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Understanding Seismic Response Analysis of Reinforced Concrete Frame Structures with Shear Walls

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Abstract—*This study investigates the effect of shear walls on the structural response of multi-storied buildings during earthquakes. A G+20 storey building was modeled with and without shear walls using FEM based software ETABS and analyzed for base shear, storey drift ratio, lateral displacement, bending moment, and shear force through nonlinear static pushover analysis. The comparison of results between the models with and without shear walls indicated that the presence of shear walls significantly reduced the base shear, storey drift and lateral displacement. These results confirm the significance of shear walls in providing stiffness and strength to multi-storied buildings during seismic loading. Therefore, the inclusion of shear walls should be considered an essential component in the design and construction of such structures. The study findings contribute to a better understanding of the behavior of multi-storied buildings during earthquakes and can be used to improve the seismic resilience of structures. The study also investigates the interaction between shear walls and moment resisting frames in the construction of multi-story buildings, the researchers investigate the lateral force distribution between the frame and shear wall. The analysis reveals that up to the bottom seven/eight storeys, more than 50% of the load is taken by the frame with a shear wall, and the lower most three storeys take about 70 to 75% of the total storey shear. This paper evaluates and comments on the interactive beahiour of RC-Frame and Shear Wall system*

Keywords:-*Shear-Wall Frame Interaction, PushoverAnalysis, Capcity Curve and Storey Shear.*

INTRODUCTION

The combination of shear wall and moment resisting frame in the same building is often advantageous, especially for medium to high-rise buildings. This system has been used in buildings ranging from 10 to 50 stories or more. The shear walls and ductile frames are designed to resist a portion of the seismic load, with the ductile frames designed to back up the shear walls when they are stressed beyond the elastic limit. The distribution of the lateral load between the shear walls and frame is shown in Figure 1. Performance-based seismic analysis is an iterative design approach that aims to limit structural damage by accurately estimating response parameters. **Kashyap Shukla (2022)** The study aimed to analyze the seismic and wind loads on high-rise rectangular building models with and without shear walls using ETABS software. The seismic loads were calculated using the equivalent static method specified in IS Code 1893 (Part-1): 2016, while imposed loads were calculated using IS Code 875 (Part-3):

2015. The analysis focused on storey displacements and drifts using four load combinations from the Indian Standard Code. The study revealed that the presence of a shear wall in the center of the building in the form of a core provided better performance against lateral loads. **Vidhya K(2021)**This literature review discusses earthquake preparedness measures, including designing earthquake-resistant structures, protecting heavy objects, and having evacuation plans. India is shown to be vulnerable to earthquakes, and civil engineering plays a vital role in creating safer structures. Shear walls are an essential building technology that can transfer earthquake forces and maintain a building's original shape during ground movement. The study focuses on the non-linear static performance of shear walls with and without openings, using ETABS software to analyze the controlled and uncontrolled performance of the structure. The findings of the study can aid in creating safer buildings in earthquake-prone areas. **Fahjan et al. (2010)** conducted a study comparing different approaches for linear and nonlinear modeling of shear walls in the structural analysis of RC buildings with shear walls. The study found that nonlinear modeling approaches, specifically the FE method, provided more accurate predictions of the behavior of shear walls and the overall structural system compared to linear modeling approaches such as the EDS method. The FE method is computationally intensive and requires more detailed information about material properties, but provides the most accurate predictions. The study recommends the use of nonlinear modeling approaches for accurate predictions of the behavior of shear walls and the overall structural system in RC buildings. **Nitin Choudhary(2014)** performed a pushover analysis on two multi-story reinforced concrete frame buildings, one with a symmetrical plan consisting of two bays of 5m in the x-direction and two bays of 4m in the y-direction, and the other with an unsymmetrical L-shaped plan. Shear walls were used to study their ability to resist lateral forces, with the effects of placing the shear wall along the longer and shorter sides of the building highlighted. The presence of shear walls along the longer and shorter sides of the building led to a decrease in base shear and displacement. The study conducted a comparative analysis of various parameters, including base shear, story drift, spectral acceleration, spectral displacement, and story displacement. The position and orientation of the shear walls have been found to be important factors in determining their effectiveness. In this study, the effect of placing shear walls along the longer and shorter sides of the building was investigated, providing insights into their optimal placement for better seismic performance. **P.P. Debnath(2016)** Frame-shear wall buildings are a common design for high-rise multi-story reinforced concrete buildings, where shear walls are placed strategically to act as an efficient lateral force resisting system while meeting other functional requirements. However, conventional analysis methods may not accurately represent the behavior of shear walls when modelled as wide columns. To overcome this, an advanced design approach called Unified Performance Based Design (UPBD) has been used in this study, which takes into consideration elastic and plastic rotations and performance level. The shear walls in the model have been modelled as multi-layered shell elements using SAP2000 software, which is an innovative addition. Non-linear analysis was performed to gain a better understanding of the behavior of shear walls, but the interpretation of their performance using the UPBD method with shell elements posed some challenges. The findings of this study have implications for the design of high-rise buildings and the use of innovative modelling techniques to improve their seismic performance. **M. K. Rahman(2012)** This paper presents a detailed 3D nonlinear static analysis for evaluating the seismic performance of an existing eight-story reinforced concrete frame-shear wall building in Madinah. The building features a dome, reinforced concrete frame, elevator shafts, and ribbed and flat slab systems at various floor levels. The seismic displacement response of the RC frame-shear wall building was evaluated using 3D pushover analysis, which was conducted using SAP2000 software incorporating inelastic material behavior for concrete and steel. Moment curvature and P-M interactions of frame members were obtained by cross-sectional fibre analysis using XTRACT. The shear wall was modelled using the mid-pier approach, and a sequence of yielding and failure of members and structural levels were identified as damage modes for the target displacement expected under design earthquake. Finally, retrofitting strategies to strengthen the building were evaluated based on the findings of this study. The results of this research have practical implications for seismic performance evaluation and retrofitting strategies for existing RC frame-shear wall buildings. **Y.M. Fahjan(2010)** Proper modelling of shear walls is crucial for accurate linear and nonlinear analysis of building structures. In linear analysis of structures, reinforced concrete (RC) shear walls are modelled using different techniques such as shell elements or combinations of frame elements. Nonlinear analyses use the nonlinear material model of mid-pier frame based on plastic hinge concept located at the end of the structural elements or distributed along the member span length. Nonlinear behavior of shell elements is modelled using multi-layer shell elements with layered material model. **Dipali Patel(2015).** The study involves the creation of 2-D models of 20, 30 and 35-storey RC frame buildings with shear walls. In the 2-D models, two exterior frames with shear walls are modelled as a single frame with double stiffness, strength, and weight. Interior frames without shear walls are modelled as a single frame with equivalent stiffness, strength, and weight. The frames are connected by rigid links at each floor level. The 2-D plane frame model is used to investigate the lateral force distribution between the exterior frames with shear walls and the interior frames without shear walls. Analysis results indicate that the frame with shear wall is capable of bearing more than 50% of the load up to the bottom seven or eight storeys, while the lowermost three storeys take approximately 75% of the total storey shear. Overall, this study provides useful insights into the interaction between shear walls and RC frames and can inform the design of more effective building structures. **Sangketa Sangma(2015)** Reinforced concrete (RC) frame-shear wall buildings are widely used as a structural system for tall buildings. The system is designed such that the frames independently resist 25% of the design base shear while the remaining 75% of the base shear is resisted by the shear walls. To ensure the desired level of performance under specific hazard levels, the Unified Performance-Based Design (UPBD) method can be employed for performance-based design of such structures. In this study, two RC frame-shear wall buildings with heights of 16 and 20 stories were analysed and designed using SAP2000 v14. Frame elements were modelled as beams and columns, while shear walls were modelled as wide columns. Column sizes were determined based on maintaining 3% to 4% steel in the column to meet the design demand. Nonlinear default hinges were assigned to the column and beam elements based on FEMA 356, while user-defined hinges were provided for the shear walls. Nonlinear time history analysis was conducted using spectrum compatible ground motions (SCGM). The study aimed to assess the suitability of the UPBD method for designing RC frame-shear wall buildings to meet target performance objectives at IO performance level with 1% drift.

Many attempts were made to study the effects of shear wall location, configuration on the performance of the structure but a very few literatures are available on the shear wall interaction. With the objected to study the interaction between the shear wall the frame, a pushover analysis is carried out on building models with shear walls on different locations.

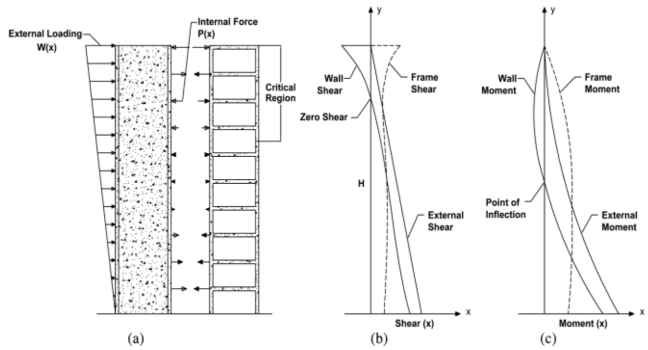


Fig. 1: Forces in RC dual system:
(a) horizontal interaction between wall and frame;
(b) typical distributions of the shear force in wall and frame; and
(c) typical distributions of moments through wall and frame

METHODOLOGY

a) Building Modeling: The first step in pushover analysis is to model the building in a software tool, such as Etabs 2016.The building is modeled using the grid system, which represents the major physical structure of the building by defining the number of grids in X, Y, and Z directions.
b) Material Properties: Once the grid system is defined, the next step is to define the material properties, such as concrete and steel, which will be used to construct the building.
c) Sectional Properties.The sectional properties of each element, such as columns, beams, and slabs, are defined based on the material properties.
d) Load Definitions: Dead load, live load, and seismic loads are defined and applied to the corresponding structural elements in the building. The seismic load is defined for both X and Y directions, with the mass source taking full dead and 50% live load.
e) Linear Seismic Analysis: In the first stage of pushover analysis, a linear seismic analysis is carried out based on the primary structural design obtained from the modeling and load definitions. This stage is carried out in accordance with IS456:2002.
f) Insertion of Hinges: Based on the design obtained from the linear seismic analysis, hinges are inserted in the structure to simulate the behavior of the structure under lateral loads.
g) Pushover Analysis: Pushover analysis is carried out on the structure by applying a pushover load in the X and Y directions. The pushover curve obtained from the analysis shows the capacity of the structure to resist lateral loads and the corresponding displacements.
h) Modification of Design and Detailing: The results obtained from the pushover curve are used to modify the design and detailing of the structure as necessary. This stage may involve making changes to the material properties, sectional properties, or load definitions.
i) Nonlinear Analysis: For a sophisticated assessment of seismic performance, modal and direct-integration time-history analyses may be coupled with P-Delta and Large Displacement effects. Nonlinear links and concentrated PMM or fiber hinges may capture material nonlinearity under monotonic or hysteretic behavior.
j) Documentation: The final stage of pushover analysis involves documenting the results obtained from the analysis, including the pushover curve and any modifications made to the design and detailing of the structure.

BUILDING DESCRIPTION AND MODELLING

A Typical 20 storey reinforced concrete building have been chosen for the analysis. The floor plan of the building is shown in figure 2. The building consists of an assembly of cast in place reinforced concrete beams, columns and shear wall. The dimensions of the building components are designed for the most critical load combination using the relevant Indian Standards IS:456 2000 and IS:1893 2016 The building is considered to be located in zone-V and importance factor=1.The building parameters are defined as, Building plan dimension= 20m x 20m, No. of bays in X and Y direction = 5 @ 4 m and 3 @ 4 m respectively , Concrete Grade= M25, Steel Grade = Fe 415 MPa, Slab thickness = 150 mm, height of each storey = 3.2m, live load on floors = 3.5 kN/m2 , Shear wall thickness = 200 mm. The dimensions of beams and columns for considered buildings are 600*350mm and 600*600mm respectively. The shear wall is provided at the different locations as shown in fig.3 ,4 and 5. Consider buildings having shear walls as well as moment resisting frames to resist lateral load in the same direction. The analysis should ensure compatibility of deformation in the walls and the frames such that the rigid floor diaphragm condition is satisfied. However, on their own the walls and the frames tend to have an entirely different deformation profile; since these combined systems forced to deform with a similar deformation profile by the floor diaphragm, interaction forces exist between the walls and the frames. After the design of the frame elements, plastic hinges were assigned to the frame elements. Kinematic hysteresis nonlinear model is considered for the rebar and mander concrete model is considered for concrete. Deformation controlled fibre P-M3 hinge is assigned for the beam elements and deformation-controlled fibre P-M2-M3 hinge is assigned for the column. Shear wall are linked to the joints using the rigid links. For nonlinear modelling of shear wall P-M3 deformation-controlled fibre hinges are assigned. A deformation-controlled pushover over analysis is carried and the capacity curves are obtained.

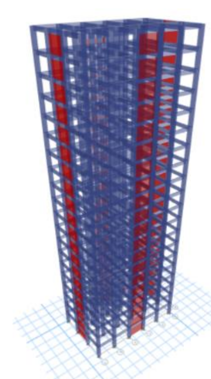


Fig. 2

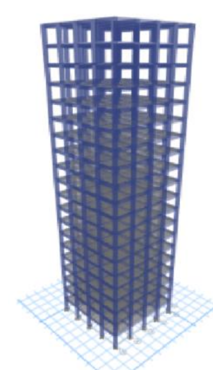


Fig. 3

Fig. 4

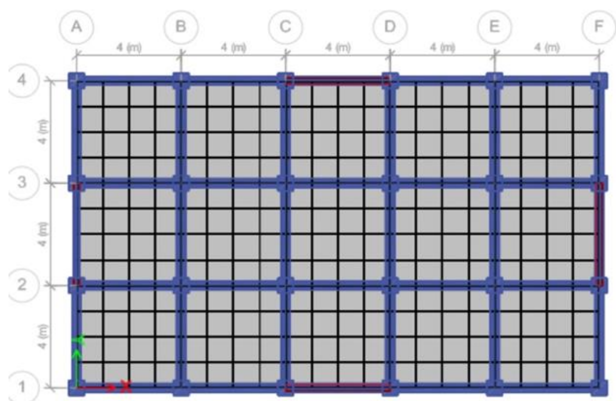


Fig.5.

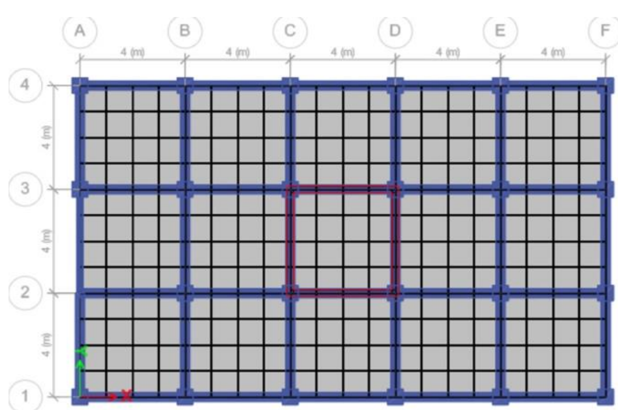


Fig. 6

Figure 2.(Model 2)	**Elevation view**	**Shear Wall along X and Y axis.**
Figure 3.(Model 1)	**Elevation view**	**Bare Frame**
Figure 4.(Model 3)	**Elevation view**	**Shear wall at Core**
Figure 5.	**Plan view**	**Shear Wall along X and Y axis.**
Figure 6.	**Plan view**	**Shear wall at Core**

RESULTS AND DISCUSSION

A pushover analysis is carried out on the three models i.e. Bare frame model, Bare frame with shear walls at the core and bare frame with shear walls at the centre of the bays along X and Y directions. Static compacity curves are obtained and compare as shown in figure. It can be observed that capacity of the bare frame model is, much lesser than the other two models. While the building with shear walls at core have shown more capacity than shear walls along X and Y. It can also be observed that shear walls at core have high stiffness as compared to other two models.

Lateral Force Analysis

Table. Shows the lateral load distributed among the frames and the shear wall for the building model with shear walls along X and Y directions. It can be observed that more than 34.2837% of the lateral force for model 2 and 25.8677% for model 3 is taken by the shear wall until storey no.17. In the bottom most storeys the maximum lateral force is taken by the shear walls itself. But the loads taken by shear walls is very minimum in the top most storey and show negative effect. This negative effect in the shear wall signifies that the load is acting in the opposite direction. The reason can be the upper storey column stiffness is more than the stiffness of the shear wall.

Table 1: Distribution of Horizontal Seismic Storey Shear in Model 2

Storey Level	Height of building(m)	Shear taken by Frames (KN)	Shear taken by Shear wall (KN)	Total Shear (KN)
20	70	1888.2043	-401.4880	1486.716
19	66.5	2991.466	135.8753	3127.341
18	63	3508.667	1259.299	4767.966
17	59.5	4211.485	2197.106	6408.592
16	56	4533.665	3515.552	8049.217
15	52.5	5150.548	4539.293	9689.842
14	49	5748.5402	5581.9273	11330.467
13	45.5	6448.488	6522.604	12971.09
12	42	7031.914	7579.803	14611.718
11	38.5	6395.510	9856.832	16252.343
10	35	11083.408	6809.560	17892.96
9	31.5	10403.10	9130.48	19533.59
8	28	10033.184	11141.034	21174.21
7	24.5	9237.576	13577.267	22814.84
6	21	11326.362	13129.107	24455.46
5	17.5	11490.591	14605.503	26096.094
4	14	10656.993	17079.726	27736.719
3	10.5	9040.335	20337.009	29377.345
2	7	11919.41	19098.56	31017.970
1	3.5	6302.475	26356.120	32658.59

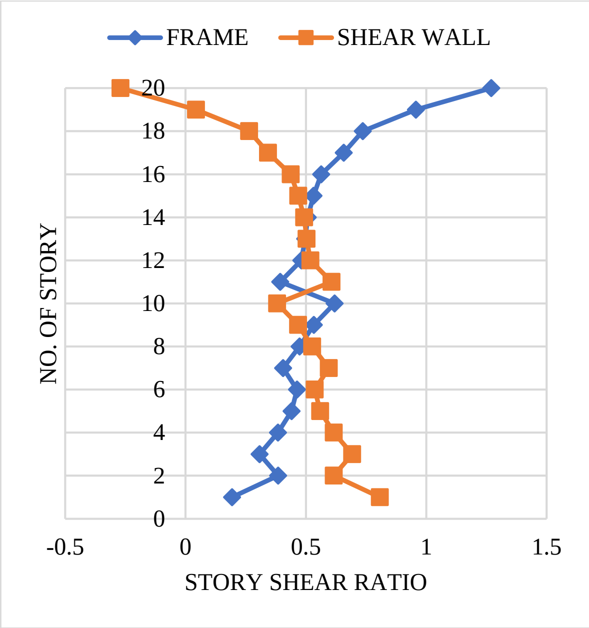


Fig. 7: Interaction between frame and shear wall for 20-storey building with shear walls along X and Y directions.

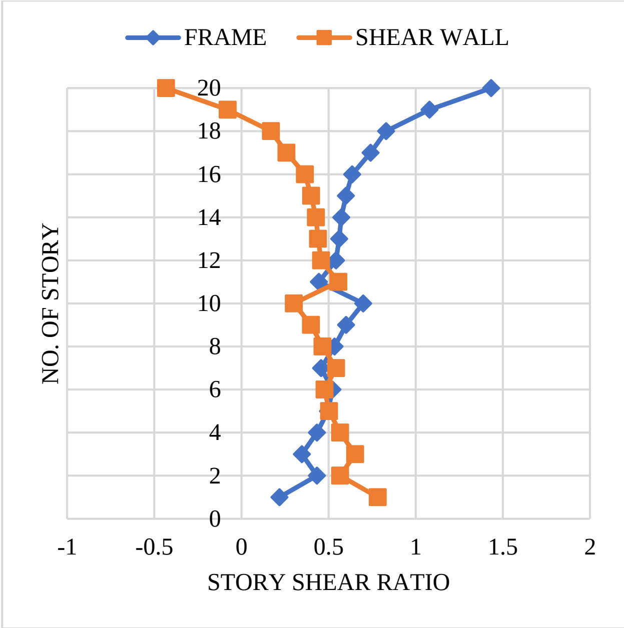
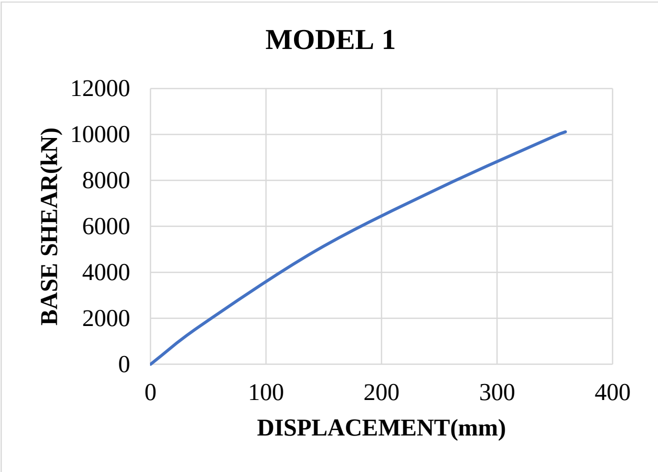


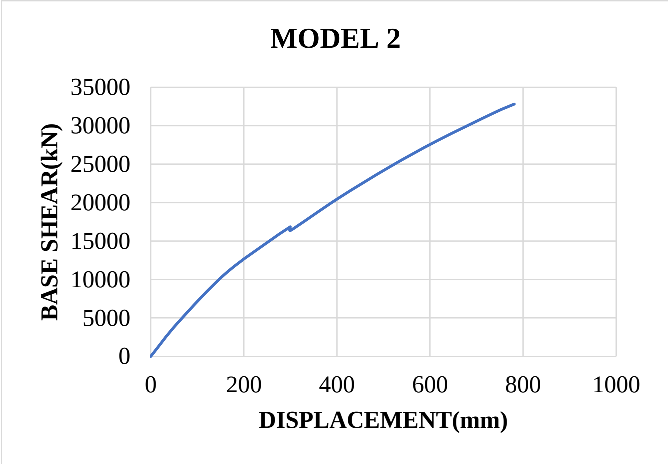
Fig. 8: Interaction between frame and shear wall for 20-storey building with shear walls along X and Y directions.

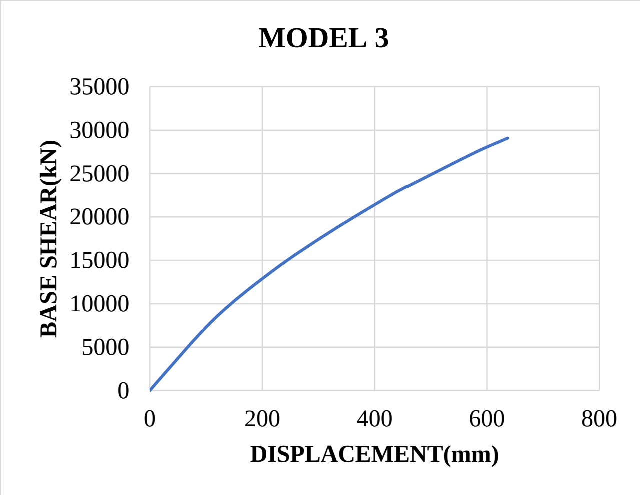
Table 2: Distribution of Horizontal Seismic Storey Shear in Model 3

Storey Level	Height of building(m)	Shear taken by Frames (KN)	Shear taken by Shear wall (KN)	Total Shear (KN)
20	70	1888.204	-255.570	1317.933
19	66.5	2991.466	279.4140	2772.302
18	63	3508.667	1302.782	4226.671
17	59.5	4211.485	2171.469	5681.041
16	56	4533.665	3357.356	7135.410
15	52.5	5150.548	4297.655	8589.779
14	49	5748.540	5253.698	10044.14
13	45.5	6448.488	6124.778	11498.518
12	42	7031.914	7092.958	12952.887
11	38.5	6395.510	9077.6647	14407.256
10	35	11083.408	6625.452	15861.62
9	31.5	10403.105	8646.741	17315.99
8	28	10033.184	10409.37	18770.36
7	24.5	9237.576	12526.753	20224.734
6	21	11326.362	12240.468	21679.103
5	17.5	11490.591	13557.979	23133.472
4	14	10656.994	15707.014	24587.842
3	10.5	9040.335	18508.598	26042.211
2	7	11919.410	17563.738	27496.580
1	3.5	6302.475	23698.887	28950.949

TARGET DISPLACEMENT



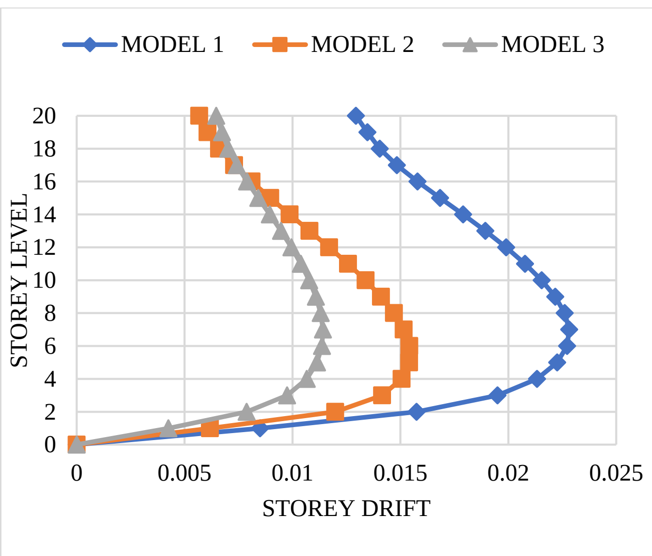




It can be seen that Bare frame Model 1 show least strength, while Model 2 and 3 performed very well as compared to the bare frame. And when Model 2 and 3 are compared, Model 2 show more strength as compared to model 3 and fails at much higher displacement.

STOREY DRIFT

Building Model 3 perform well as compared to Builing model 1 and 2.



Based on the analysis results of the considered RC frame, it can be concluded that the lateral load distribution between the shear wall and RC frame varies with the height of the building.At the top 2 to 3 storeys, the RC frame alone takes the entire lateral load, while the contribution of the shear wall is almost negligible. On the other hand, at the storey levels 1 to 3 from the bottom, more than 69.2269% of the lateral load is taken by the shear wall and the remaining 30.7731% is resisted by the RC frame. At the intermediate storey levels, the lateral load is distributed differently, 38.0572% of the lateral load is resisted by the frame with a shear wall, while the remaining 61.9428% load is resisted by the frame without a shear wall. The shear wall and RC frame work together to carry the external load at the lower and intermediate floors. As the height of the building decreases, the higher forces are resisted by the frame with a shear wall as compared to the frame without a shear wall. At a certain intermediate height, both the shear wall and frame carry the same load. However, at lower heights/storeys, the shear wall carries a higher percentage of the load as compared to the RC frame. Up to the bottom eight storeys, more than 52.616037% of the lateral load is taken by the frame with a shear wall. Therefore, the distribution of lateral forces between the RC frame and shear wall is also varying with the height of the building.

CONCLUSIONS

The present study investigates the interaction between shear walls and reinforced concrete (RC) frames in 20 storey RC frame building with Shear wall along X and Y axis and with Shear wall at Core. The analysis is carried out using CSI Software(ETABS). The study finds that the shear wall and RC frame work together to carry external loads at the lower and intermediate floors.At the top 2 to 3 storeys, the RC frame alone carries the entire lateral load, and the contribution of the shear wall in resisting lateral force is negligible. At the bottom storeys upto storey 3, 70 to 75% of the lateral load is taken by the shear wall, and the remaining 30 to 25% is resisted by the RC frame. At intermediate storeys, the shear wall resists almost 40% of the lateral load, and the remaining 60% is resisted by the frame.As the height/storey decreases, the shear wall resists higher forces compared to the frame. At a certain intermediate height, the shear wall and frame carry the same load and show pure dual action, but at the lower height/storey, the shear wall carries a higher percentage of lateral loads compared to the RC frame.Overall, the study provides insights into the behavior of RC frame buildings with shear walls under lateral loads, and the findings can inform the design of such structures for improved performance and safety.

Conflict of Interest

The authors have no conflicts of interest to declare. All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work.

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