

# Comparative Study of Pushover Analysis of the Conventional Slab System with two Outrigger levels

Santhosh D.<sup>1</sup>, R. Prabhakara<sup>2</sup>, Sahana Ponnamma T.D.<sup>3</sup>

Assistant Professor, Department of Civil Engineering, M.S.Ramaiah Institute of Technology, Bangalore, Karnataka,  
India<sup>1</sup>

Head of Department, Department of Civil Engineering, M.S.Ramaiah Institute of Technology, Bangalore, Karnataka,  
India<sup>2</sup>

Research Scholar, Department of Civil Engineering, M.S.Ramaiah Institute of Technology, Bangalore, Karnataka,  
India<sup>3</sup>

**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 with 1 and 2 outrigger levels are 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 and relevant conclusions were drawn. The outrigger struts was placed at 0.25h & 0.5h, 0.25h & 0.75h, 0.25h & 1h, 0.5h & 0.75h, 0.5h & 1h, 0.75h & 1h to check for the most beneficial location for the 2 outrigger levels in a structure. 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, 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 are 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 were much lower than the building frames without outriggers. A lot of analytical studies are needed to understand the influence of the performance parameters and the no. of outrigger levels in the structural performance of the conventional slabs systems. This scholarship of knowledge will be useful for the design engineers to effectively model the structure for seismic performance.

## 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 [8] 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 [7]. Po Seng Kian [4] and Kiran Kamath, et al [3] 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 2<sup>nd</sup> 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 [9]. In our present work, the behaviour of 30 storey RC frame building having conventional slab system was studied with one outrigger level and 2 outrigger levels so as to know the effect of no. of outrigger levels in a structure on its lateral force resistance.

### 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:

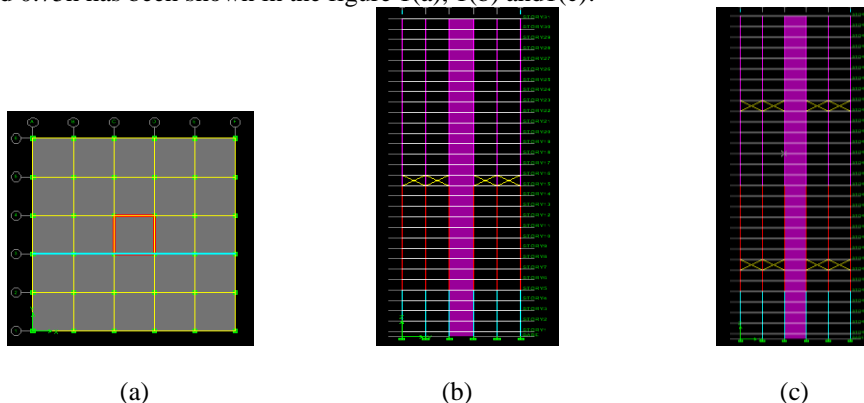
Case 1: RC bare frame with conventional slab system and central shear wall core with single outrigger level at the optimum height of 0.5h [CVBFSW015]

Case 2: RC bare frame with conventional slab system having shear wall with 2 outrigger levels

- Outrigger struts at 0.25h & 0.5h [CVBFSW07,15]
- Outrigger struts at 0.25h & 0.75h [CVBFSW07,22]
- Outrigger struts at 0.25h & 1h [CVBFSW07,30]
- Outrigger struts at 0.5h & 0.75h [CVBFSW015,22]
- Outrigger struts at 0.5h & 1h [CVBFSW015,30]
- Outrigger struts at 0.75h & 1h [CVBFSW022,30]

#### 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 & elevation of RC frame with conventional slab system and central shear wall core with single Outrigger level at 0.5h and elevation of RC frame with conventional slab system and central shear wall core with 2 Outrigger levels at 0.25h and 0.75h has been shown in the figure 1(a), 1(b) and 1(c).



**Figure 1:** Plan & elevation of the models with one and two outrigger levels

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 10, October 2015

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
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 <sup>2</sup>
Poisson's ratio	0.2
Coefficient of thermal expansion	9.900E-06
Shear modulus	10416666.7 kN/m <sup>2</sup>

### 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/m<sup>2</sup>  
Default load combinations given in the software were considered.
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.

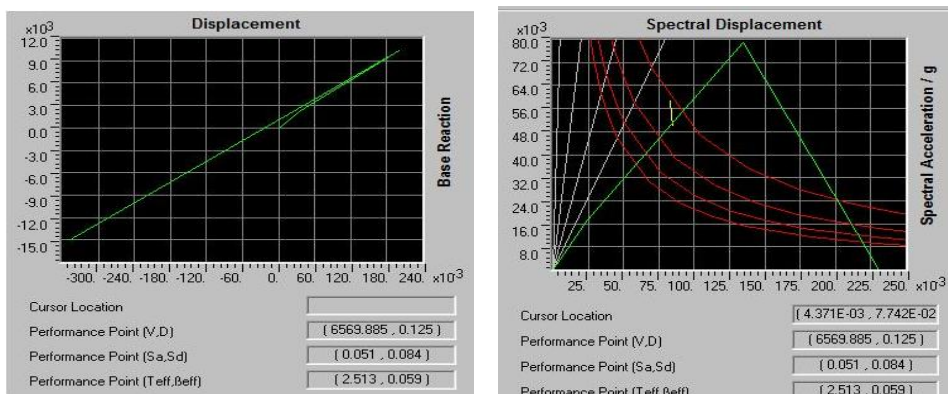
Typically a gravity load pushover is force controlled and lateral pushover is displacement controlled. In our analysis in Etabs 9.7.4 more than 1 pushover load cases were defined and were run in the same analysis. The user defined pushover displacement magnitude of 3.66m obtained by default for each 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. After the analysis was complete, static nonlinear pushover curve and the pushover table was obtained. As the values of seismic coefficient of acceleration, Ca & seismic coefficient of velocity Cv, damping ratios etc., were varied, the pushover curves and performance point values changed accordingly. The required Ca & Cv 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

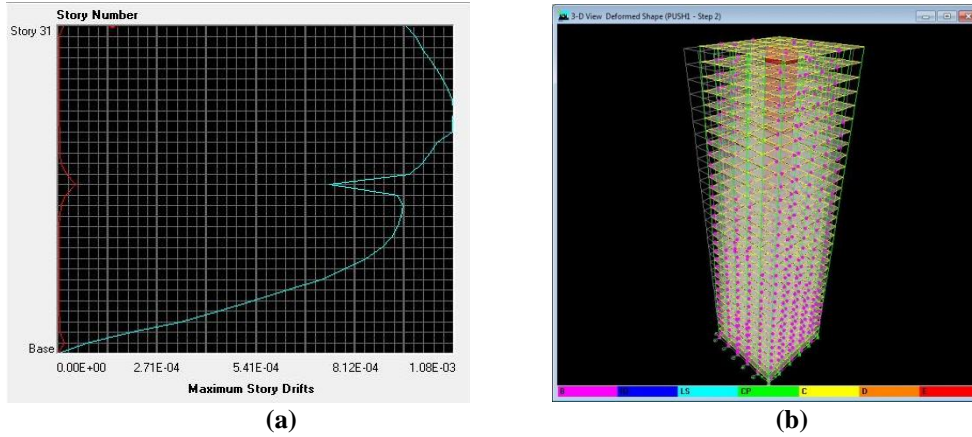
The efficient lateral force resistance was seen in the structure with two outrigger levels compared to single outrigger level. Detailed observations of the results obtained from the analysis of 30 storey building having shear wall with 1 and 2 outrigger levels were recorded and are given below:

#### 4.1 Single outrigger level

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(a), 3(b) and table 3 respectively.



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



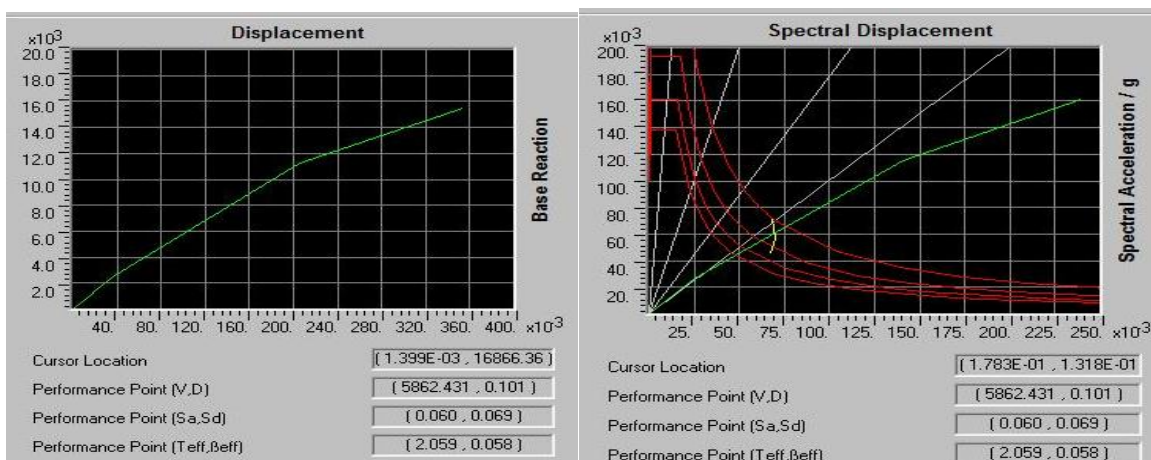
**Figure 3(a):** Storey drift diagram along EQX direction for CVBFSW015 (b) Status of plastic hinges at the performance point for CVBFSW015

**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	-15099.956	5952	0	0	0	0	0	0	0	5952

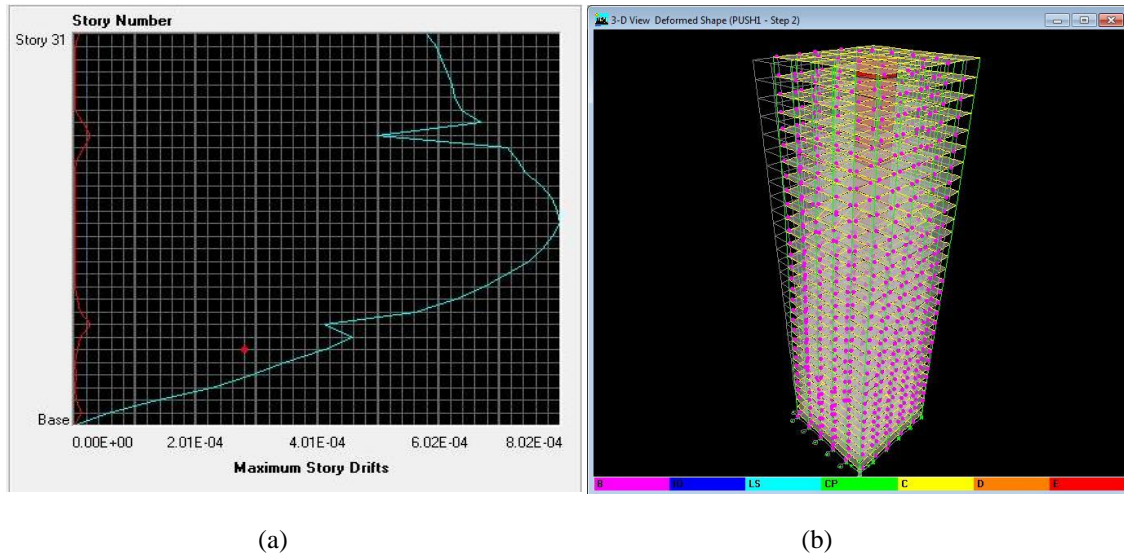
**4.2 Two outrigger levels**

The Pushover curve and the demand curve for the bare frame with conventional slab system and central shear wall with outriggers at floor 7 & 22 model are represented in the figure 4(a) and 4(b). Storey drift diagram along EQX direction, Status of plastic hinges at the performance point, Data of pushover curve for the CVBFSW07, 22 are presented in the figure 5(a), 5(b) and table 4 respectively.



**Figure 4: a)** Pushover curve obtained for CVBFSW07, 22 **b)** Capacity curve obtained for CVBFSW07, 22





**Figure 5:** a) Storey drift diagram along EQX direction for CVBFSW07, 22 b) Status of plastic hinges at the performance point for CVBFSW07, 22

**Table 4:** Data of pushover curve for CVBFSW07,22

Step	Displacement (m)	Base Force (kN)	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	0.0373	2602.8035	4462	1490	0	0	0	0	0	0	5952
2	0.2050	11241.5078	3890	1940	118	4	0	0	0	0	5952
3	0.3544	15460.8838	5952	0	0	0	0	0	0	0	5952

### 4.3 Discussions

In order to have a comparative evaluation of single and two outrigger level systems, variations of the performance parameters at the performance point are given in the following table 5. The comparison of base force and displacement separately in the form of bar charts for both one and two outrigger level cases are shown in the figure 6 & 7 respectively. 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 reduction in displacement for CVBFSW, CVBFSW07,15, CVBFSW07,22, CVBFSW07,30, CVBFSW015,22, CVBFSW015,30 and CVBFSW022,30 in comparison with CVBF are shown in the table

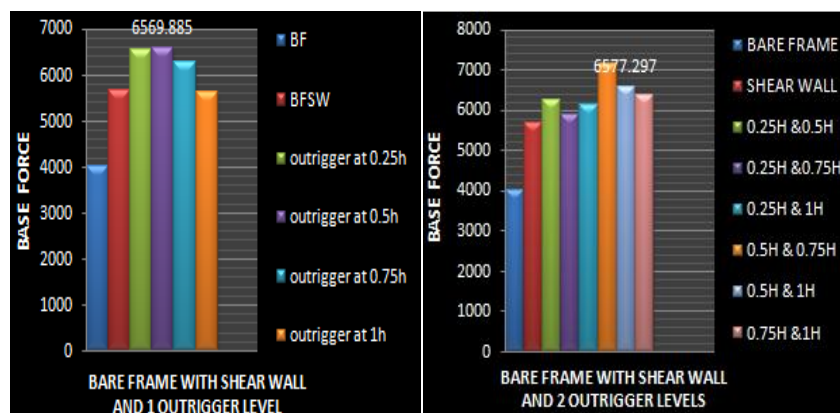
## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

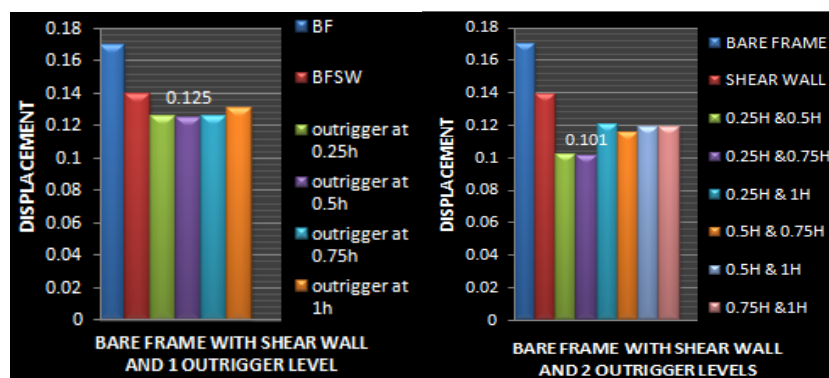
Vol. 4, Issue 10, October 2015

**Table 5:** Comparison of Performance parameters at the performance point for the models with Conventional slab system having one outrigger level and two outrigger levels are shown below

Case	Type	Outrigger level	Base force (kN)	Displacement (m)	S <sub>a</sub> (m <sup>2</sup> /s)	S <sub>d</sub> (m)	T <sub>eff</sub> (s)	β <sub>eff</sub>
One outrigger level	BF	-	4008.658	0.170	0.030	0.130	4.155	0.076
	BFSW	-	5677.788	0.139	0.045	0.095	2.847	0.059
	BFSW	7 <sup>th</sup> floor	6561.417	0.126	0.054	0.084	2.506	0.057
	BFSW	15 <sup>th</sup> floor	6569.885	0.125	0.051	0.084	2.513	0.059
	BFSW	22 <sup>nd</sup> floor	6278.692	0.126	0.047	0.089	2.703	0.061
	BFSW	30 <sup>th</sup> floor	5625.841	0.131	0.044	0.094	2.797	0.058
Two outrigger levels	BFSW	7 <sup>th</sup> & 15 <sup>th</sup> floor	6254.230	0.102	0.064	0.066	1.984	0.059
	BFSW	7 <sup>th</sup> & 22 <sup>nd</sup> floor	5862.431	0.101	0.060	0.069	2.059	0.058
	BFSW	7 <sup>th</sup> & 30 <sup>th</sup> floor	6127.097	0.120	0.049	0.084	2.500	0.058
	BFSW	15 <sup>th</sup> & 22 <sup>nd</sup> floor	7161.599	0.115	0.053	0.080	2.411	0.060
	BFSW	15 <sup>th</sup> & 30 <sup>th</sup> floor	6577.297	0.119	0.050	0.083	2.480	0.058
	BFSW	22 <sup>nd</sup> & 30 <sup>th</sup> floor	6361.188	0.119	0.047	0.089	2.704	0.061



**Figure 6:** Comparison of Base force (kN) at performance point obtained for the models of one and two outrigger levels



**Figure 7:** Comparison of Displacement (m) at performance point obtained for the models of one and two outrigger levels

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 10, October 2015

**Table 6:** Storey drift values of each floor for CVBFSW07,15, CVBFSW07,22, CVBFSW07,30, CVBFSW015,22, CVBFSW015,30 and CVBFSW022,30 models are shown below

STOREY NO.	STOREY HEIGHT (m)	Drift X (m)					
		CVBFW 07,15,	CVBFW 07,22,	CVBFW 07,30,	CVBFSW 015,22,	CVBFW 015,30	CVBFW 022,30
STORY30	91.5	0.000724	0.000582	0.000517	0.000704	0.000482	0.00035
STORY29	88.5	0.000745	0.000598	0.000725	0.000724	0.000657	0.000496
STORY28	85.5	0.000755	0.000606	0.000759	0.000733	0.000686	0.000524
STORY27	82.5	0.00077	0.000615	0.00082	0.000743	0.000736	0.000563
STORY26	79.5	0.000785	0.000624	0.000886	0.000751	0.000789	0.0006
STORY25	76.5	0.000799	0.000628	0.000949	0.000753	0.000838	0.000637
STORY24	73.5	0.00081	0.000638	0.001006	0.000759	0.00088	0.000662
STORY23	70.5	0.000816	0.000671	0.001057	0.00079	0.000914	0.000698
STORY22	67.5	0.000817	0.0005	0.001102	0.000593	0.00094	0.000485
STORY21	64.5	0.000812	0.000715	0.001138	0.000815	0.000957	0.000805
STORY20	61.5	0.000811	0.000733	0.001184	0.000819	0.000977	0.000881
STORY19	58.5	0.000776	0.000745	0.001178	0.000814	0.000953	0.000937
STORY18	55.5	0.000758	0.000772	0.00119	0.000827	0.000947	0.001001
STORY17	52.5	0.000737	0.000789	0.001191	0.000838	0.000938	0.001054
STORY16	49.5	0.000705	0.000798	0.001183	0.000832	0.000913	0.001094
STORY15	46.5	0.000541	0.000802	0.001169	0.000668	0.000716	0.001127
STORY14	43.5	0.000664	0.000789	0.001136	0.000844	0.000899	0.001136
STORY13	40.5	0.000663	0.000774	0.001103	0.000867	0.000917	0.00114
STORY12	37.5	0.000646	0.00075	0.001058	0.000872	0.000915	0.001133
STORY11	34.5	0.000626	0.000716	0.001002	0.000873	0.00091	0.001113
STORY10	31.5	0.0006	0.000675	0.000937	0.000864	0.000896	0.001081
STORY9	28.5	0.000569	0.00063	0.000868	0.000842	0.00087	0.001036
STORY8	25.5	0.000517	0.000563	0.00077	0.000806	0.00083	0.000978
STORY7	22.5	0.000386	0.000413	0.000558	0.000756	0.000776	0.000906
STORY6	19.5	0.000431	0.000458	0.000618	0.000692	0.000709	0.00082
STORY5	16.5	0.000392	0.000413	0.000554	0.000607	0.00062	0.000711
STORY4	13.5	0.000331	0.000345	0.000461	0.000515	0.000525	0.000598
STORY3	10.5	0.000283	0.000293	0.00039	0.00043	0.000438	0.000497
STORY2	7.5	0.000221	0.000227	0.0003	0.000328	0.000333	0.000378
STORY1	4.5	0.000135	0.000138	0.000182	0.000195	0.000198	0.000224
Base	1.5	0.000054	0.000055	0.000072	0.000075	0.000076	0.000084



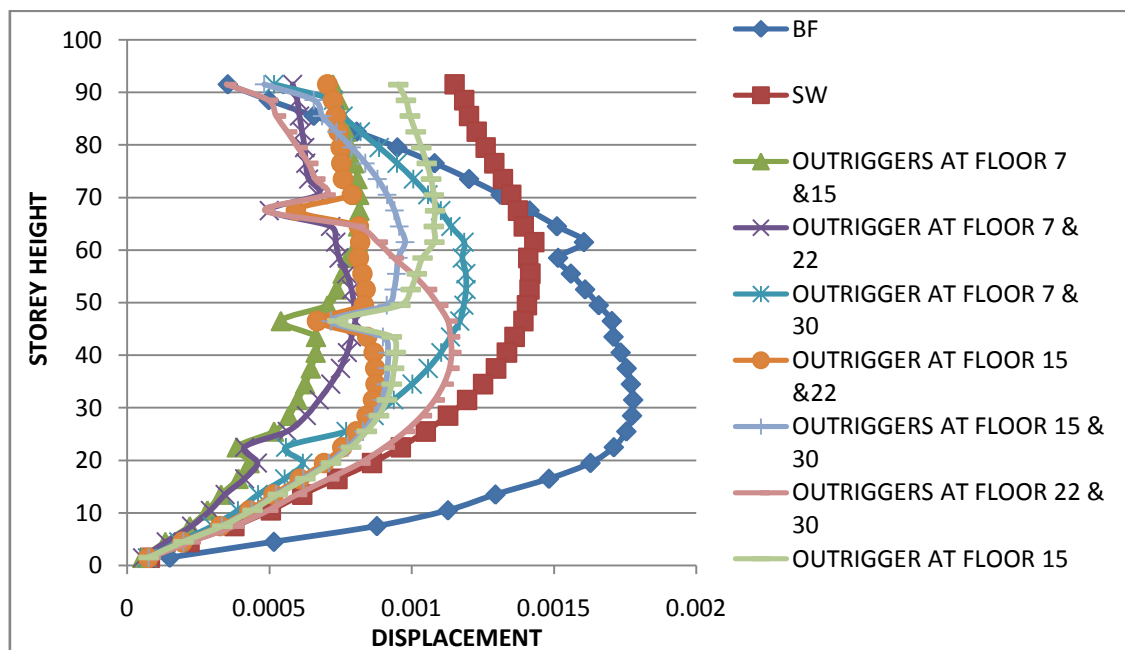
# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 10, October 2015

**Table 7:** The percentage increase in base force and displacement for CVBFSW, CVBFSW07,15, CVBFSW07,22, CVBFSW07,30, CVBFSW015,22, CVBFSW015,30 and CVBFSW022,30 in comparison with CVBF are given below

	Percentage increase in Base force	Percentage reduction in displacement
CVBFSW	41.638%	18.235%
CVBFSW07,15	56.018%	40.000%
CVBFSW07,22	46.244%	40.588%
CVBFSW07,30	52.846%	29.411%
CVBFSW015,22	78.653%	32.352%
CVBFSW015,30	64.077%	30.000%
CVBFSW022,30	58.686%	30.000%



**Graph 1:** Storey height vs. displacement due to EQX plotted for CVBF, CVBFSW, CVBFSW07,15, CVBFSW07,22, CVBFSW07,30, CVBFSW015,22, CVBFSW015,30, CVBFSW022,30 and CVBFSW015 models

It is observed that the percentage increase in base force obtained from the model with two outrigger levels was found to be 0.112% higher than one outrigger level case and percentage reduction in the displacement was found to be 19.2% less than the model with just one outrigger level. By providing 2 outrigger levels, the lateral displacement reduced with a good margin without much increase in base force. The storey drift variation along the building height of the 2 outrigger level models to that of the single outrigger level.

## V. CONCLUSIONS

The current investigation was carried out to analyse the effect of no. of outrigger systems. 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.
- It was concluded that the optimum level for providing outriggers is at 0.25h and 0.75h for the 2 outrigger level case.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 10, October 2015

- Provision of 2 outriggers in a structure gave reduced lateral displacement when compared to the single outrigger level case.
- 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.

## REFERENCES

- [1] Sahana Ponnamma T.D., Santhosh D., R. Prabhakara, "Comparative Study of Pushover Analysis of the Conventional Slab System with Outrigger and Flat Slab System with Outrigger", International Journal of Innovative Research in Science, Engineering and Technology, ISSN: 2319-8753, Vol. 4, Issue 8, August 2015
- [2] D. Santhosh, "Pushover analysis of RC frame structure using ETABS 9.7.1", IOSR Journal of Mechanical and Civil Engineering, ISSN: 2278-1684, Volume 11, Issue 1 Ver. V, Feb. 2014.
- [3] Kiran Kamath, N. Divya and Asha U. Rao, "A Study on Static and Dynamic Behaviour of Outrigger Structural System for Tall Buildings", Bonfring International Journal of Industrial Engineering and Management Science, Vol. 2, No. 4, December 2012.
- [4] Po Seng Kian, "The use of outrigger and belt truss system For high-rise concrete buildings", Dimensi Teknik Sipil, ISSN 1410-9530, Vol. 3, No. 1, Maret 2001.
- [5] Srividya, Kalayani Rao, Kavya and R. Prabhakara, "Cracking Load and Deflection of Infilled Frames Using Pushover Analyses", Proceedings of international conferences on advances in Architecture and civil engineering, Vol.1, Paper ID sam209, June 2012.
- [6] Santhosh. D.and N. Jayaramappa, "Non linear static analysis of RC frame structures", IOSR journal of mechanical and civil engineering, ISSN: 2278-1684Vol. 11, Issue 02, Ver 2., pp 78-89 March april-2014.
- [7] N. Herath, N. Haritos, T. Ngo & P. Mendis, "Behaviour of Outrigger Beams in High rise Buildings under Earthquake Loads", Australian Earthquake Engineering Society Conference, Civil & Environmental Engineering, University of Melbourne, Parkville, Victoria 3010, 2009.
- [8] Hi Sun Choi and Leonard Joseph, "Outrigger system deisgn considerations", International journal of high-rise buildings, Vol. 1, No. 3, september 2012.
- [9] S. Fawzia and T. Fatima, "Deflection Control in Composite Building by Using Belt Truss and Outriggers Systems", International Scholarly and Scientific Research & Innovation, World Academy of Science, Engineering and Technology, Vol. 4, 2010-12-22, 2010.
- [10] IS 1893 "Criteria for Earthquake Resistant Design of Structures, Part1: General Provisions and Buildings", Bureau Of Indian Standards, ICS 91.120.25, Fifth Revision, 2002, Reaffirmed 2007.