Seismic Behaviour of High Rise Building with Composite Shear Wall

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***Abstract*—Steel concrete composite structures which are formed by combining steel and concrete elements, performs superior structural properties than that of individual members could achieve. This technology is efficiently exploited in seismic engineering. Shear walls, the most appropriate lateral load resisting systems when utilising the structural properties of composite technology can result in excellent seismic resistant structures. Different types of composite shear walls such as double skin composite shear wall, steel plate encased type, steel plate encased with I section and shear walls with I sections are analysed in this research by response spectrum analysis and compared with RCC shear walls. The responses of the structures in terms of displacement, storey drift and storey stiffness are taken into consideration.**

***Index Terms*—composite shear walls, storey drift, storey stiffness, response spectrum analysis.**

1. INTRODUCTION

Earthquakes cause strong sudden ground motions which results in the ultimate or partial collapse of the structures and causes severe life threats also. Shear walls, the effective lateral load resisting system against earthquake and wind load reduces the severe damages caused to the structure in terms of stiffness, energy absorption capacity and ductility. Shear walls improves the shear capacity of the structure and resist uplift force and overturning. Reinforced cement concrete shear walls and steel plate shear walls are the conventional systems in practice. Apart from the advantages, these two lateral loads resisting systems possess many disadvantages also when they are subjected to strong cyclic loadings. Buckling of steel, development of tension cracks, corner crushing and reinforcement congestions are some of the major drawbacks associated with the conventional shear wall systems.Then there comes the second thought of overcoming these disadvantages and leads to an efficient system that is the Composite Shear Wall technology.

When two or more structural load-carrying members that are integrally connected and act as a single unit are referred as composite construction.The combination of steel& concrete elements or any other elements which utilizes the unique properties of both forms the composite system. Superior structural properties of composite structures are by the composite action takes place in the system.

In this research, steel concrete composite technology is taken into consideration. Concrete and steel which are the two widely used construction materials, in which steel sections are resistant to tensile loading also they are ductile in nature but are prone to buckling, whereas concrete is safe in compression and provide corrosion resistance and thermal insulation. So, when these two materials are structurally joined together by shear studs or shear connectors, their strengths can be exploited superiorly which result in a highly efficient and lightweight design.Composite construction ensures greater economy and strength parameters than either material alone could achieve. The other structural members such as composite columns, beams and slabs are already in practice whereas composite shear wall studies are started recently over past 15-20years and also their practical applications are still in the beginning stage.

The term composite walling is introduced by H. D. Wright *et al* [1] in 1990's.Loss of strength and adherence problem in boundary zone in reinforced concrete shear walls can overcome by the steel plates in composite walls and also they show more ductile behaviour than reinforced shear walls (S.Bahadir Yüksel and Alptug Ünall [2]). Steel sheets with shear studs shows ductile behaviour in double skin composite shear wall and showed higher shear resistance in static loading (K. Sai Lakshmi *et al*. [3]).The seismic and wind analysis in multistorey buildings can be understood from the review performed by A.A. Kale and S.A Rasal[4].Also, Steel plate silica fume concrete composite shear wall can reduce the displacement (Vineeth Vijayan *et al.* [5]). Steel plate thickness in composite shear walls influences the overall load bearing capacity and shear studs are more effective than lateral ties which was experimentally demonstrated by Wei Wanga*et al*. [6]. V. B. Dawari *et al*. [7] 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 was selected. Composite shear wall with L shaped elements with double skin type by Wenhui He *et al.* [8] experimentally concluded that the overall seismic performance was satisfactory in terms of energy dissipation, deformation and ductility. Increase in stiffness and shear capacity is observed in a new composite shear wall were a high ductile engineered cementitious composites (ECC) is used as an alternative to ordinary concrete panels (Xiao Yang *et al.*[9]). The review of composite shear walls in high rise buildings by Athira Haridas and S.A Rasal gives a clear understanding on different types of composite shear walls and its advantages.

In view of the literature survey conducted, it is necessary to study the seismic performance of different types of composite shear walls in high rise buildings and alsothe effect of change in thickness of shear walls. This is an important area which has to be taken for detailed research because if the utilisation of composite technology can reduce the size ofthe members without compromising the structural strength then it will be very much advantageous in highly populated area like Mumbai as the limitation of land area leads to the construction of high-rise buildings a necessity. Thus, seismic resistance and structural safety is the prime important criteria in such buildings along with sufficient utility area. So, this research aimed to give a new insight to these problems with the help of composite shear walls.

2. OBJECTIVE

- Objective of the present research is to study the response of different type of composite shear walls (CSW) such as Double skin composite shear wall (DS CSW), Steel plate encased composite shear walls (SE CSW), Steel plate encased composite shear walls with I section at boundary element (SEI CSW), Shear wall with I section at boundary element (I Sec CSW) in 20 storey model.
- Responses of the CSW's are taken in terms of displacement, storey drift and storey stiffness which are compared with the RCC shear wall models.
- All the models are modelled for 300 mm and 200 mm thickness shear walls

3. MODELLING DETAILS

A. Structural Modelling

For the analysis 20 storeyed RCC framed buildings of H shaped plan in which shear walls are at the core area / lift area and at the corners are modelled by ETABS 2017 software. The modelling details of the building asin table 1.

Table 1: Structural Modelling Details

Input Data	Details
Plan area	37 x 31.5 m
Shape of building	H shape
No of storey's	G+20
Storey height	3m
Column size & grade	300X 900; M50 (15th floor) & M40(16th floor and above)
Beam size & grade	300 x 750 mm M40
Slab thickness & grade	150 mm; M40
Shear wall thickness & grade	300 mm & 200 mm M50 (15th floor) & M40 from 16th floor and above
Software	ETABS 2017

Table II shows the loading pattern adopted in this study were the results are analysed by response spectrum analysis.

TableII: Loading Pattern

Item	load	Load cases
Dead load	Software generated	Linear static
Live load	3 Kn/m^2	Linear static
Floor finish	1 Kn/ m^2	Linear static
Roof load	1.5 Kn/ m^2	Linear static
Wall load (AAC Block)	2.16 Kn/m	Linear static
EQX & EQY	Software generated	Linear static
RSX & RSY	Software generated	Response spectrum

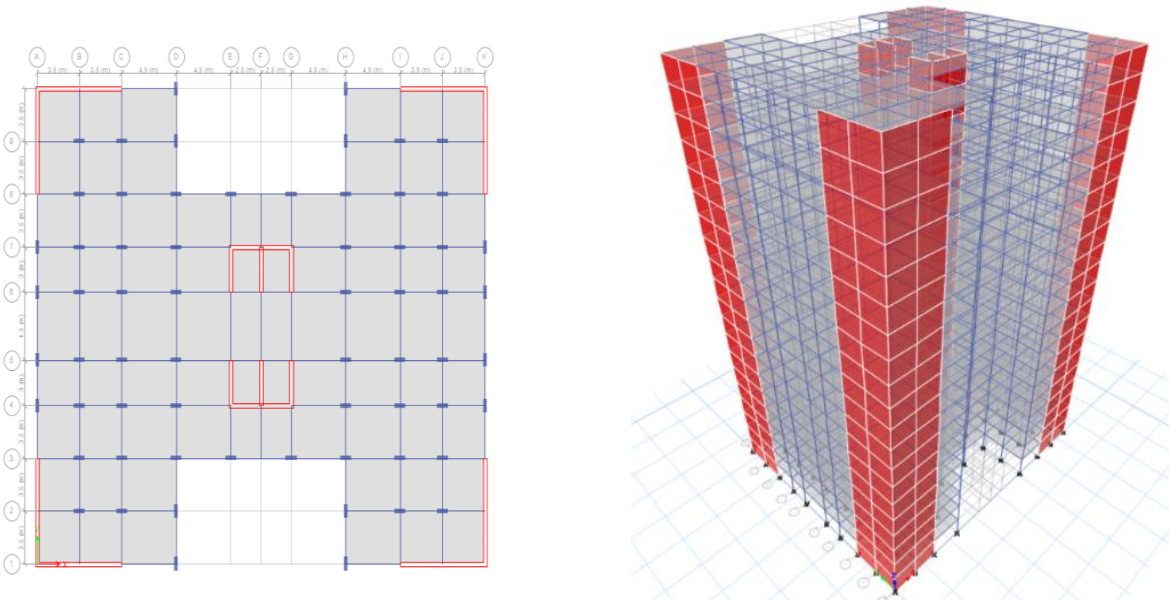
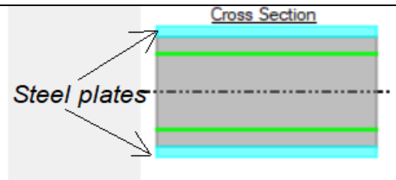
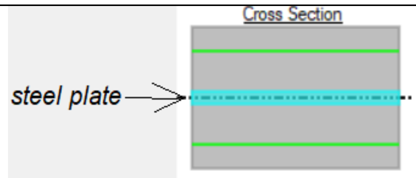
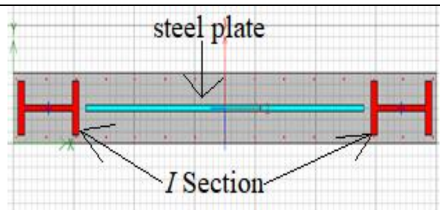
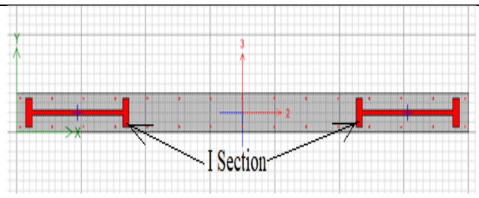


Fig:1Plan And 3D View of H Shaped Model with Shear Walls

B. Composite Shear Wall Models

Four different types of composite shear walls are selected for the research and are modelled as below in table III.

Table III: Composite Shear Wall Types and Modelling Details

TYPE	CONFIGURATION	ETABS SECTION DETAILS
Double Skin Composite Shear Wall (DS CSW)	Two steel Plates of 25 mm thick of grade Fe 345 are provided at both the ends of the central RCC panel/wall of 250 mm and 150 mm to form 300 mm and 200 mm SW respectively.	
Steel Plate Encased Composite Shear Wall (SE CSW)	The type of CSW where a single steel plate (Fe 345) is encased centrally to the RCC shear wall throughout the length. RCC wall is of 300 mm and 200 mm thick	
Steel Plate Encased Composite Shear Wall With I Section (SEI CSW)	Similar to above model with extra I section is provided at the ends of 600 mm wide web of 25 mm thickness, flanges of 50 mm thick and 230 mm wide for 300 thick wall and flange width is reduced to 150 mm for 200 mm wall.	
Shear Wall With I Section Composite Shear Wall (I Sec CSW)	Here only I section is provided at the boundary elements with same configuration of I sectionas that of SEI CSW with only change in length of web which is increased to 800 mm	

Seismic input data for the modelling is such that zone factor is .16 and importance factor is 1.2, Response reduction factor 5 is taken as per IS 1893:2016. The time period is manually calculated and obtained as .88775 s and .9621 s for X and Y directions.Response spectrum analysis results of the composite shear walls are as below. RSX results shows the response of the models in X direction and RSY results gives the response of the models in Y direction.

4. ANALYSIS AND RESULTS

From the response spectrum analysis, the responses of the models with composite shear walls are plotted graphically. In the graphical representation the different types of composite shear wall models are compared for 300 mm and 200 mm thickness shear walls.

A. Lateral Displacements

According to IS: 456:2000, maximum allowable lateral displacement is H/500, where H is the height of building. Here for 20 storey model, limit of maximum displacement is 120 mm. Lateral displacement is maximum at the top storey, sofor the comparative study maximum value of each model is taken and graphically plotted.Also, it is to be noted that the maximum displacements of all the models falls under the limit. Fig 2 and Fig 3 shows the displacement at 20th storey by response spectrum analysis in X direction and response spectrum analysis in Y direction respectively. Both 300 mm and 200 mm shear walls (SW) of all the composite shear walls along with RCC shear wall model is plotted in Fig:2 & Fig:3.

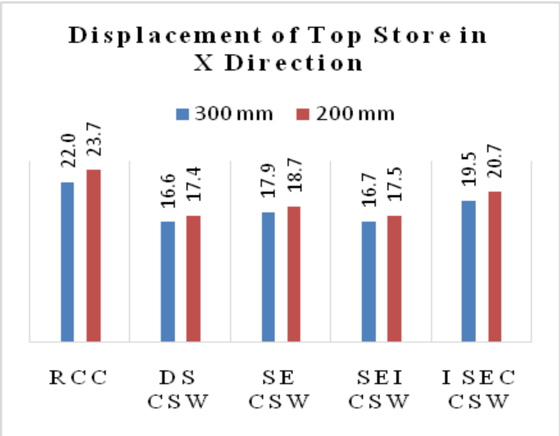


Fig: 2Displacement of models with 300 mm and 200 mm thickness SW at top storey in X direction

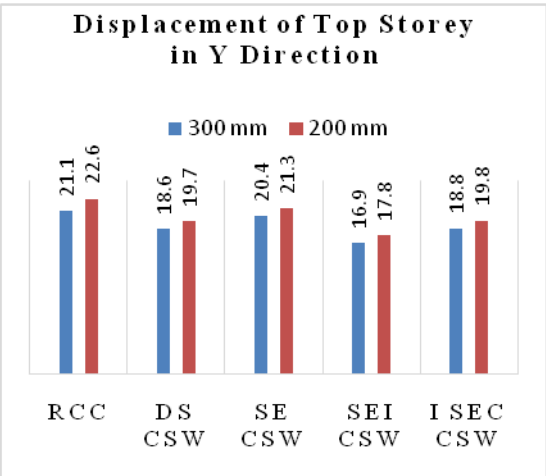


Fig:3 Displacement of models with 300 mm and 200 mm thickness SW at top storey in X direction

Fig 2 and Fig 3 clearly shows that Composite shear walls reduces the displacements where maximum decrease in both the direction is obtained by SEI CSW and then comes DS CSW, there after the SE CSW and I Sec CSW. It has to be noted that decrease in thickness normally increases displacement but here CSWincreases slightly or remains almost same. SEI CSW could reduce displacement by 24.33 %& 19.94 % reduction in X direction and Y direction for 300 mm and 26.3% and 21.1 % for 200 mm X direction and Y direction respectively. DSCSW reduces the displacement by 24 %&10 % for 300 mm shear wall model and 26.68 % and 13% for 200 mm shear wall model in X & Y direction respectively. Where as in SE CSW reduces the displacement by 18.6% &3.3% in X direction &Y direction for 300 mm and 21% & 5.5 % for 200 mm respectively. Similarly, for SW with I section shows 11.4 %&10.8% of reduction in X direction and Y direction of 300 mm and 12.7% & 12.4% reduction in displacement in X direction and Y direction of 200 mm shear wall models.

Considering the effect of 300 mm and 200 mm thickness shear walls, while decreasing the thickness from 300 mm to 200 mm the displacement in RCC shear wall model increase by 8% where as in case of double skin composite shear wall, steel encased composite shear wall and steel encased with I section CSW this increase is only 5% and in shear wall with I section this increase is by 6%.

B. Storey Drift

lateral displacement of any one storey of the building in relative to the storey below is said to be storey drift and it should be always less than .004 times the height of storey as per Indian code. Storey Drift of the structures with composite shear walls resulted that the storey drift is reduced with the introduction of composite shear walls.

The results obtained are compared in terms of percentage difference of CSW models with respect to RCC shear wall models. Maximum drift observed in RCC shear wall models of 20 storey height is at 11th and 10th for 300 mm and 200 mm walls respectively. Thus, to understand the responses of CSWs in terms of drift, percentage difference is calculated at the above-mentioned storey levels. Storey drift of above-mentioned storey levels are graphically plotted as in Fig:4 &Fig:5.

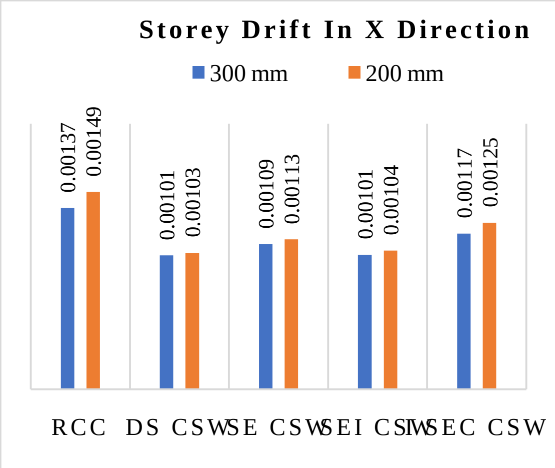


Fig:4 Storey Drift in X Direction of 300 mm and 200 mm thick shear wall models

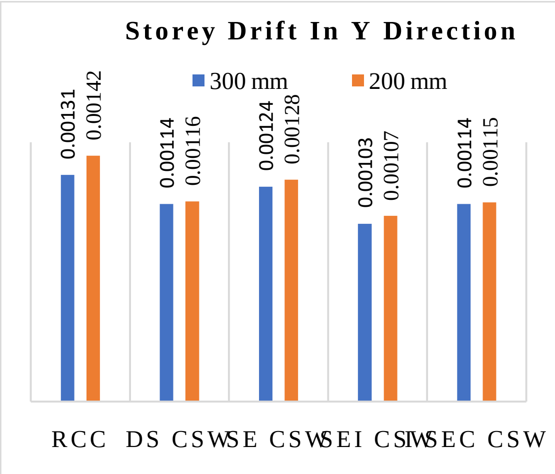


Fig:5 Storey Drift in Y Direction of 300 mm and 200 mm thick shear wall models

In 20 storey model of 300 mm thickness DS CSW model reduces the drift by 26 % and 12.8 % in X and Y direction, where as in 200 mm shear walls this reduction is obtained as 30.77% and 18.5% respectively. SEI CSW also reduces the drift in same percentage that of DS CSW in X direction but in Y direction the decrease in percentage increases to 21.5% and 24.4% for 300 mm and 200 mm thickness.SECSW shows comparatively less percentage of decrease than that of other two models especially in Y direction, that is by reducing drift by only 5.2% and 9.7 % for 300 mm and 200 mm walls, whereas in X direction this value is of 20% and 24%. For I SEC CSW responds in similar way for both the directions for both thicknesses. 14% and 13% reduction are observed in 300 mm wall models and 16 % and 19% for 200 mm walls.Also, from the above graph it is understood that the storey drift increases when the thickness of shear wall reduced in RCC models but in every composite models the storey drift remains almost same.

From the analysis results it is also noted that while decreasing thickness, storey drift at the abovementioned floor level increases by 9% in RCC shear wall models whereas in double skin composite shear wall this increase only 2%, in steel encased composite shear wall and steel encased with I section composite shear wall this increase is by 3% and in I section composite shear wall this decrease is around 8%.

C. Storey Stiffness

As per IS 1893: 2016,lateral stiffness of a particular storey is less than that of storey above then the building is said to be soft storey or have stiffness irregularity.Here all models are regular in terms of stiffness.Storey stiffness is maximum at the bottom most storey for every model. And this maximum value is taken for the comparative study. Composite shear walls increase the overall stiffness of buildings and Fig:6and Fig:7 shows the storey stiffness of models at first storey level in X direction and Y direction respectively.

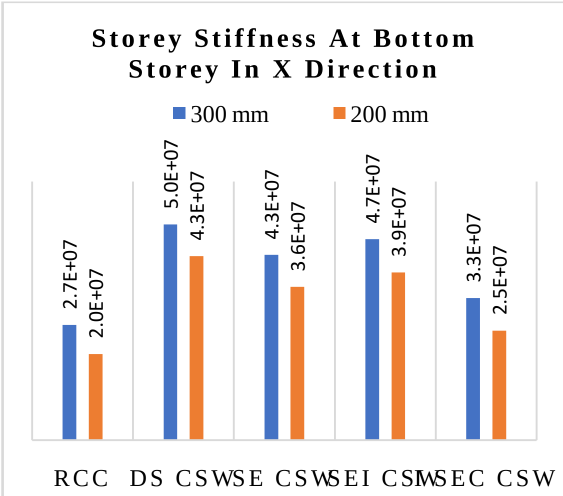


Fig:6 Storey Stiffnessin X Direction of 300 mm and 200 mm thick shear wall models

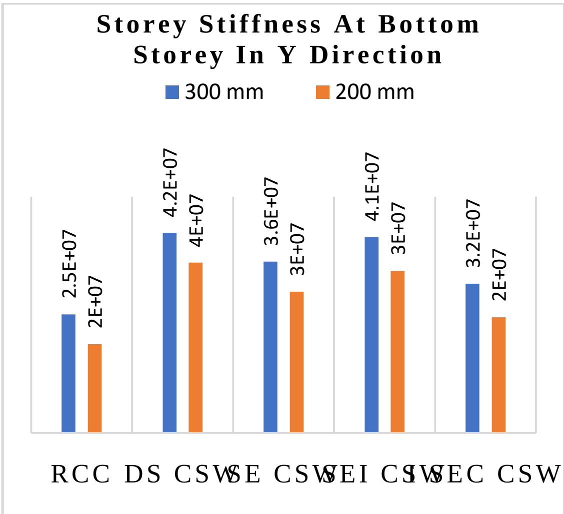


Fig:7 Storey Stiffnessin Y Direction of 300 mm and 200 mm thick shear wall models

From the above graph of figure 6 & 7, it is clearly understood that CSWs increases stiffness considerably. DS CSW increases stiffness by 87% and 68% in X and Y directions in 300 mm wall and this value is increased to 113% and 91.7 % for 200 mm walls. 74% and 65% of increase is obtained in SEI CSW in both directions of 300 mm thickness and 94.8 % & 82.2 % in 200 mm wall. Even though the percentage of steel is reduced the SEI shows almost same increase that of DS CSW. SE CSW increases the stiffness by 60.67% and 44.33% in 300 mm wall and 78 % and 59 % in 200 mm of X and Y directions. Least percentage of increase is noticed in I SEC CSW where the increase in X & Y directions by 23 % and 25.6% in 300 mm walls and then for 200 mm wall this value is of 27% and 30%.

Similar to other parameters of analysis the stiffness of the models also showed some interesting results in terms of thickness. While decreasing thickness of shear walls from 300 mm to 200 mm, 25% of decreases in storey stiffness is observed in RCC model. But for composite shear walls this decrease is less when compared to RCC models. Double skin composite shear wall, 14% of decrease is observed and in steel encased composite shear wall and steel encased with I Section shows decrease in stiffness by 17% and in last model of I section composite shear wall this decrease is by 22%.

5.CONCLUSION AND FUTURE SCOPE OF THE WORK

A.Conclusion

- Composite Shear walls improves the performance of building in terms of displacement, drift and stiffness.
- Thickness of shear wall can be effectively reduced. Reduced thickness in CSW results in better performance than that of reduced RCC SW section.
- Reduction in thickness can reduce the overall seismic load on building.This gives better area of utility for high rise buildings which is an important criteria in urbanized locations.
- Steel plate encased with I sectioncomposite shear wall (SEI CSW) shows better response with respect to reinforced shear wall (RCC) model when compared to other models.
  - ➢ This reduces displacement by a maximum percentage of 20% to 25%.
  - ➢ Drift is reduced in the range of 20% to 30%
  - ➢ Stiffness is increased by 65% to 95%.
- Double skin (DS CSW) shows slightly less performance that of steel encased with I Section (SEI CSW) but higher stiffness due to more area of steel.
  - ➢ This type composite shear wall performs better in X directions, where displacement is reduced by 10% to 27%.
  - ➢ 12% to 30% reduction in storey drift is obtained.
  - ➢ And storey stiffness increasedby 68% to 110%.
- Steel plate encased (SE CSW) did not perform well in the Y direction and in X direction the performance is satisfactory.The overall percentage change can be consolidated as
  - ➢ 3%-20% reduction in terms of displacement.
  - ➢ 5%-25% reduction in terms of storey drift.
  - ➢ And increases storey stiffness by 40% to 77%
- Shear wall with I section composite shear walls, the percentage of structural steel used is less when compared to other three models, so this model can be considered economical and the structural performance is also comparable with the other types. This type CSW buildings responds in such a way that in both direction percentage change is almost same. That means it shows satisfactory results irrespective of direction. And the overall percentage change can be noted as
  - ➢ 10-12% reduction in terms of displacement
  - ➢ 13%-19% reduction in terms of storey drift
  - ➢ And storey stiffness increases by 23% to 30%
- Also, it has to be noted that in Steel plate encased composite shear walls with I sections, percentage of increase of stiffness does not decreases considerably than double skin SW, even though the percentage of steel is reduced and the other structural performances also.
- Thus, providing I section at boundary element improves the overall seismic performance of the models.

B.Future Scope of the Work

The present work reports the response of buildings with different type of composite shear wall in two different thickness of shear wall of 20 storey model. The comparative study conducted between different types of composite shear walls is highlighted in the work. In view of this, following points are outlined as the aspects for the similar studies to be undertaken in the future.

Different configuration of steel plate/section in boundary elementswith connection details of steel plates such as shear connectors and the buckling of steel plate in composite shear walls can be studied. Effect of other lateral loads such as wind load on composite structures/shear walls is another area of scope for research. Effect of composite shear walls in sky scrapers and different type of support condition /foundation also can be undertaken for future studies.

ACKNOWLEDGEMENT

The author wishes to express her sincere gratitude to the Department of Civil Engineering, Datta Meghe College of Engineering, Airoli (Affiliated to the University of Mumbai) for the support provided throughout the work.

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