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BEHAVIOUR OF FLAT-SLAB IN TALL BUILDINGS ALONG WITH OUTRIGGER SYSTEM

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Abstract: The rate of population extension is increasing gradually in urban areas, so to save space and accommodate more occupants', tall structure construction is extensively adopted by the builders. In addition to that, flat slab system has also gained popularity because of its architectural and construction advantages in the business. As the building's height rises, it should have a good lateral load resisting capacity to counter wind and earthquake load peril. However, flat slab system alone cannot counter the load and cannot directly be adopted in tall buildings because of its poor stiffness. Thus, to improve the performance of flat slab tall structures under wind and earthquake loads, an outrigger system is considered and a parametric analysis is performed in this study. It is mainly deliberated to observe the behavioural difference of flat slab system along with and without outrigger system by analysing the characteristics such as lateral displacement, base shear, drift, and stiffness. The study is carried out on a tall building with the ETABs models considering shear walls and braces as an outrigger system at different locations. In addition to that, the most optimum models are also compared with RC frame building.

Keywords: Flat-slab, Outrigger system, displacement, storey drift, base shear, Structural performance

I. INTRODUCTION

A. General

Tall structures are spreading over the world, especially in rising economies, thanks to recent technological advancements in construction materials, methods of construction, machinery, and structural analysis and designing tools. Tall buildings have an important role as key components in metropolises and sophisticated cities. Tall structures could be a viable option from an economic, environmental, and social standpoint. The contest to create the tallest innovative building is largely fuelled by the development of better and more inventive lateral load resisting systems. Nowadays, flat slab systems are also admired for various types of tall buildings

B. Flat slab

Flat slabs are RC slabs with long spans that span several bays and are simply supported by columns, with no beams. Flat slab construction is simple and efficient since it just requires the least building height for a given number of levels. A significant bending moment and vertical forces develop in a zone of supports in such a structure. When compared to reinforced concrete, this results in a very efficient structure that uses less material and has a shorter economic span range. Posttensioning significantly improves the structural behaviour of flat slab structures.

Figure 1 Flat slab

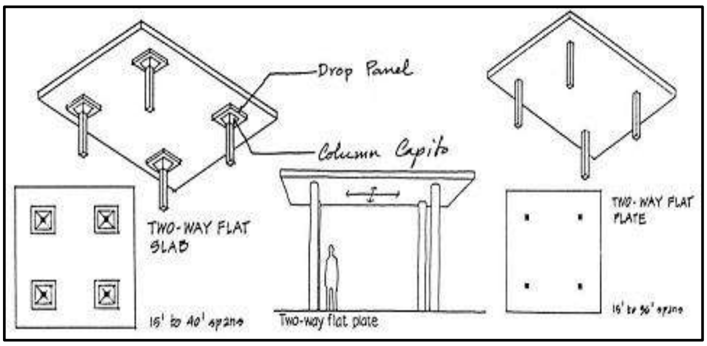

Figure 2 Flat slab components

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C. Behaviour of flat slab

The behaviour of flat slabs and flat plates is identical to those of two-way slabs with beams. The bands of slabs in the two orthogonal directions along the column lines may be considered to act as beams. The column strips behave, as a continuous beam supported on columns as shown in Figure 1.3. The deflections at column support A, B, C, and D are zero and maximum at mid-spans (at E, F, G, and H). The middle strips also behave as a continuous beam supported on column strips. The deflections in middle strips are minimum at their supports on column strips and maximum at their mid-span (I). As the middle strips are supported on column strips, the loads are transferred from the middle strips to column strips which in turn transfer the loads on columns. The column strips are more heavily loaded than the middle strips resulting in a higher value of moments in the column strips than that in the middle strips. The transfer of load from slab to column causes excessive shear stress in the slab adjacent to the column. This causes the initiation of shear cracks at a distance of effective depth of slab from the face of the column. These cracks propagate towards the top. The failure occurs at the bottom compressed edge of the slab surrounding the column through punching.

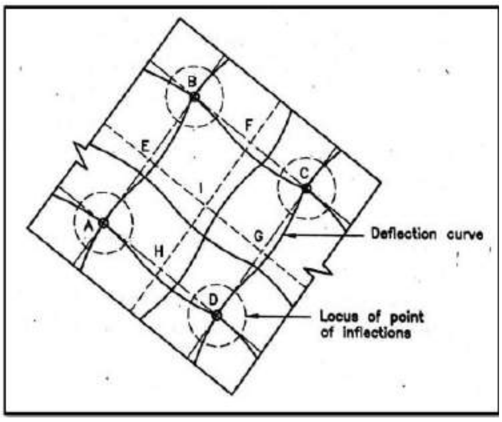

Figure 3 Behaviour of flat slab

D. Outrigger system

Outrigger is a connecting and tying member between two structural members, which is generally core of building and peripheral columns. The outrigger system typically engages the core with columns to increase the lateral stability and stiffness of a building. It is also defined as a, rigid horizontal structural members to improve building overturning stiffness and strength by connecting the building core to a peripheral column. The core structure of a high-rise building is the most important unit, as indicated in Figure-4. It is made up of several components such as lifts, stairwells, ducts, and so on.

The perimeter system, on the other hand, is made up of mega columns. Outriggers are used to connect the core system to the outer mega columns.

Types of outrigger system:

1. Conventional
2. Offset
3. Virtual

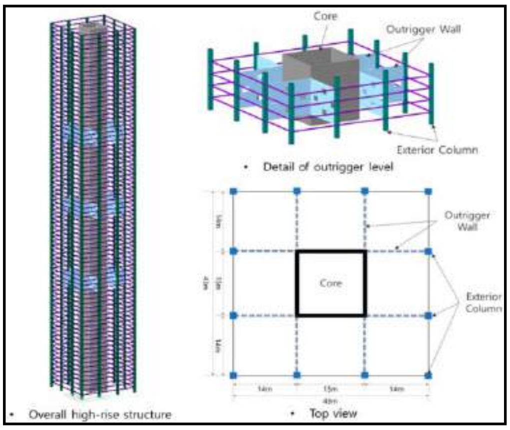

Figure 4 Outrigger system

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E. Principle of outrigger structural system

Due to wind or seismic stresses, tall buildings experience significant lateral displacement. Cantilever deformation occurs in the core structure of a high-rise building, as shown in below figure, on the other hand portal deformation occurs in the frame structures surrounding the core. The structure suffers from a lot of drift and overturning as a result of this. Outriggers are used to effectively manage excessive drift caused by lateral loads. As a result, structural and non-structural damage to the structure can be avoided. Outriggers, as seen below, minimize the core moment from top to bottom under lateral loads.

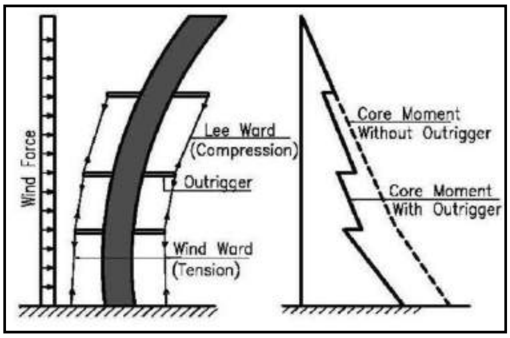

Figure 5 Moment diagraph for outrigger frame

II. LITERATURE REVIEW

Wael Alhaddad (2020) [3], has illustrated the components, configurations, and types of outrigger system from various perspectives, as well as the elements that affect performance, the structural system behaviour under various loading types, and the advantages and disadvantages of outrigger systems.

Wael et al (2020) [4], has investigated Outrigger and belt-truss system design for tall structures which is the subject of a number of different loadings. This section provides an instruction for optimum location and size of the outrigger system by presenting and assessing as many relevant great resources as possible.

Reza Kamgar and Reza Rahgozar (2017) [5], have approached for calculating the optimum position of a flexible outrigger system in this paper, which is based on maximising the strain energy of an outrigger-belt truss system. The authors describe a method for determining the best placement for a flexible outrigger system.

Murat et al (2012) [6], have discussed non liner behaviour of 50 story RC tall building in terms of three lateral load resisting system. 1) concrete core shear wall only 2) core shear walls with flat slab elements and 3) core shear wall with damped outrigger system. The lateral drift, story level acceleration and behaviour of flat plates are investigated.

Gadkari and Gore (2016) [8], have studied the performance of an outrigger structural system in a high-rise RC building under seismic and wind loads This paper reviews the literature on several features of the outrigger structural system, including: Outrigger structural system behaviour in a high-rise RC building, Outrigger structural system behaviour in high-rise steel and composite buildings, Outrigger structural system behaviour the effect of seismicity on irregularly shaped structures and the system in vertically irregular structures.

III. NUMERICAL STUDY

A. Structural model consideration

The system is idealized symmetric buildings consisting of rigid deck supported by structural elements. The following assumptions are made for the system under consideration:

1. The floors of the superstructures are considered rigid.
2. The force-deformation relationship of the structure is within the elastic range.

The following conditions are fulfilled by the flat slab and outrigger system.

1. Inclined steel members are in fixed connection with columns.
2. Central core is fixed with foundation.

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3. Core to outrigger connections is also kept rigid.

B. Numerical Studies

Problem description:
In this study 25 story flat slab is considered for the response spectrum and wind analysis with the different types of outriggers and its positions to understand its behaviour and its effectiveness on the Flat-slab structure.

Study is mainly divided based on 3 types of the models.
1. Based on number of outriggers and its location
2. Based on type of outrigger
3. Based on type of lateral loading (Method of Analysis)

1. Models based on number of outriggers and its location
a) Zero outrigger (Base model)

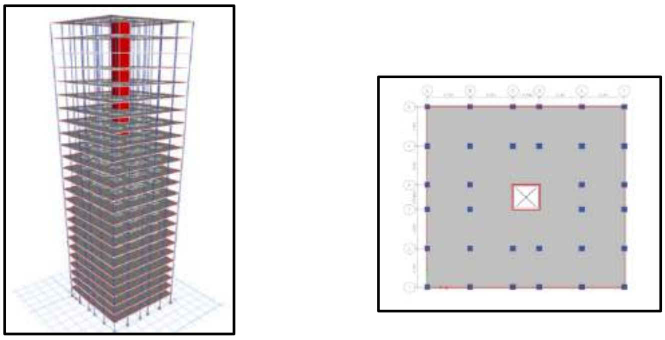

Figure 6 Flat slab base model

b) Single outrigger
- Outrigger on 25th story
- Outrigger on 24th story
- Outrigger on 13th story (At mid)
- Outrigger on 8th story (At maximum story drift)

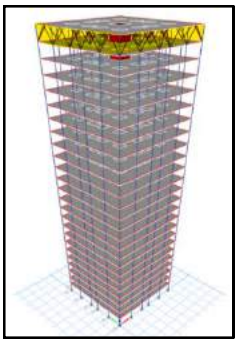

Figure 7 Model 1

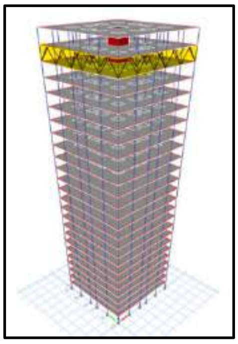

Figure 8 Model 2

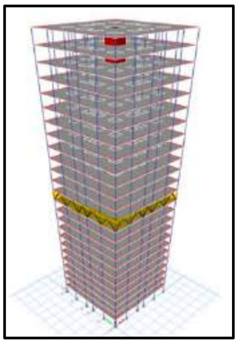

Figure 9 Model 3

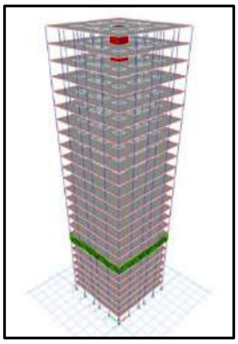

Figure 10 Model 4

c) Double outrigger
- Outriggers on 13th and 25th story
- Outriggers on 12th and 25th story
- Outriggers on 8th and 24th story (base on best results of single outrigger positions)

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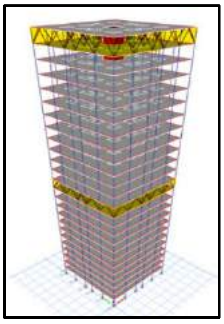

Figure 11 Model 1 (Double outrigger)

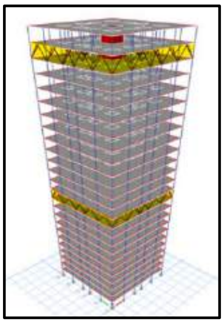

Figure 12 Model 2 (Double outrigger)

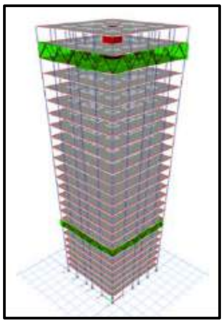

Figure 13 Model 3 (Double outrigger)

2. Based on type of outrigger
a) Steel truss as an outrigger (Steel member taken in this study is ISMB 550)
b) Shear wall as an outrigger (180mm thick, M30)

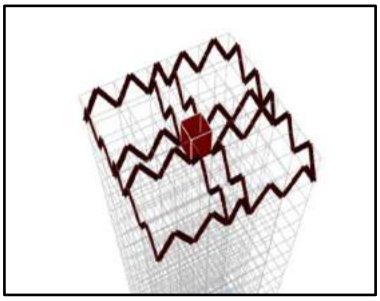

Figure 14 Steel truss outrigger

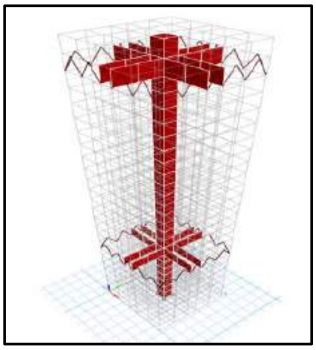

Figure 15 Shear wall outrigger

3. Based on type of lateral loading (Method of Analysis)
a) Response spectrum analysis
b) Static wind analysis

C. Parameters

TABLE I BUILDING PARAMETERS

No of storeys	25
Story height	3.2 m
Plan dimensions	18.5 m*18.5 m
Total height	80 m

TABLE II

Size of peripheral beam	0.350 m*0.5 m
Size of column	0.55 m*0.55 m
Slab thickness	0.15 m
Drop thickness	0.3 m
Grade of concrete	M30 & M35
Shear wall thickness	0.18 m
Grade of steel	Fe415

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SECTIONAL PROPERTIES

TABLE III WIND LOAD AND SEISMIC-FACTOR

Dead load	1.5 kN/m^2
Live load	3 kN/m^2
Seismic zone	V
Importance factor	1
Soil conditions	Medium
Wall load	11.7 kN/m

D. Results

The peak responses of base shear & story displacement, concrete quantity is obtained for every model in each case using ETABS which are shown in Tables along with maximum story drift.

1. Flat slab with no outrigger's response spectrum and wind analysis results (BASE MODE)

TABLE IV RESPONSE SPECTRUM AND WIND ANALYSIS RESULTS FOR BASE MODEL

Due to RS		
Story Displacement	66.7497	*mm*
Base Shear	1485.58	*kN*
Story Drift	0.00115	
Due to WL		
Story Displacement	146.872	*mm*
Base Shear	3535.53	*kN*
Story Drift	0.00268	

2. Results for single outrigger with flat slab

TABLE V RESULTS FOR SINGLE OUTRIGGER MODELS

		RS		**WL**	
1 OUTRIGGER AT TOP		ISMB 550	Shear wall	ISMB 550	Shear wall
Story Displacement	*mm*	64.978	65.103	146.455	145.8216
Base Shear	*kN*	1507.37	1512.058	3667.76	3667.76
Story Drift		0.001165	0.00117	0.00275	0.002749
1 OUTRIGGER AT 24TH					
Story Displacement	*mm*	64.29623	64.2856	144.9473	144.043
Base Shear	*kN*	1515.19	1522.02	3667.76	3667.76
Story Drift		0.001167	0.001175	0.002749	0.00274
1 OUTRIGGER AT CENTRE					
Story Displacement	*mm*	61.7672	60.72	124.1889	118.841
Base Shear	*kN*	1617.825	1661.5	3667.76	3667.76
Story Drift		0.001217	0.0012	0.002627	0.0026
1 OUTRIGGER AT MAX STORY DRIFT					
Story Displacement	*mm*	61.218	59.856	118.638	111.824
Base Shear	*kN*	1691.086	1768.6	3667.76	3667.76
Story Drift		0.00109	0.0011	0.002	0.0019

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3. Comparison graphs comparison graphs with single outrigger

a) Effect Of Single Outrigger in Compare to Base Model

- RS analysis results

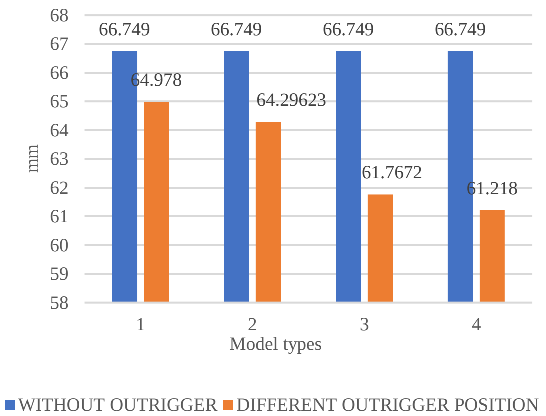

Figure 12 Max story displacement

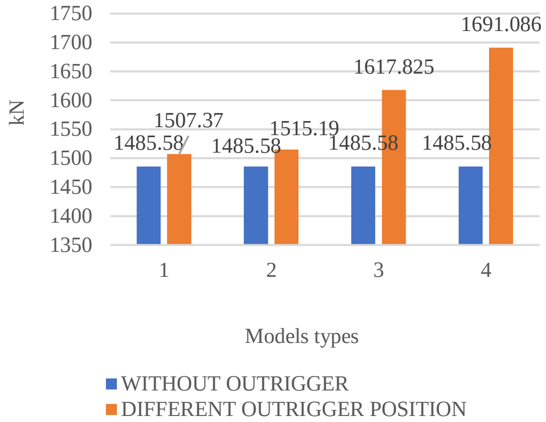

Figure 11 Base shear

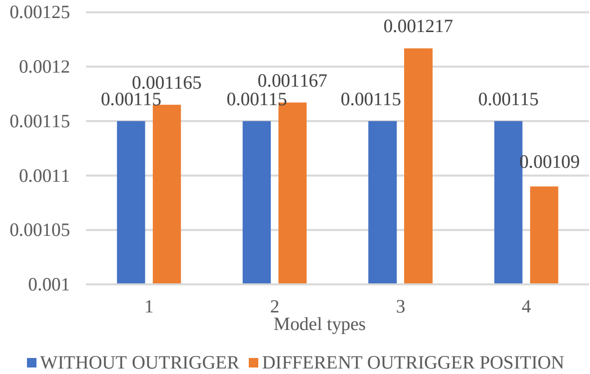

Figure 13 Story drift

- WL analysis results

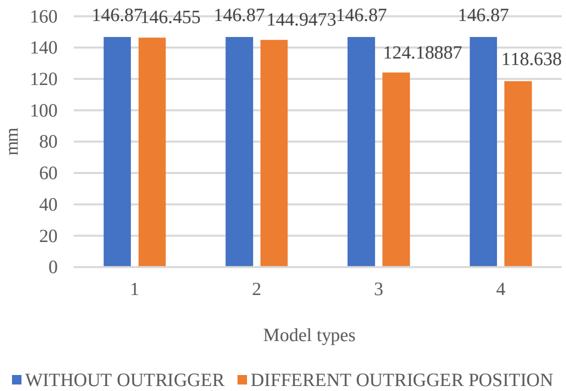

Figure 19 Max story displacement

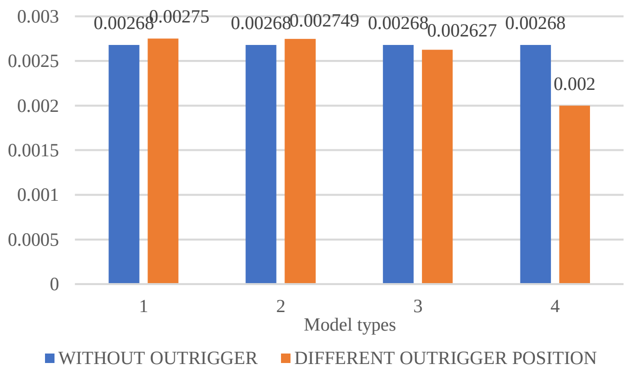

Figure 20 Story drift

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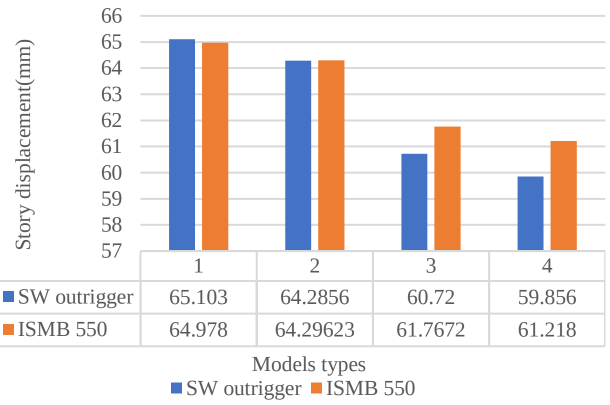
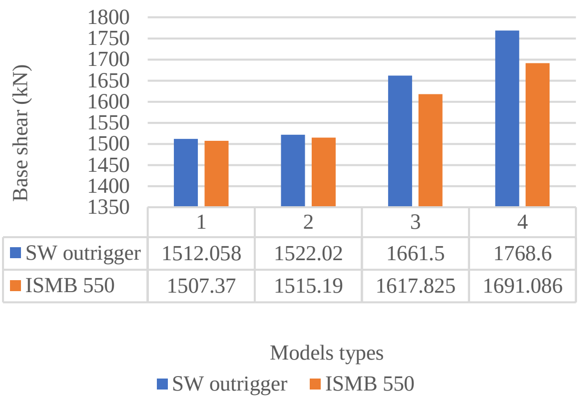
b) Comparison of Shear-wall outrigger with inverted truss Outrigger

- RS analysis results



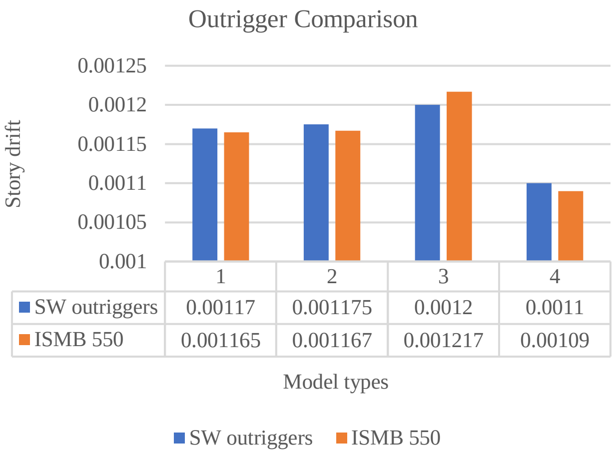
	1	2	3	4
SW outrigger	65.103	64.2856	60.72	59.856
ISMB 550	64.978	64.29623	61.7672	61.218

Figure 21 story displacement comparison



	1	2	3	4
SW outrigger	1512.058	1522.02	1661.5	1768.6
ISMB 550	1507.37	1515.19	1617.825	1691.086

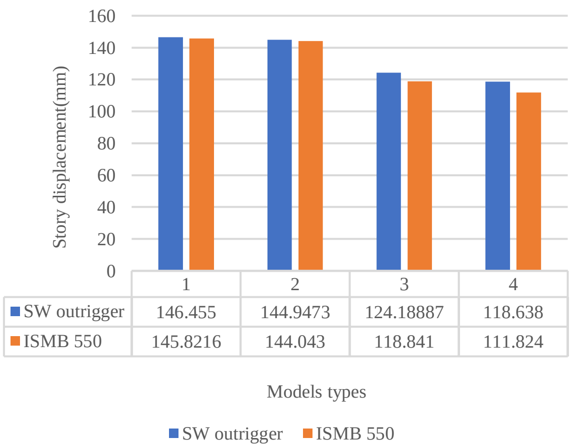
Figure 22 Base shear comparison



	1	2	3	4
SW outriggers	0.00117	0.001175	0.0012	0.0011
ISMB 550	0.001165	0.001167	0.001217	0.00109

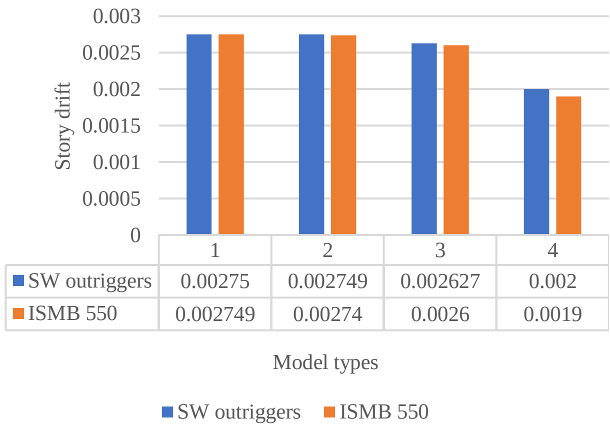
Figure 23 Story drift comparison

- WL analysis results



	1	2	3	4
SW outrigger	146.455	144.9473	124.18887	118.638
ISMB 550	145.8216	144.043	118.841	111.824

Figure 24 Story displacement comparison(WL)



	1	2	3	4
SW outriggers	0.00275	0.002749	0.002627	0.002
ISMB 550	0.002749	0.00274	0.0026	0.0019

Figure 25 Story drift comparison for (WL)

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4. Effectiveness check of the system with RC frame

RC frame Model considered to check effectiveness of the most optimized Flat-slab structure. Selected model, loading conditions, soil condition, seismic zone everything is kept as identical as possible to get the accurate results. Moreover, wind analysis (most critical) data are compared for both the types. Because, RS analysis data might show inaccurate results due to differences in seismic weight and many other variables. On the other hand, static wind analysis has controllable variables.

- Comparison models form flat slab models(cases)

1. Model type 4 from single outrigger
2. Model type 3 from double outriggers
3. Model type 3 from double shear wall outriggers

TABLE VI SECTIONAL PROPERTIES OF RC BUILDING MODEL

Size of peripheral beam	0.350 m*0.5 m
Size of column	0.55 m*0.55 m
Slab thickness	0.15 m
Inner beams	0.33*0.5 m
Grade of concrete	M30 & M35
Shear wall thickness	0.18 m
Grade of steel	Fe415
No of stories	25
Story height	3.2 m

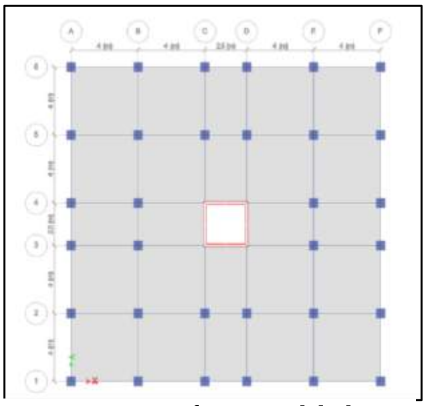

Figure 26 RC frame model plan

- WL analysis results for RC frame

TABLE VII RC FRAME MODEL RESULTS

	Flat slab	RC frame	% (Difference)
Story Displacement	146.872	122.942	16.2931
Base Shear	3535.53	3479.1142	1.595682
Story Drift	0.00268	0.002236	16.56716

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- Comparison (with all the cases considered)

TABLE VIII COMPARISON

	Flat slab	RC frame	case 1	case 2	case 3
Story Displacement	146.872	122.942	118.638	113.6956	106.205
Base Shear	3535.53	3479.1142	3667.76	3667.7	3667.7
Story Drift	0.00268	0.002236	0.002	0.00207	0.001996
% Reduction in disp.	0	16.29309875	19.22354	22.58865	27.68874

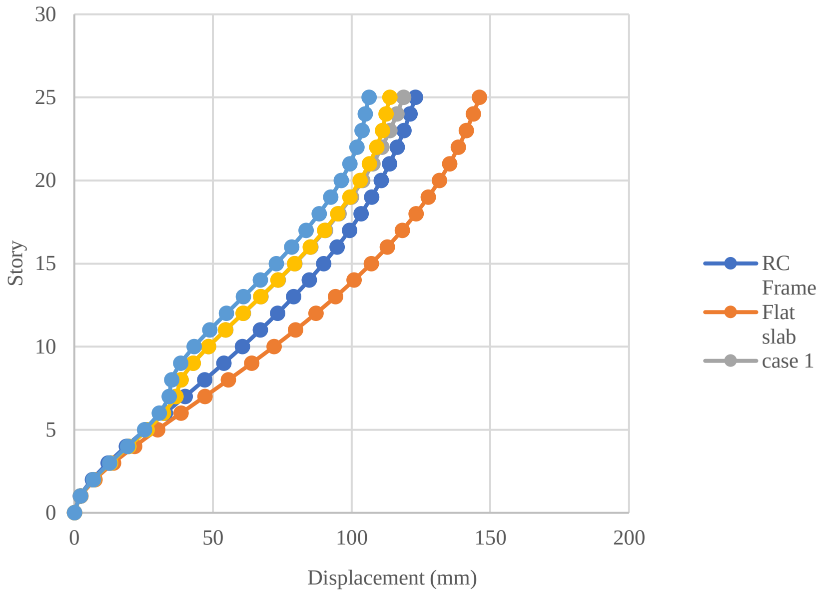
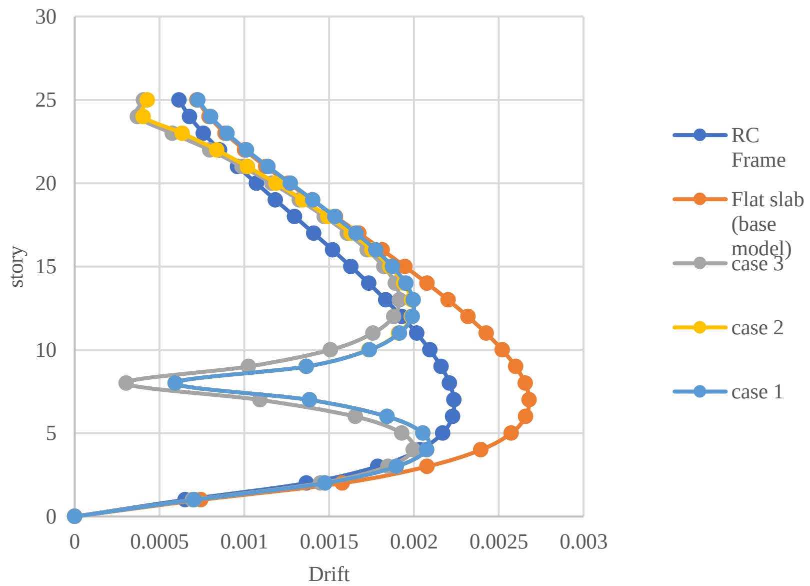


Figure 24 Story displacement comparison



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IV. CONCLUSION

- Top placement of outrigger doesn't control story displacement significantly. For truss type outriggers it shows 3-4% of the reduction in story displacement for earth quake forces in G+25 flat slab structure compares to base model. Whereas, central level placement of the outrigger controls displacement up to 9% for earthquake load and around 18-20% for wind loads.
- Provision of outrigger at the max story drift controls highest displacement for Flat slab structure. (Ref. Model 4)
- Infusion of outriggers increases base shear in flat slab structure. Outrigger at the story which has maximum story drift, increases the base shear about 16% compare to non-outrigger flat-slab building.
- Minor changes in the placement of outrigger level doesn't depict notable control in the story displacement. (Displacement for single outrigger model 1 is 64.9 mm and model 2 is 64.29mm)
- Truss as outriggers gives almost same performance as SW as outrigger against seismic force for optimized single outrigger system. However, in case of wind forces SW outrigger shows 23.9% reduction where truss outrigger reduction is 19.1% compare to base model.
- Addition of outrigger at particular story improves its story stiffness remarkably.(Ref-comparison graph-Fig-29)

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