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Advances in Composite Walling and Shear Wall Design for Seismic Resilience in High-Rise Buildings: A Comprehensive Review

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Abstract: This collection of research papers presents a comprehensive study of various aspects related to composite walling and shear walls in high-rise buildings. The papers focus on investigating the behavior, performance, and advantages of different types of shear walls under lateral loads and seismic events. The set of technical papers explores the concept of composite walling, which involves a load-bearing system formed by two skins of light gauge profiled steel sheeting infilled with concrete. The studies investigate the two stages of structural performance, construction stage and service stage. Tests are conducted to examine the composite wall's behavior under axial bending, highlighting its advantages over traditional construction methods. Additionally, the use of steel-concrete composite structures is shown to enhance seismic performance and reduce construction costs. Further, research delves into the behavior of concrete columns confined by fiber composites, the lateral load resistance of buildings with shear walls, and the seismic response of steel-concrete composite shear walls. These studies demonstrate that the use of fiber composites increases the strength and ductility of concrete, while shear walls provide effective resistance to lateral forces and reduce seismic damage. The importance of shear walls in high-rise irregular buildings is explored, and various types of shear walls, including steel plate shear walls, are compared in terms of their seismic performance. The results reveal that composite shear walls exhibit higher ductility and energy dissipation, making them an effective option for resisting seismic effects in buildings. Additional investigations focus on the influence of parameters such as aspect ratio, shape, thickness, and presence of openings on the behavior of shear walls. Studies reveal that increasing the thickness of steel plates improves the ultimate bearing capacity and that the presence of holes can enhance deformation capacity. Composite shear walls with external stiffeners are found to offer better seismic behavior, reducing buckling and improving overall lateral resistance. The research papers collectively emphasize the significance of shear walls and composite walling systems in enhancing the seismic performance and overall structural integrity of high-rise buildings. The findings contribute valuable insights into optimizing design approaches for safer and more resilient structures in seismic-prone regions.

Keywords: *composite shear walls, fibre composites, multi-storey building, Storey drift.*

INTRODUCTION:

Composite shear walls have gained significant attention in the field of building structures due to their enhanced performance in terms of strength, stiffness, and energy dissipation compared to conventional shear wall systems. This review paper aims to provide a comprehensive overview of the design, analysis, and performance of composite shear walls in building structures. The paper discusses various aspects of composite shear walls, including their construction methods, structural behavior, experimental investigations, and analytical modeling techniques. It also highlights the advantages, challenges, and applications of composite shear walls in different seismic zones. The review encompasses both experimental and numerical studies conducted by researchers worldwide, providing valuable insights into the behavior and performance of composite shear walls under various loading conditions. Additionally, the paper explores recent advancements in composite shear wall technologies, such as the use of steel plate-concrete combinations, fiber-reinforced polymers, and innovative connection details. The findings from this review contribute to a better understanding of the design and performance aspects of composite shear walls, facilitating their effective utilization in building structures for enhanced seismic resistance.

Composite shear walls, consisting of two skins of light gauge profiled steel sheeting infilled with concrete, have emerged as a promising structural system for building structures. The combination of steel and concrete in composite shear walls offers advantages such as increased strength, stiffness, energy dissipation, and enhanced seismic resistance. This review paper aims to consolidate the existing knowledge on composite shear walls, covering various aspects related to their design, analysis, and performance. By analyzing the findings from experimental studies, numerical simulations, and case studies, this paper provides a comprehensive understanding of the behavior and effectiveness of composite shear walls in different structural configurations.

REVIEW OF LITERATURE:

The term composite walling is introduced by H. D. Wright *et al* [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 four specimens, two were short with length to thickness ratio is 12.7 and other two 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 3. 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.

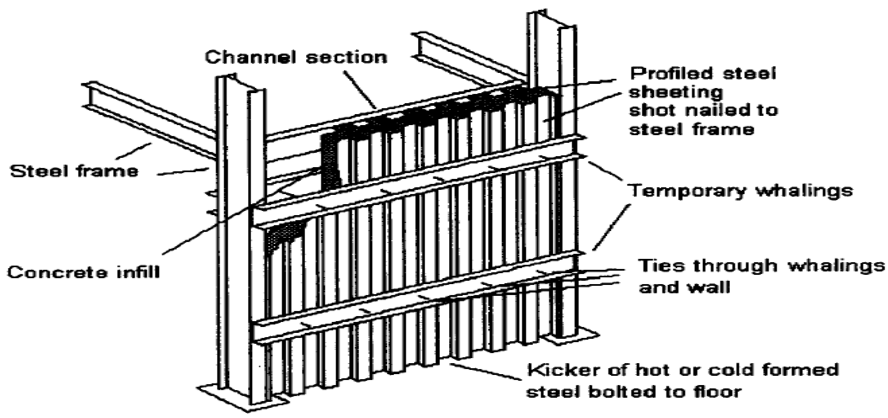

Fig 3: Diagram of composite wall adopted by H.D Wright *et al.* [1]

Further, Amir Mirmiran and Mohsen [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 *et al.* [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 *et al* [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 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 *et al* [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.

Significance of Shear Wall in Highrise Irregular Buildings is examined by Ravikanth Chittiprolu and Ramancharla Pradeep Kumar [6] by response spectrum analysis in ETABS software. An irregular model of G+15 storey is selected with and without RCC shear wall. Drift and lateral forces on the model is taken for study in which lateral forces reduces in model with shear wall and drift also. The torsion in buildings can be reduced by shear wall system.

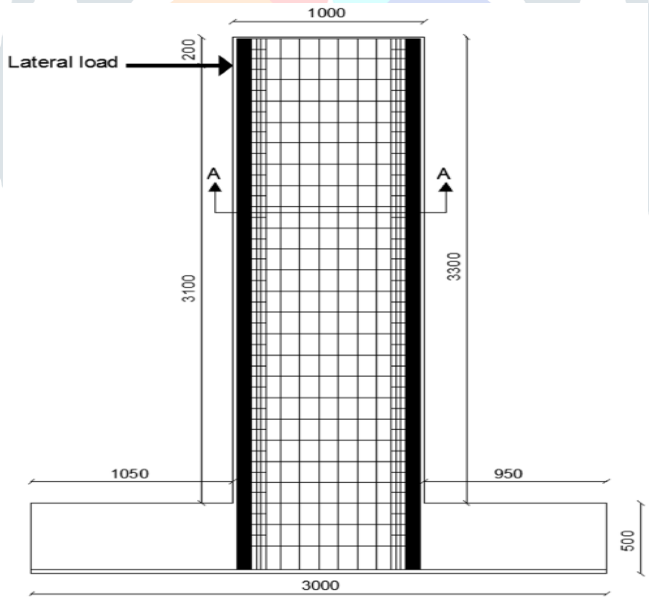

Fig 5: elevation view of the test setup of composite shear wall with L shaped steel plate at boundary the region.[7]

S.Bahadir Yuksel and Alptug Unall [7] experimentally investigated the Composite Shear Walls Having L Shape Steel Sections in Boundary Regions. The elevation view of the test setup of composite shear wall with L shaped steel plate at boundary the region is shown in Fig:5. 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.

K. Sai Lakshmi *et al.* [8] 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 *et al*. [9] 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 maximum stress concentration initially develops at the base of the shear wall and then propagates to the wall-slab junction the. 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 *et al* [10] 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*. [11] 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 *et al* [12] for steel plate shear wall (SPSW) in G+ 9 storey building in seismic zone III. 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* [13] 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 [14] 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.

To understand the seismic response of steel plate reinforced composite shear walls (SPRW) such as ductility, load carrying capacity, failure mechanism, and energy dissipation experimental study was conducted by Wei Wanga *et al* [15]. The test set up include 16 SPRW specimens and 3 traditional RCC shear wall were constructed and performed cyclic quasi-static test at the State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji University. Mode of failure in the specimens where bending failure, bending and shear failure and foundation anchorage failure. From the test results it is inferred that the load carrying capacity and displacement is increased by more than 100%. Also, there is increase ductility index and equivalent viscous damping coefficient. wall and steel plate thickness influence the overall load bearing capacity. Also shear studs are more effective than lateral ties.

Different shapes of shear wall in High rise symmetrical building is an interested research area, which was carried out by Rajesh G. Patel and Bhavin S. Bhagat [16]. z, u, and T shaped flanged shear walls in 15,20,30 storey building is analysed using response spectrum analysis in ETABS software. Authors concluded that the shape of shear wall have influence on the time period, that is T & Z shape shear wall buildings have higher time period. displacement and drift values are better in U and I shaped shear wall buildings. But in case of storey shear T shear wall building shows good performance.

In the Beijing Key Laboratory of Engineering Anti-earthquake and Structural Diagnosis of the Beijing University of Technology Zhihua Chen *et al*. [17] 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 *et al.* [18] numerically studied the seismic behaviour and lateral resistance of steel plate concrete composite shear wall (SPCCSW) using pushover analysis. The model used were incased 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 Fig: 6

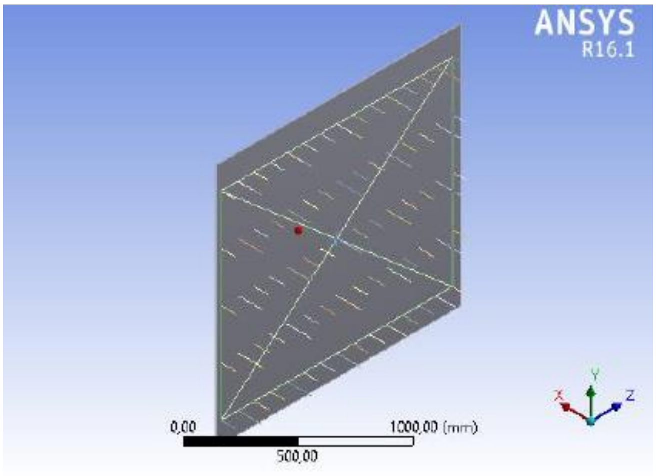

Fig 6: Diagonal arrangement of stiffeners in SPCCSW [18]

Recently Vineeth Vijayan *et al.* [19] 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, Pravin Gunawareand S.R. Bhagat [20] 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 *et al*. [21].As per the Response spectrum, it is found out that composite shear wall gives better results in terms of resistance and ductility when compared to RCC shear wall. From the results it 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.* [22]. The model proposed was four reinforced concrete shear walls under tension bending test after analysing 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 *et al.* [23] 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 is found out that strength, stiffness and displacement capacity of shear wall in intact frame is more that 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.

In order to understand the seismic performance of shear wall at the bottom of shear wall of high-rise building Xin Nie et al. [24] experimentally studied the four RCC Shear Walls under tension-bending Shear-Combined Cyclic Load. Direct strut action and inclined cracks are observed which indicate the shear compression failure. Increase in axial tension loading increases drift ratio and decreases shear capacity. Also, a simplified design formula was proposed in the research work.

Recently V. B. Dawari *et al* [25] took the composite shear wall with encased steel profiles for the study were RCC with I-sections and hollow box steel sections at different locations is selected. Also, author compared composite shear wall with RCC shear wall. Design details of composite shear wall is done using EURO codes. Ductility of the specimens are analysed using ductility coefficient which is the ratio between horizontal displacement and lateral displacement at yield. From the research it is observed increase in ductility and margin of safety against collapse. This system exhibits higher stiffness and less probability toward damage for midrise building. The response of coupled shear wall is explained I terms of degree of coupling (DC). The depth of coupling beam is slightly greater than RCC shear wall. Composite shear wall showed improvement in terms of stiffness and displacement.

Also, composite shear wall with L shaped elements with double skin type was proposed and studied by Wenhui He *et al.* [26]. Two specimens for experimental setup where of different width and same thickness and same height. From the results it was observed that hysteresis curve of the specimens was plump. The shear span ratio had impact over the peak load. Energy absorption was more for shear wall with wide span. It was concluded that overall seismic performance was satisfactory in terms of energy dissipation, deformation and ductility.

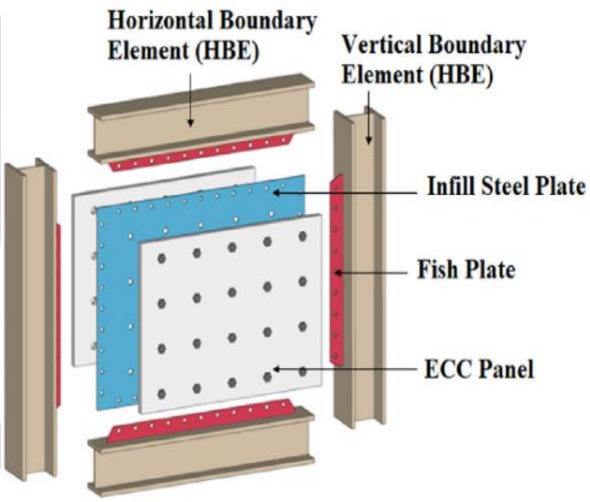

Fig 7: CSPSW restrained by ECC panels [27]

Xiao Yang *et al.* [27] introduced a high ductile engineered cementitious composites (ECC) as an alternative to concrete in ordinary composite shear walls panels as cover panels. Increase in stiffness and shear capacity is observed in this model. With Non-linear finite element analysis in Abacus, mechanical properties of the steel plate shear wall, composite steel plate shear wall and shear wall with ECC panel is studied. Parametric analysis was also included in the work. Fig. 7 shows the composite shear wall with ECC panel. Thickness & number of ECC panel increases the shear capacity was observed after analysis. the damage on cover panels and also steel plate damage can be reduced by this novel system. ECC panel offers better retrains over steel plate and through bolts partial shear loads can be transferred more efficiently than ordinary systems. The gap between the panel should be provided properly otherwise buckling near bolt area is observed. This system is more effective in shear wall with high slenderness ratio.

Further, Athira Haridas and S. A. Rasal [28, 29, 30] presented that; Shear walls provide lateral load resistance against seismic loading. Researchers mainly focused on the performance of composite shear wall in comparison with reinforced and steel plate shear wall. Introducing Composite construction technology in shear wall can improves overall seismic performance of the structure. The tension cracks, buckling in steel, reinforcement congestion, increased thickness of shear walls can be reduced. Composite shear wall system is advantageous over conventional RC and steel shear wall in terms of ductility, stiffness, shear resistance, energy dissipation, displacement and overall seismic performance of the building.

Experimental investigations give the better response of composite shear wall under cyclic loading. Reduction in dead load and reduction in storey shear, reduced cost and time of construction are other notable points in composite technology. High ductility of steel leads to better seismic resistance of the composite section. Steel component can be deformed in a ductile manner without premature failure and can withstand numerous loading cycles before fracture. Buckling in steel plate can be retrained by the adjacent concrete panels and steel plates enhance the compressive strength of the concrete by restraining lateral deformation in concrete Composite action is the key behind the better performance of composite shear wall. Cost of formwork is lower compared to RCC construction in case of concrete infill or box type composite wall.

SUMMARY:

The collection of research papers discussed various aspects related to composite walling and shear walls in high-rise buildings. The studies focused on understanding the behavior, performance, and advantages of different types of shear walls under lateral loads and seismic events. The research on composite walling highlighted the benefits of using a load-bearing system formed by two skins of light gauge profiled steel sheeting infilled with concrete. The construction and service stages of composite walls were investigated, showing promising results in terms of structural stability and cost-effectiveness compared to traditional construction methods. Additionally, steel-concrete composite structures demonstrated improved seismic performance and ductility during earthquakes.

Further studies examined the behavior of concrete columns confined by fiber composites and the lateral load resistance of buildings with shear walls. It was found that fiber composites increase the strength and ductility of concrete, while shear walls effectively resist lateral forces and reduce seismic damage. The presence of shear walls at critical locations in buildings led to enhanced stiffness and reduced drift, indicating their importance in seismic design. Comparisons between different types of shear walls, including steel plate shear walls and composite shear walls, were made to understand their seismic response. Composite shear walls exhibited higher ductility and energy dissipation, making them effective for resisting seismic effects in high-rise buildings.

Researchers also investigated the influence of various parameters on the behavior of shear walls, such as aspect ratio, shape, thickness, and presence of openings. The findings suggested that increasing the thickness of steel plates improved the ultimate bearing capacity, and the presence of holes enhanced the deformation capacity. External stiffeners were found to improve the seismic behavior of shear walls, reducing buckling and improving lateral resistance. It has been observed that;

CONCLUSION:

The research papers collectively underscore the significance of shear walls and composite walling systems in enhancing the seismic performance and overall structural integrity of high-rise buildings. Composite walling, with its efficient construction process and seismic advantages, offers a promising alternative to conventional methods. Steel-concrete composite structures exhibit improved strength and ductility, making them favorable for seismic design.

The studies on various types of shear walls provided valuable insights into optimizing design approaches for safer and more resilient structures in seismic-prone regions. Composite shear walls demonstrated superior ductility and energy dissipation, making them an attractive choice for high-rise buildings subjected to seismic forces.

The research also emphasized the importance of considering parameters like thickness, shape, and presence of openings while designing shear walls. Optimal combinations of these parameters can significantly influence the lateral resistance and deformation capacity of shear walls.

In conclusion, the findings from these research papers contribute to advancing the understanding of composite walling and shear wall behavior. The knowledge gained can guide engineers and architects in developing more robust and earthquake-resistant high-rise buildings, ultimately improving the safety and performance of structures in seismic regions.

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