

Comparative Study of Pushover Analysis of the Conventional Slab System with Outrigger and Flat Slab System with Outrigger

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ABSTRACT: Outrigger systems have been efficient in stiffening the structure against lateral loads like wind or earthquakes. So, in order to know more about their effects on the structure and their behaviour under earthquake loads, an overall seismic evaluation and comparison of 30 storey building located in zone 2 with conventional slab system having a central shear wall core and 1 outrigger level and flat slab system having central shear wall core and 1 outrigger level is demonstrated in this paper. Pushover analysis was performed using ETABS 9.7.4 on the models and using the performance parameters like Base force, Displacement, Storey drift, Spectral acceleration and Spectral displacement, relevant conclusions were drawn. The outrigger struts for both conventional and flat slab case was placed at 0.5h which is the most beneficial location for an outrigger level in a structure according to the literatures. Also, the status and location of plastic hinges at the performance point obtained from static pushover results showed that performance levels for almost all the models were found to lie in between Life safety to Collapse prevention range.

KEYWORDS: Pushover analysis, Outrigger systems, Flat slabs, Inter storey drifts, Plastic hinges.

I. INTRODUCTION

Pushover Analysis predicts the structural response similar to that of the other 2 methods- response spectra and time history analysis since it incorporates $p - \Delta$ effects and material non linearity which is true in real structures. Performances of structures are normally predicted accurately by analysing carefully, the performance parameters obtained from pushover analysis results. The demand curve, capacity curve and the category of performance level it belongs to like Immediate occupancy, Life Safety or Collapse Prevention directly tells us if the structure is safe or about to collapse. Outrigger systems are the horizontal elements like a deep beam or cross bracing struts designed to improve the structure's overturning stiffness and strength by connecting the building core or spine to the distant or exterior most columns and keeping the columns in their position in turn reducing sway. By providing outrigger systems in high rise buildings, it was seen that the lateral displacement and inter storey drifts in the top stories are much lower than the building frames without outriggers. It was observed from the literatures that the developers are going for flat slab systems to increase the business area as they have many advantages over conventional RC Frame building in terms of architectural flexibility, use of space, easier formwork and shorter construction time. But the failure of RC flat slab systems during severe earthquakes has led to widespread rejection of flat slab as a viable system in regions of high seismicity. A lot of analytical studies are needed to understand the influence of the performance parameters in the structural performance of the conventional and flat slabs systems. This scholarship of knowledge will be useful for the design engineers to effectively model the structure for seismic performance.

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II. REVIEW OF LITERATURE

A large number of literatures available on the above topic were collected, systematically reviewed and some of the useful reviews are given here. Hi Sun Choi and Leonard Joseph discussed about the outrigger system design guide, considerations for outrigger application, effects on behaviour of the structure. They observed that the Outriggers improve the stiffness against overturning by developing a tension-compression couple in perimeter columns when a central core tries to tilt, generating restoring moment acting on the core at the outrigger level [9] and thereby reduce the lateral displacements.

N. Herath, et al conducted a parametric study on the behaviour of Outrigger Beams in High rise Buildings under Earthquake Loads and suggested the optimum outrigger height for the building from the base to be 0.44-0.48 times the total height for both earthquake and wind loads. Po Seng Kian [10] and Kiran Kamath, et al [2] have also concluded the mid height of the structure to be the optimum outrigger height. The best location for one outrigger in a structure was found to be 0.6 times the height of the whole structure and 2nd of 2 outriggers in the structure was at 0.5 times the structure height while one is fixed at the top level according to S. Fawzia and T. Fatima [11]. Shivacharan K, et al [12] documented their study on Optimum Position of Outrigger System for Tall Vertical Irregularity Structures and it was concluded that the optimum location of the outrigger was between 0.5 times its height.

Navyashree K and Sahana T.S. studied the use of flat slabs in multi-storey commercial building situated in high seismic zone and found that the structural efficiency of the flat-slab construction was hindered by its poor performance under earthquake loading. As per their conclusions, the base shear of flat plate building was less than the conventional R.C.C building where as the storey drift was significantly more as compared to conventional R.C.C building [7]. Therefore, the characteristics of the seismic behaviour of flat slab and conventional RC Frame buildings suggest that additional measures for guiding the conception and design of these structures in seismic regions are needed.

The object of the present work was to compare the behaviour of 30 storey RC frame building having flat slabs and RC frame with that of conventional slab system with and without outrigger systems at the mid height of the building.

III. MODELLING AND ANALYSIS

3.1 Scope of present work

After understanding the literature, the objectives of the present investigation were carved. Analysis of the 3D models of the 30 storey building located in zone 2 has been performed and overall seismic evaluation of the structures were carried out using the performance parameters obtained from the Pushover analysis using the software ETABS 9.7.4 for the cases given below:

Case 1: RC bare frame with conventional slab system [CVBF]

Case 2: RC bare frame with conventional slab system and central shear wall core [CVBFSW]

Case 3: RC frame with conventional slab system and central shear wall core with outrigger struts at 0.5h [CVBFSW015]

Case 4: RC frame with flat slab system [FSBF]

Case 5: RC frame with flat slab system having a central shear wall core [FSBFSW]

Case 6: RC frame with flat slab system having a central shear wall core and struts at 0.5h [FSBFSW015]

The comparison between performance parameters obtained for both conventional and flat slab systems are outlined.

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3.2 Structural details and material properties

In the present study, 30 storey building with plan area 25m x 25m and 5 no. of bays in both x and y direction was considered. The typical floor height was taken as 3m and plinth level being 1.5m from the base giving a total height of the structure 91.5m. The beams, columns, shear walls and outriggers were assumed as concrete structure. The Plan & 3D view of RC frame with conventional slab system and central shear wall core with Outrigger struts at 0.5h has been shown in the figure 1(a) & 1(b) and the Plan & 3D view of RC frame with flat slab system and central shear wall core with Outrigger struts at 0.5h has been shown in the figure 1(c) & 1(d).

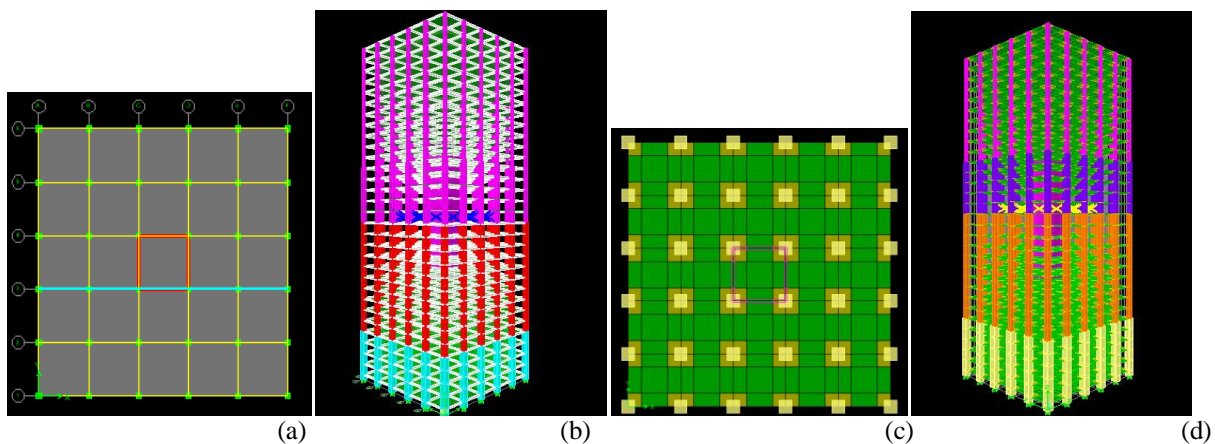


Figure 1: Plan & 3D view of the models of both conventional and flat slab systems

The geometric properties, material properties and the structural properties in the form of the data to be given in the ETABS are outlined in the table 1

Table 1: Geometric properties, Material properties and the Structural properties assigned to the models

Column to Column spacing		
In X-direction		5m
In Y-direction		5m
Support condition		Fixed
Conventional Slab thickness		150mm
Flat Slab thickness		150mm and at the drop 200mm
Infill wall thickness		230mm
Outrigger size		300 x 300mm
Shear wall thickness		300mm
Column sizes-	1-5 floors	1000 x 1000mm
	6-15 floors	800x800mm
	16-20 floors	700x700mm
	21-30 floors	500x500mm
Beam size		All the floors 230x 450mm
Grade of concrete		M25
Grade of steel		Fe 415
Modulus of elasticity of M25		25000000kN/m ²
Poisson's ratio		0.2
Coefficient of thermal expansion		9.900E-06
Shear modulus		10416666.7 kN/m ²

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3.3 Modeling and Analysis

Modeling is an important stage in the analysis of multistoried buildings. The steps followed in modeling the structure are listed below:

1. Creating the basic computer model (without the pushover data)
2. Choosing the concrete frame design code preference.
3. Defining material properties
4. Evaluation of the sectional properties of the beams, columns, slabs using trial runs. [Regular shaped slabs like rectangular were designed as membrane type and irregular shaped slabs and shear walls were designed as shell element. Load distribution pattern in the model was taken as 2 way slab type.]
5. Positioning of the beams, columns, slabs and shear walls.
6. Assigning boundary conditions- In all the models, base was considered to be fixed support.
7. Defining the static load cases- Dead load, Live load, Super dead load and seismic loadings as per IS 1893-2002 were considered. In order to have a realistic analysis, the structural properties and model details were arrived based on the previous literatures and is given in the table 2. User defined time period, seismic coefficients, factors and storey ranges were input in to the software.

Table 2: Structural properties and Model details

Type of structure	OMRF
Damping ratio	5%
Seismic details conforming to IS 1893(Part 1): 2002	
Zone factor	0.10
Importance factor	1
Type of soil	Type II (Medium)
Reduction Factor	3

8. Specification of structural loads and load combinations

Loads assigned to the slabs, Live load = 3 kN/m²

Load combinations considered other than the default load combinations available in the software are given below:

- (DL + LL + FL) X 1
- (DL + LL) X 1.5
- (DL + LL + FL) X 1.5

9. Defining mass source as per IS 1893(Part 1): 2002

Analysis in ETABS 9.7.4

A detailed analysis was carried out in the PG lab at the department of Civil Engineering, MSRIT, Bangalore, affiliated to VTU, Belagavi. Analysis of the models consists of 3 stages, viz., Static analysis, Designing and Pushover analysis. After the modelling, the basic static analysis was run followed by the designing process of the concrete frame structure. For the next stage, which is pushover analysis, prefixing of the hinge points were carried out. The software Etabs includes several built in default hinge properties that are based on average values from ATC-40 (Applied Technology Council) for concrete and average values from FEMA-273 (Federal Emergency Management Agency) for steel members. In this analysis, only user defined hinge properties were considered. For the columns, default PMM hinges were assigned and for the beams, default M3 hinges were taken.

Typically a gravity load pushover is force controlled and lateral pushover is displacement controlled. In our analysis in Etabs 9.7.4 more than 1 pushover load cases were defined and were run in the same analysis. The user defined pushover displacement magnitude of 3.66m obtained by default for each model was applied and load pattern was taken as acceleration in direction X for a scale factor of -1. Finally, the static non linear pushover analysis was run.

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After the analysis was complete, static nonlinear pushover curve and the pushover table was obtained. As the values of seismic coefficient of acceleration, C_a & seismic coefficient of velocity C_v , damping ratios etc., were varied, the pushover curves and performance point values changed accordingly. The required C_a & C_v values were entered depending on the soil type and seismic zone considered and the observations were made regarding the performance of the model and relevant conclusions were drawn by reviewing the pushover displaced shaped, the performance point and sequence of hinge formation.

IV. RESULTS AND DISCUSSIONS

The structure with outrigger struts showed efficient lateral force resistance for both conventional and flat slab systems than the structure without outrigger struts. It was also observed that the performance parameters were different for the conventional and flat slab systems. Detailed observations of the results obtained from the analysis of 30 storey building with shear wall and outrigger at 15th floor were recorded under the two headings – conventional slab system and flat slab system.

4.1 Conventional slab system

For the better understanding of the performance of the structure, the Pushover curve and the demand curve represented in the figure 2(a) and 2(b) has been plotted. The Storey drift diagram along EQX direction, Status of plastic hinges at the performance point, Data of pushover curve for the 30 storey bare frame with conventional slab system and central shear wall core with outrigger at floor 15 are presented in the figure 3, 4 and table 3 respectively.

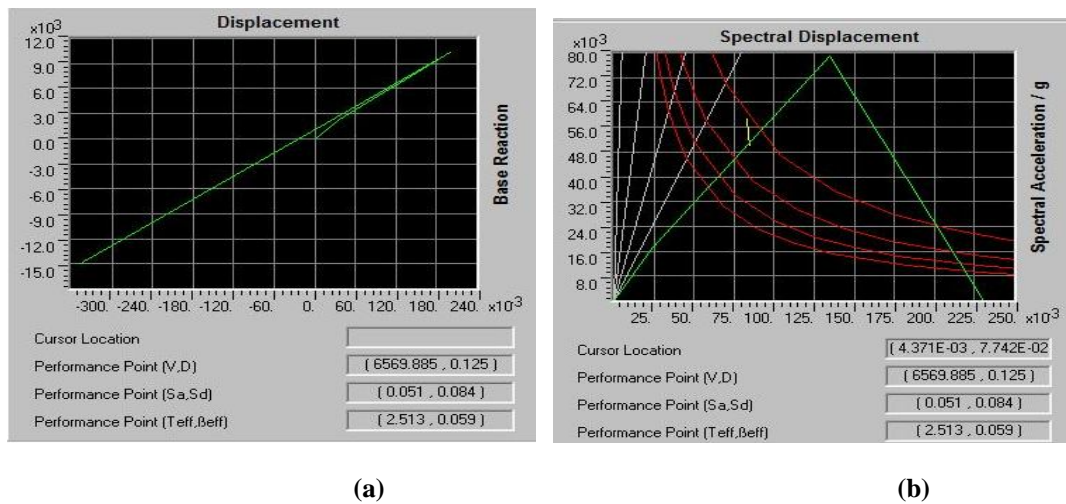


Figure 2: a) Pushover curve obtained for CVBFSW015 b) Capacity curve obtained for CVBFSW015

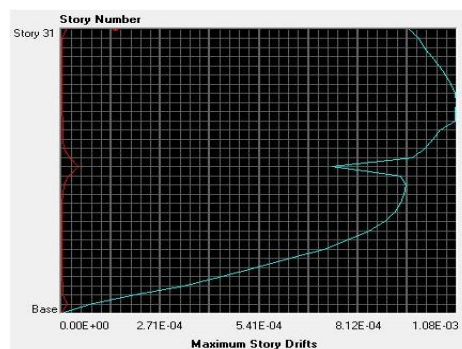


Figure 3: Storey drift diagram along EQX direction for CVBFSW015

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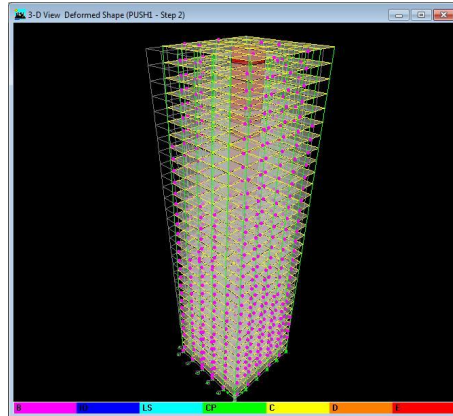


Figure 4: Status of plastic hinges at the performance point for CVBFSW015

Table 3: Data of pushover curve for CVBFSW015

Step	Displacement	Base Force	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	TOTAL NO. OF HINGES
0	0.0000	0.0000	5948	4	0	0	0	0	0	0	5952
1	0.0369	2254.0728	4912	1040	0	0	0	0	0	0	5952
2	0.2006	10288.3516	3874	2052	26	0	0	0	0	0	5952
3	-0.3491	15099.9561	5952	0	0	0	0	0	0	0	5952

4.2 Flat slab system

The Pushover curve and the demand curve for the flat slab system model are represented in the figure 5(a) and 5(b) from which the performance parameters at the performance point are picked and are presented in the table 8. Storey drift diagram along EQX direction, Status of plastic hinges at the performance point, Data of pushover curve for the 30 storey bare frame with flat slab system and central shear wall core with outrigger at floor 15 is presented in the figure 6, 7 and table 4 respectively.

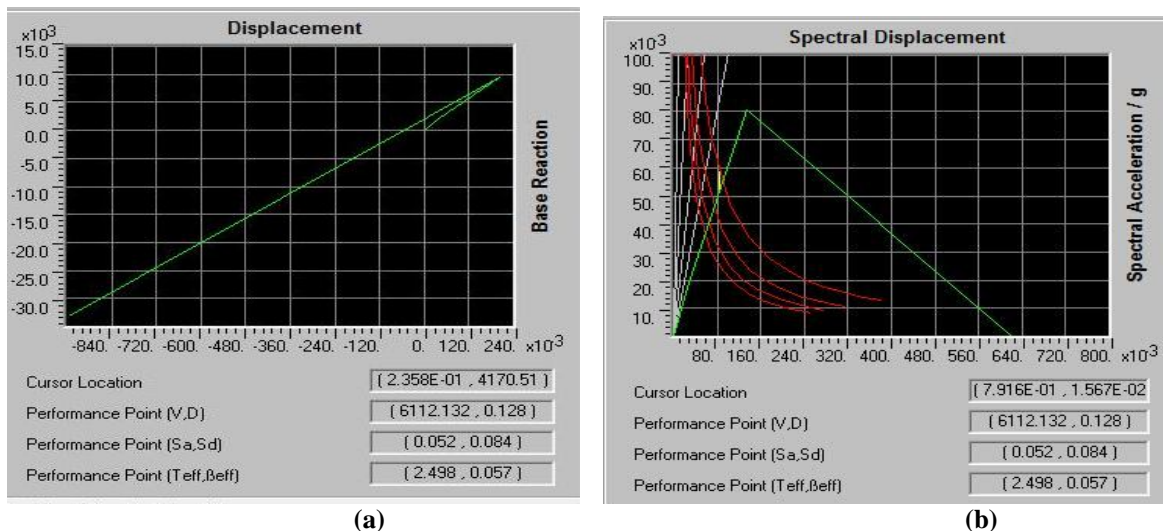


Figure 5: a) Pushover curve obtained for FSBFSW01515 b) Capacity curve obtained for FSBFSW015

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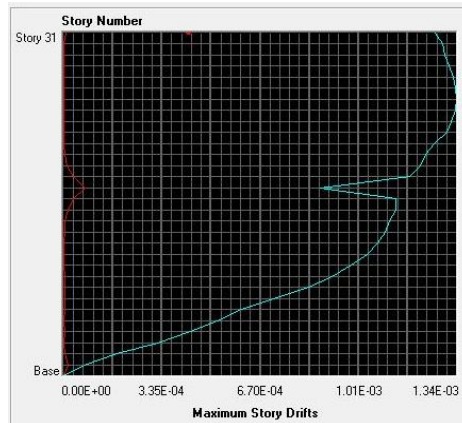


Figure 6: Storey drift diagram along EQX direction for FSBFSW015

Table 4: Data of pushover curve for FSBFSW015

Step	Displacement	Base Force	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	TOTAL NO. OF HINGES
0	0.0000	0.0000	2224	8	0	0	0	0	0	0	2232
1	0.0379	2012.5704	2116	116	0	0	0	0	0	0	2232
2	0.2038	9529.7246	1202	816	194	16	0	4	0	0	2232
3	-0.9553	-33157.7422	2232	0	0	0	0	0	0	0	2232

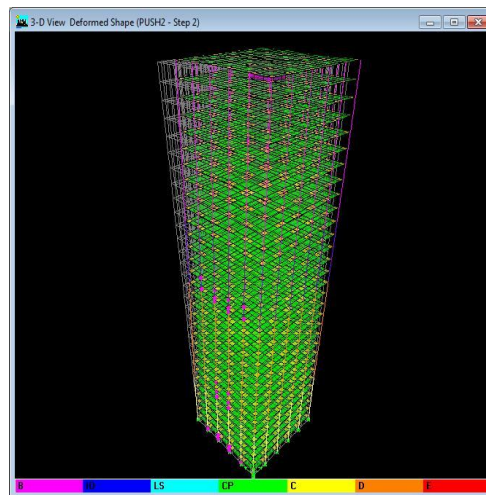


Figure 7: Status of plastic hinges at the performance point for FSBFSW015

4.3 Discussions

In order to have a comparative evaluation of the conventional and flat slab systems, variations of the performance parameters at the performance point for the 2 types of slab systems are given in the following table 5. The comparison of base force and displacement separately in the form of bar charts for both conventional and flat slab systems are shown in the figure 8 & 9 respectively.

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Table 5: Comparison of Base force, Displacement, Spectral acceleration, Spectral displacement, T_{eff} and β_{eff} at the performance point for the different cases of conventional and flat slab systems

Case	Type	Outrigger level	Base force (kN)	Displacement (m)	Sa (m ² /s)	Sd (m)	T_{eff} (s)	β_{eff}	Max. storey drift due to EQX
Conventional slab system	BF	-	4008.658	0.170	0.030	0.130	4.155	0.076	0.001779
	BFSW	-	5677.788	0.139	0.045	0.095	2.847	0.059	0.001431
	BFSW	15 th floor	6569.885	0.125	0.051	0.084	2.513	0.059	0.001082
Flat slab system	BF	-	3214.989	0.224	0.028	0.169	4.895	0.052	0.003657
	BFSW	-	4908.354	0.152	0.044	0.100	2.915	0.053	0.001938
	BFSW	15 th floor	6112.132	0.128	0.052	0.084	2.498	0.057	0.001337

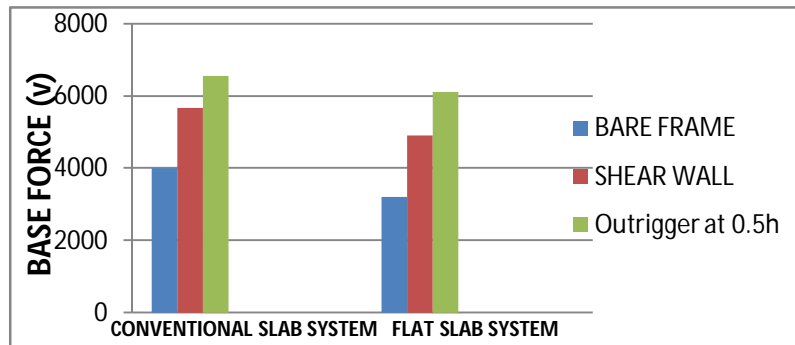


Figure 8: Comparison of Base force at performance point obtained from pushover analysis of different cases of conventional slab system and flat slab system

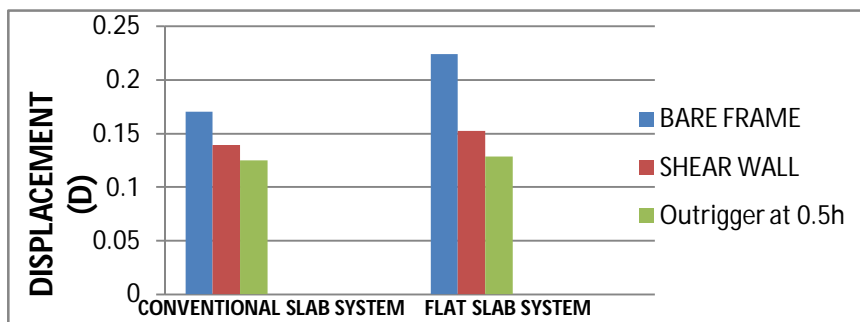


Figure 9: Comparison of Displacement at performance point obtained from pushover analysis of different cases of conventional slab system and flat slab system

Storey drift values for each floor and the graph of storey drift vs. storey height is plotted in a graph for all the models are given in the table 6 and graph 1. The percentage increase in base force and displacement for CVBFSW & CVBFSW015 in comparison with CVBF are shown in the table 7 from which it is inferred that the base shear values were considerably high for the conventional slab cases when compared to the flat slab cases as the self weight of the flat slab building is less compared to the former.

It is feasible to provide the outriggers for the conventional slab system with the highest base shear of 6569.885kN and displacement of 125mm and base shear of 6112.132kN with the least displacement of 128mm for the flat slab systems. When the spectral displacement value obtained from the capacity demand curve is carefully observed, we can see that it is same for both conventional and flat slab model with outrigger provided at floor 15 i.e., 8.4cm. The provision of outriggers has made both conventional and flat slab models behave similarly. Even the other performance

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parameters values for the models with outrigger for flat slab systems are close to the values of conventional slab systems. Hence, it is concluded that the provision of outriggers in flat slab systems improves its lateral load resistance and behaves almost as good as conventional slab systems in the seismic regions.

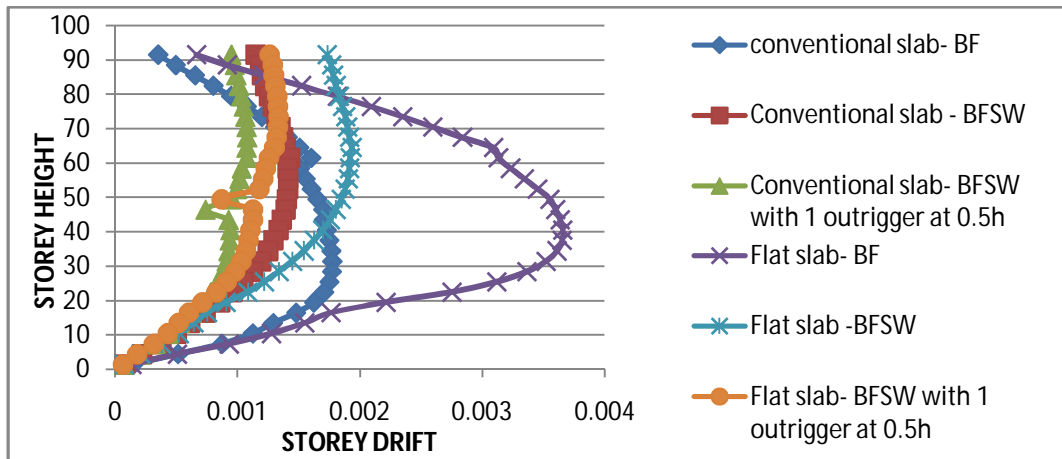
Table 6: Storey drift values of each floor for CVBF, CVBFSW, CVBFSW015, FSBF, FSBFSW and FSBFSW015 models are shown below

STOREY NO.	STOREY HEIGHT (m)	Drift X (m)					
		CVBF	CVBFSW	CVBFSW015	FSBF	FSBFSW	FSBFSW015
STORY30	91.5	0.000354	0.001151	0.000953	0.000668	0.001736	0.001266
STORY29	88.5	0.000498	0.001185	0.00098	0.00092	0.00177	0.001291
STORY28	85.5	0.000656	0.001202	0.000994	0.001218	0.001785	0.001301
STORY27	82.5	0.000807	0.001229	0.001014	0.001523	0.001809	0.001315
STORY26	79.5	0.00095	0.00126	0.001034	0.001816	0.001836	0.001328
STORY25	76.5	0.001081	0.001291	0.001053	0.002093	0.001861	0.001337
STORY24	73.5	0.001202	0.001321	0.001068	0.002352	0.001885	0.00134
STORY23	70.5	0.001313	0.00135	0.001078	0.002598	0.001904	0.001336
STORY22	67.5	0.001415	0.001374	0.001082	0.002839	0.001918	0.001323
STORY21	64.5	0.001511	0.001394	0.001078	0.003093	0.001938	0.001306
STORY20	61.5	0.001606	0.001431	0.00108	0.003132	0.001922	0.001264
STORY19	58.5	0.001515	0.00141	0.001038	0.003231	0.001919	0.001236
STORY18	55.5	0.00156	0.001417	0.001018	0.003342	0.001905	0.001216
STORY17	52.5	0.00161	0.001414	0.000997	0.003451	0.001883	0.001181
STORY16	49.5	0.001658	0.001405	0.000961	0.003553	0.001851	0.000875
STORY15	46.5	0.001704	0.001393	0.000741	0.003598	0.001806	0.001132
STORY14	43.5	0.00171	0.001362	0.00093	0.003636	0.001759	0.001133
STORY13	40.5	0.001735	0.001335	0.000944	0.003657	0.0017	0.00111
STORY12	37.5	0.001756	0.001297	0.000938	0.003652	0.001629	0.001096
STORY11	34.5	0.001771	0.001251	0.00093	0.003611	0.001546	0.001073
STORY10	31.5	0.001779	0.001195	0.000913	0.003521	0.00145	0.001035
STORY9	28.5	0.001775	0.001128	0.000885	0.003366	0.001341	0.000982
STORY8	25.5	0.001755	0.00105	0.000842	0.003121	0.001221	0.000916
STORY7	22.5	0.001711	0.000962	0.000787	0.002753	0.001086	0.000834
STORY6	19.5	0.001629	0.000861	0.000717	0.002214	0.00091	0.000716
STORY5	16.5	0.001483	0.000739	0.000627	0.001764	0.000756	0.000605
STORY4	13.5	0.001295	0.000616	0.00053	0.001552	0.000646	0.000524
STORY3	10.5	0.001128	0.000506	0.000441	0.001277	0.000525	0.000432
STORY2	7.5	0.000878	0.000378	0.000335	0.000933	0.00038	0.000318
STORY1	4.5	0.000516	0.00022	0.000199	0.000511	0.000213	0.000182
Base	1.5	0.00015	0.000081	0.000076	0.00014	0.000077	0.000068

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Graph 1: Storey drift vs. Storey height due to EQX for CVBF, CVBFSW, CVBFSW015, FSBF, FSBFSW and FSBFSW015 models.

Table 7: The percentage increase in base force and displacement for CVBFSW & CVBFSW015 in comparison with CVBF are given below

	Percentage increase in Base force	Percentage reduction in displacement
CVBFSW	41.638%	18.235%
CVBFSW015	63.892%	26.470%
FSBFSW	52.282%	32.142%
FSBFSW015	90.113%	42.857%

V. CONCLUSIONS

The current investigation was carried out to analyse the effect of outrigger systems on 2 different slab systems- conventional slab and flat slab. This attempt was made in order to understand the potential use and efficiency of outriggers in seismic zones. Based on the pushover analysis conducted and the observations made during the present investigation the following conclusions were drawn:

- It was observed that the Pushover analysis was an efficient, simple method for seismic evaluation of structures whose results are comparable to the other 2 methods of analysis.
- As per the present study, the percentage difference between the base force and displacement of conventional and flat slab models with outrigger at mid height are 6.9674% and 2.4%. So, we can conclude that the flat slab systems are almost as efficient as conventional slab systems in the earthquake prone regions. Therefore, the outriggers are the best engineering solution for the use of flat slab systems in seismic areas.
- The pushover analysis results obtained showed that the percentage increase in base force for CVBFSW and CVBFSW015 in comparison with CVBF are 41.638% and 63.892% respectively. Similarly, the percentage reduction in displacement for CVBFSW and CVBFSW015 in comparison with CVBF are 18.235% and 26.470% respectively.
- Drift value shows efficient behaviour when the outriggers were provided. Storey drift was found to be 1.082mm in the conventional slab system case and 1.337mm in case of flat slab system.
- The hinge status and location has been noted down at the performance point obtained from static pushover results and the overall performance levels for almost all the 30 storey building models were found lie in between Life safety to Collapse prevention range.

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