After Analysis of building with Steel plate shear wall and CSW, result is studied in terms of Story Displacement, Story Lateral Force, Story Shear, Story Stiffness and Maximum Story Drift. Its observed that top displacement and maximum storey drift decreased in CSW in both the zones. Storey stiffness is maximum for CSW which indicate the decrease in displacement of the structure under lateral loading.

The analysis and design carried out by Anjana R K Unnithan and Dr. S Karthiyaiani [11] was for steel plate shear wall (SPSW) in G+ 9 storey building in seismic zone

I. The model selected is with Shear wall located at core and centrally at the four sides. Response spectrum analysis with ETABS is used for the study. Displacement, storey drift, storey shear, overturning moment is analyzed for 8,16,24,32,40,48,56,64,72,80 mm thick steel plate shear wall. From the results obtained its understood that displacement decreases with increase in thickness. Minimum displacement is for 80 mm thick SPSW. Storey overturning moment decrease with increase in thickness. Storey drift varies differently with thickness.

Further, Deepna u *et al* [12] analyzed the effect of various thickness of RCC shear wall, steel plate shear wall and steel plate infill composite shear wall on G+ 20 storey building and compared the base shear and storey drift using ETABS. From the study it was observed that when thickness of steel plate is reduced, storey drift of building with RCC shear wall and Composite shear wall decreases. Base shear value also influenced by thickness. Least base shear is observed in RCC and maximum is in building with steel plate shear wall.

Reslan N, Masri A and Machaka M [13] attempted analytically the efficiency of composite shear wall in multistorey building. This study highlighted the structural characteristics of the Composite shear wall and its

performance is compared with Reinforced concrete shear wall.The Composite wall model consist of panel with two steel horizontal and vertical boundary elements each with central steel plate encased within concrete layer on both sides . Shear wall in 8, 14,20 storey buildings are analysed by equivalent static analysis, time history and response spectrum method. From the analysis it is observed that significant reduction in storey shear for 20 storey and 8 storey building. Inelastic drifts in the RC shear walls building was less than building with composite shear wall. The stiffness of the building with Composite shear wall is higher due to the rigidity of steel plates (EI). Composite shear walls show higher ductility and energy dissipation.

In the Beijing Key Laboratory of Engineering Anti- earthquake and Structural Diagnosis of the Beijing University of Technology Zhihua Chen *et al*. [14] conducted low-cycle reciprocal loading tests on steel plate concrete shear wall (SPSW) to understand the effect of different size of holes in SPSW. From the study it is also tried to figure out the mode of failure, influence of axial compression ratio and effect of thickness of steel plate. A comparative study of both theoretical and experimental value was carried out in which the norms of the Architecture Institute of Japan and the calculation method of Ono reduction rate is adopted for numerical study. The model adopted was the SPSW was in accordance with the shear walls in Nuclear power plants. In SPSW structures with and without holes develop failures at the roots of shear walls. But SPSW with small holes developed steel plates crack along the corners of the holes. Structures with large holes develop significant deformation and better ductility than SPSW structures with small holes but at low ultimate loads. Even though increase in hole size decreases the bearing capacity, its deformation capacity is enhanced. Whereas increase in thickness of steel plate increases the ultimate bearing capacity. Holes at eccentric position decrease the energy-dissipation capacity which is not preferred in seismic design. It is concluded that the calculation formulas, AIJ codes and Ono formula are suitable for the calculation of ultimate shear capacity of steel plate concrete shear wall with holes.

In Ansys Workbench Praseedha R and Bhavya C**.**[15] numerically studied the seismic behaviour and lateral resistance of steel plate concrete composite shear wall (SPCCSW) using pushover analysis. The model used were infill concrete with steel plates on both sides with variations in aspect ratios, shape and number of shear studs and stiffeners. From the results its observed that aspect ratio influences the performance of shear wall. Shear wall with aspect ratio1 shows good lateral resistance. Even though shape of shear studs does not cause much variation in load carrying capacity, circular shear stud is slightly superior to other rectangular, L shaped and square shaped studs. Providing diagonal stiffeners improves the seismic behaviour and reduces the buckling of steel plates. The Diagonal arrangement of stiffeners in Ansys workbench is as in Figure: 4

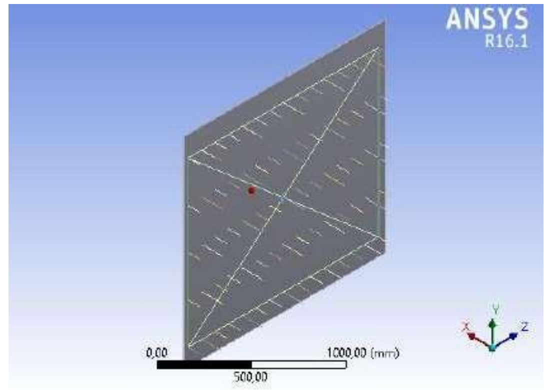

Figure:4: Diagonal arrangement of stiffeners in SPCCSW [15]

Recently Vineeth Vijayan *et al***.**[16] analyzed different types of lift shear wall in high rise buildings by response spectrum method. Analytical study of G+20 & G+21 & G +51 building is modelled with irregular plan using ETABS software. Out of the 4 models selected, three are conventional concrete shear wall ,steel plate shear wall and silica fume concrete shear wall. The composite shear wall is the steel plate silica fume concrete shear wall. From the study it is evaluated that there is considerable reduction in storey shear which result in the reduction of the demand for bending and shear in the composite shear wall. There is also reduction in storey drift was noticed. It is also found out that silica fume concrete is effective in reducing displacement. More than half percentage of displacement is reduced in composite shear wall thus it confirms the use of composite shear wall is effective in resisting seismic effect in building.

Sanjivan Mahadik *et al*. [17] examined the behaviour steel fibre reinforced concrete shear wall (SFRC) under later loading. Authors used ETABS software to model concrete shear wall with and without opening and steel fibre reinforced concrete shear wall with same specification as the selected conventional model. From the analytical study it is found out that there is an increase in load carrying capacity considering strength criteria by 2.45% for SFRC shear wall and 1.8% increase for SFRC shear wall with opening.

Load carrying capacity of shear wall decreased by 56.6% due to the presence of 16% central opening. Considering stiffness criteria, the load carrying capacity of SFRC shear wall increase by 10% and 9.4% increase for SFRC shear wall with opening.

Study of composite shear wall in comparison with steel plate shear wall and conventional shear wall for G+20 storey building was done by Mahammadasfak Memon and Ashutosh Patel [18].As per the Response spectrum, it was found out that composite shear wall gives better results in terms of resistance and ductility when compared to RCC shear wall. From the results its obtained that displacement in Composite shear wall is less as compared to conventional shear wall.

National Key Research Program of China and the Key Research Program of China Railway Corp financially funded for the experimental program conducted by Xin Nie *et al.* [19]. The model proposed was four reinforced concrete shear wall under tension bending test after analyzing the various data acquired from the earthquake occurred in 2010 chile. This study focused to obtain a new experimental program for getting shear resistance of transverse reinforcement. A new data base was established in order to get a simplified design formula for safety against earthquake loading. From the experimental results its observed that inclined crack and direct strut action is the mode of failure in each specimen. The increase in axial load causes degradation of shear strength and increase in drift ratio.

Hurmet Kucukgoncu and Fatih Altun.[20] experimentally demonstrated the performance of external RC shear wall for strengthening frames. The one bay one storey intact and damaged RC frame models were selected which consist of external shear wall with steel tie and beam were subjected to reverse cyclic loading. At the end of the tests it was found out that strength, stiffness and displacement capacity of shear wall in intact frame was more than damaged frame whereas ductility and energy dissipation properties are more in shear wall in damaged frame. It is very well understood from the experimental results that the response of the strengthening shear wall is influenced by the behaviour of connecting frames.

CONCLUSION

This paper gives an overview on the seismic behavior of high rise building with shear walls. Based on the literature pertaining to the different researchers had studied different type of problems related to conventional shear wall system, the broad conclusions are given below:

- Researchers mainly focused on the performance of different types of composite shear wall in comparison with reinforced and steel plate shear wall.
- Composite shear walls are prominent and an effective method to resist lateral earthquake load.
- Composite shear wall system is advantageous over conventional RC and steel shear wall in terms of ductility, stiffness, shear resistance, energy dissipation and overall seismic performance of the building.
- Experimental investigations give the better response of composite shear wall under cyclic loading.

All the same, it can be concluded that the composite action is the key behind the better performance of composite shear wall. Although remarkable progress has been observed in this field, there is still substantial scope for future research, such as the effect of these composite sections in the boundary column beam junctions, there performance in skyscrapers, the behaviour of different type and shape of structural steel using in composite construction also the use of high performance light weight concrete. Also there is no exact Indian code provision for this effective composite shear wall system which is necessary for the better utilization of composite shear wall in large scale.

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