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Seismic Time History Performance of Conventional Multi-Outriggers with Mega Columns

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Abstract - *In the modern society, High-rise buildings have become a major asset to a city or state. While high-rise structures offers many advantages in the functioning of a city it also poses great challenge for structural and geotechnical engineers, particularly if it is situated in seismically active region. The use of Outriggered System is widely used in the field of high rise construction majorly to resist wind load. The performance of Outriggers is very underrated to resist Seismic loads. There is a need to give an opportunity to assess the performance of Outriggers with various configurations and estimate its effectiveness in areas of high seismicity.*

Key Words: *High-rise Structure, Outriggers, Belt Truss, Virtual Outriggers, Seismic Analysis, Time History analysis*

1. INTRODUCTION

The concept of outrigger was employed in the sailing ship in order to increase the stability and the strength of the masts subjected to wind forces. From this point of view, a tall building could be considered analogous to the mast of a ship in presence of further elements similar in behaviour to the spreaders and stays. Thus, the engineers understood that it was possible to couple the internal core of the building with the exterior columns.

1.1 Working principle of Outriggers

When horizontal loading acts on the structure, the rotation of the core is reduced by the axial force that arises in the external columns, in particular tensile force in the windward columns and compressive force in the leeward ones. The efficiency of the outrigger system depends upon the flexural stiffness of the girder and the axial stiffness of perimeter vertical columns. In addition, including deep spandrel girders, which work as belts surrounding the entire building, it is possible to mobilize also the other peripheral columns to assist in restraining the outriggers, providing an improvement up to 25-30 per cent in stiffness.

2. PROBLEM FORMULATION

In this study, 5 different models of 35 stories are created in ETABS software to assess the performance of Outriggers with different configurations under static, dynamic & time history load cases.

2.1. Executive summary of Models:

1. Seismic Zone: *Zone-V (as per IS1893-2002)*
2. Soil Type: *Type 1 (Hard Soil, per IS1893-2002)*
3. Grade of Concrete & Rebar: *M70 (for Columns), M30 (for beam-slabs) & Fe-500*
4. Size of beams: *375 X 850mm (typical)*
5. Size of Columns: *750X750mm(typical), 1000X1500mm (mega columns)*
6. Size of bracing member for Outrigger steel truss: *SHS 400X400X16 (Hollow Square section of Fe-250)*
7. Height of floors: *3.5m typical*
8. Frame Type: *SMRF (Special Moment Resisting Frame)*
9. Response reduction factor (R): *4 (IS-1893:2002)*
10. Time History data: *El Cantro Earthquake in Time domain*

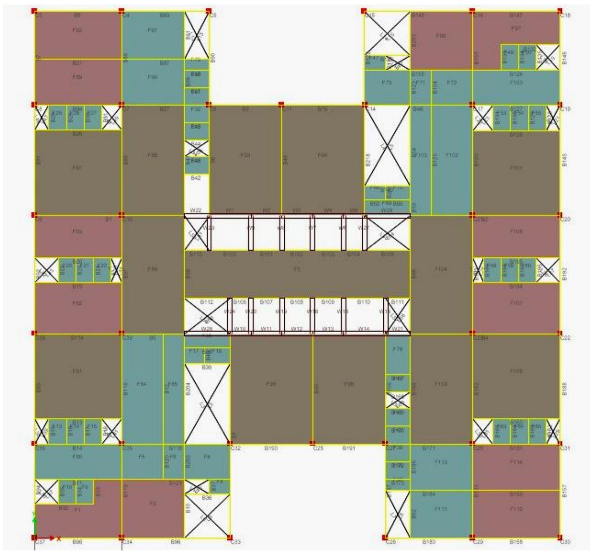

Fig -1: Structural layout plan of the model showing different elements

2.2 Combinations for Models

Based on the literature review and the gaps found in the research, the combinations of model for different Outrigger systems are obtained. The various model combinations are listed below;

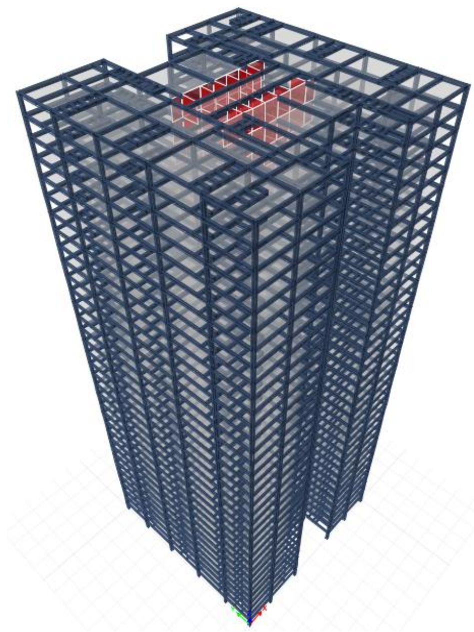

Fig -2: Three dimensional extruded view of the 35 storied building frame

1. *RCC bare frame with shear core walls (base model for comparison)*
   The model has a shear wall core and beam column frame
2. *Two Outrigger Model*
   The model has bare frame with shear walls with one outrigger at top story and another outrigger at a mid height storey
3. *Two Outriggers with Belt truss*
   The configuration is same as the model with two outriggers with belt truss on complete periphery of Outrigger story
4. *Three Outriggers*
   Three Outriggers are modeled out of which one is placed at top and another two are equally spaced throughout the height
5. *Outriggers with Mega Columns*
   This model is same as “Two Outrigger” model with additional Mega Columns of larger size supporting the outer side of the Outriggers.

All of above configuration are so decided that the versatile performance of Outriggers can be judged.

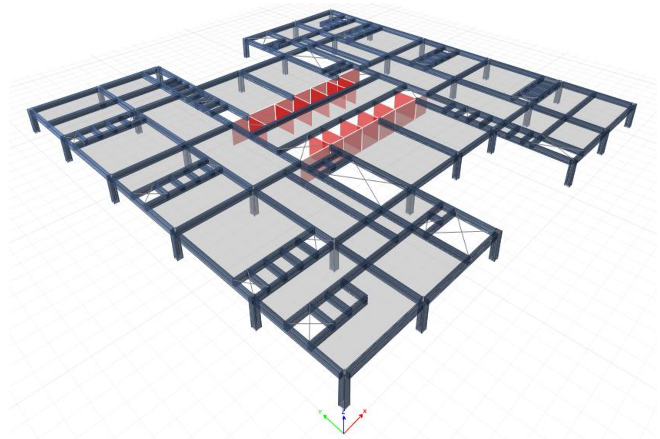

Fig -3: Three dimensional extruded view of typical storey layout

3. METHODOLOGY

A brief description of linear and non liner methods of assessment of structure with Finite Element theory is explained below.

3.1. Linear Analysis

For Linear Static Analysis, Seismic Coefficient Method which is suggested in IS-1893-2002 shall to be performed. In this method, mass of the structure multiplied by design seismic coefficient, acts statically in a horizontal direction. It is also assumed here that the magnitude of the coefficient is uniform for the entire members of the structure. Design shears at different levels in a building shall be computed from the assumption of linear distribution horizontal accelerations, varying from zero at the base of the structure to a maximum at the top. For important and complicated structures this method is not adequate.

Furthermore, all the model combinations are analysed with Response Spectrum method, which is a Linear Dynamic method of analysis. There are certain computational advantages in using the Response Spectrum method of Seismic Analysis for prediction of displacements and member forces in structural system. The method involves the calculation of only the maximum values of the displacements and member forces in each mode of vibration using smooth design spectra that are the average of several earthquake motions. The seismic analysis of structures cannot be carried out simply based on the peak value of the ground acceleration as the response of the structure depend upon the frequency content of ground motion and its own dynamic properties. To overcome the above difficulties, earthquake response spectrum is the most popular tool in the seismic analysis of structures.

3.2. Nonlinear Analysis

When the load acting on a structure and the resulting deflections are small enough, the load-deflection relationship for the structure is linear. This permits the program used for analysis (ETABS/SAP2000) to form the equilibrium equations using the original (un-deformed) geometry of the structure. Strictly speaking, the equilibrium equations should actually refer to the geometry of the structure after deformation.

- P-delta (large-stress) effect: when large stresses (or forces and moments) are present within a structure, equilibrium equations written for the original and the deformed geometries may differ significantly, even if the deformations are very small.
- Large-displacement effect: when a structure undergoes large deformation (in particular, large strains and rotations), the usual engineering stress and strain measures no longer apply, and the equilibrium equations must be written for the deformed geometry. This is true even if the stresses are small.
- Material nonlinearity: when a material is strained beyond its proportional limit, the stress-strain relationship is no longer linear. Plastic materials strained beyond the yield point may exhibit history-dependent behavior.

For Nonlinear Dynamic analysis of this study, Time History method of analysis is performed on all the models. In Time History method, the non-linear properties of the structure are considered as part of a time domain analysis. This approach is the most rigorous, and is required by some building codes for buildings of unusual configuration or of special importance. However, the calculated response can be very sensitive to the characteristics of the individual ground motion used as seismic input; therefore, several analyses are required using different ground motion records to achieve a reliable estimation of the probabilistic distribution of structural response. Since the properties of the seismic response depend on the intensity, or severity, of the seismic shaking, a comprehensive assessment calls for numerous nonlinear dynamic analyses at various levels of intensity to represent different possible earthquake scenarios.

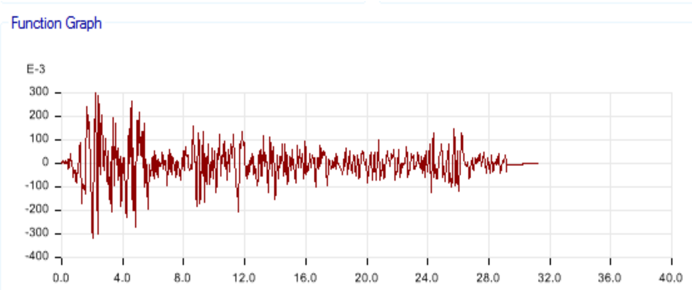

Fig -4: El Centro Earthquake Function input spectra in ETABS 2015

In which, structure will be subjected to various Time-history Load Functions of major earthquakes in world (for example- El Centro, Santa Monica) and time-history behaviour of the structure subjected to these Load Functions shall be studied using ETABS software.

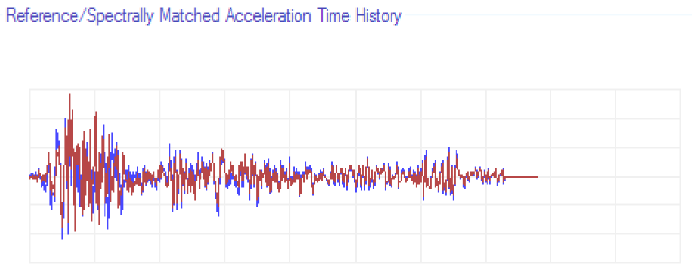

Fig -5: Time History function matched to Codal spectral function in Time domain using ETABS 2015

3. RESULTS AND DISCUSSION

The bifurcations on assessment of seismic performance is done on basis of following parameters namely,

a. Story displacement
b. Time Period
c. Inter-story drift

3.1 Storey Displacement

The diaphragm centre of mass displacement in ETABS which represents deviation of top most story in X and Y direction for various models with different heights are studied and discussed below.

Table -1: Top story deflection of various models of 35 stories

Top story deflection of various models of 35 stories					
Load Case	1- Bare Frame	2- Two Outrigger at Top and Centre		3-Two Outrigger with Belt truss	
	UX or UY (mm)	*UX or UY (mm)*	% Reduction to Bare Frame	*UX or UY (mm)*	% Reduction to Bare Frame
EQX	80.8	65.8	**19%**	66.1	**20%**
SPECX	48.7	45.4	7%	44.5	9%
THX	38.8	38	2%	37.1	4%
EQY	254	218	14%	209.9	17%
SPECY	122	106.3	13%	102.7	16%

Load Case	4- Three Outriggers		5-Two Outriggers with Mega Columns	
	UX or UY (mm)	% Reduction to Bare Frame	*UX or UY (mm)*	% Reduction to Bare Frame
EQX	61.4	24%	56.1	31%
SPECX	43.4	11%	41.6	15%
THX	37.6	3%	37.4	4%
EQY	186.8	**26%**	183.8	**28%**
SPECY	91.1	25%	89.5	27%

Diaphragm centre of mass displacement of individual stories of various models in both X and Y directions are mentioned, plotted and discussed below;

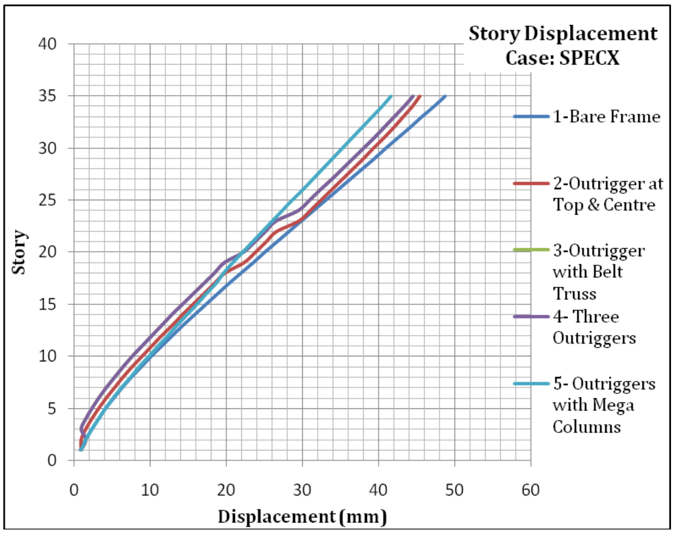

Chart -1: Story displacement for 35 storied models in load case Response Spectrum X

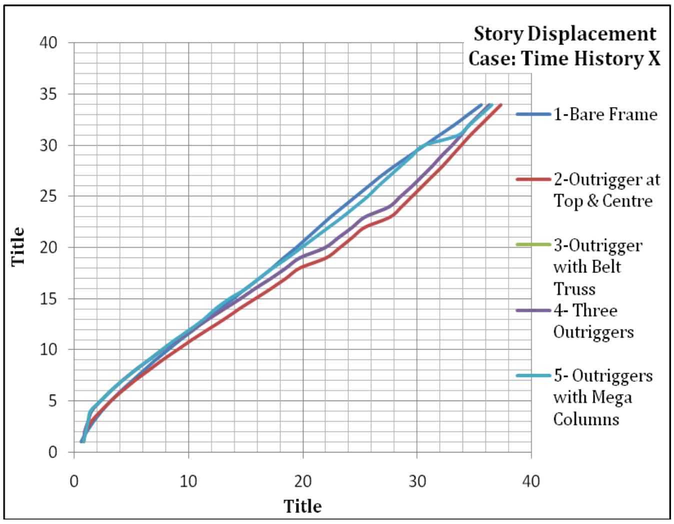

Chart -2: Story displacement for 35 storied models in load case Time History X

Observations:

i. Model with two outriggers gives more reduction in displacement for 35 storied models

ii. Addition of belt truss to conventional outrigger gives marginal reduction in displacement of around 4% to 5%.

iii. The reduction pattern in displacement is consistent among Static and Response spectrum load cases except for Time History due to its incoherent character.

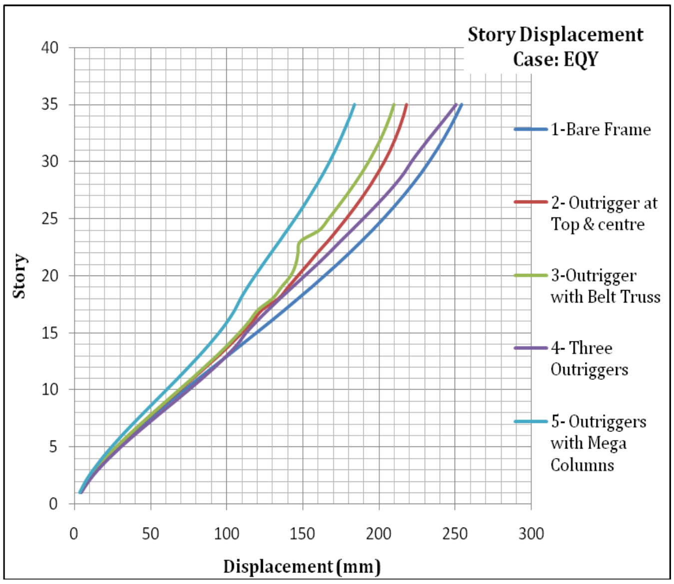

Chart -3: Story displacement for 35 storied models in load case EQY

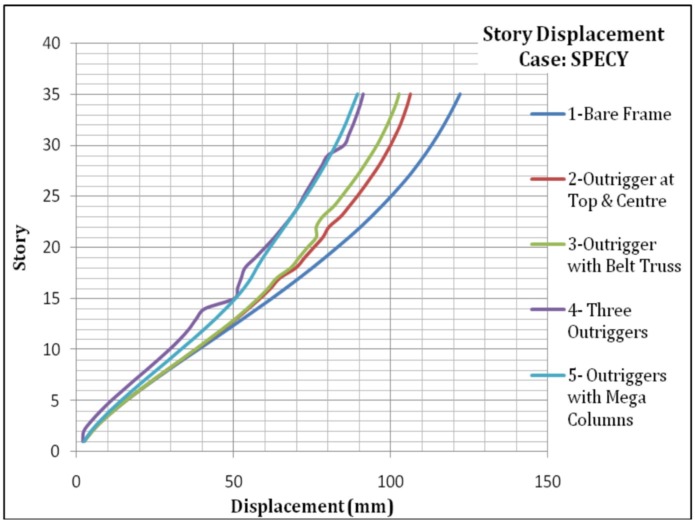

Chart 4-: Story displacement for 35 storied models in load case Response Spectrum Y

Observations:

iv. Models with three outriggers give more reductions in displacements as compared to two outriggers.

v. for higher number of stories, higher no of outriggers could be used to enhance the behaviour

vi. Model with two outriggers + mega columns gives maximum reduction in displacements even compared to models with three outriggers

3.2 Time Period

Resonant frequency of any given system is the frequency at which the maximum-amplitude oscillation occurs. All buildings have a natural, period, or resonance, which is the number of seconds it takes for the building to naturally vibrate back and forth.

Table -2: Modal v/s Equivalent Static Time Period Comparison

Time Period Modal v/s Equivalent Static (IS code)				
No of Stories	Models	1- Bare Frame	2-Outrigger at top and centre	3-Outrigger with belt truss
		(sec)	*(sec)*	*(sec)*
35 Storied Models	Equivalent Static	*2.879*	*2.879*	*2.879*
	Modal Time Period	*5.739*	*5.347*	*5.278*
% Increase in Modal Analysis		**199%**	**186%**	**183%**
No of Stories	Models	4- Three Outrigger	5-Outriggers with Mega Columns	
		(sec)	*(sec)*	
35 Storied Models	Equivalent Static	*2.879*	*2.879*	
	Modal Time Period	*4.929*	*4.865*	
% Increase in Modal Analysis		**171%**	**169%**	

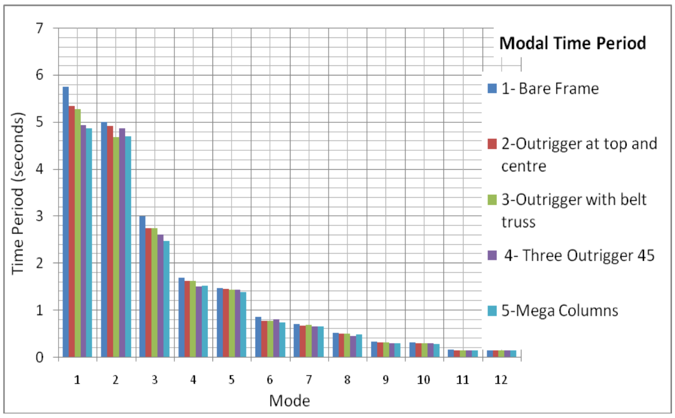

Chart -5: Modal Time Period for 35 storied models

Observations:

i. In case of bare frame, the IS codal time period is almost half as compared to Response spectrum
ii. Spectral time period keeps on decreasing by adding more no of Outrigger.
iii. Addition of outrigger reduces the Spectral time period and subsequently makes the structure more rigid.
iv. Minimum time period is observed in case of outrigger with mega columns
v. 12% of significant decrease is observed in case of model with mega columns as compared to bare frame.
vi. Difference in time period between three outriggered model and Mega column model is marginal.
vii. Difference in time period between Conventional and Outrigger with belt truss is marginal.

3.3 Inter-story Drift

Inter-story drift is the difference between the roof and floor displacements of any given story as the building sways during the earthquake, normalized by the story height. As per IS-1893 (part-I)-2002, inter-story drift shall not exceed 0.004 times the story height under minimum design seismic force.

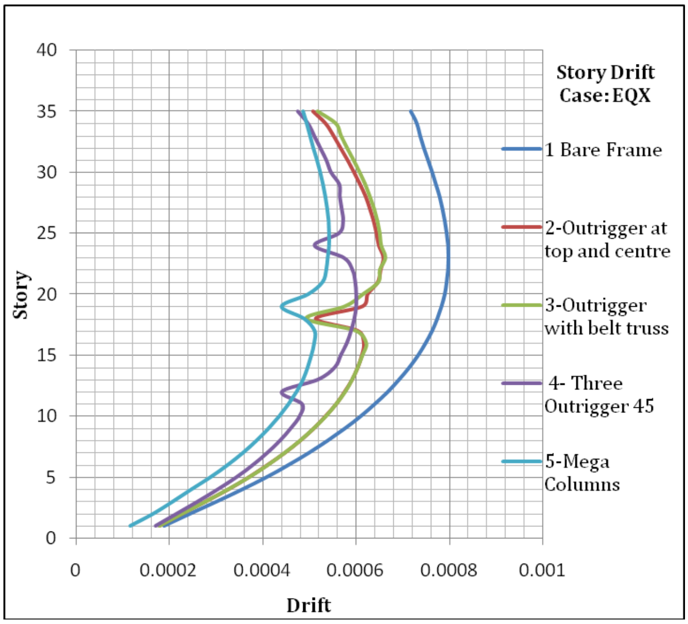

Chart -6: Inter-storey Drift of 35 storied models under load case EQX

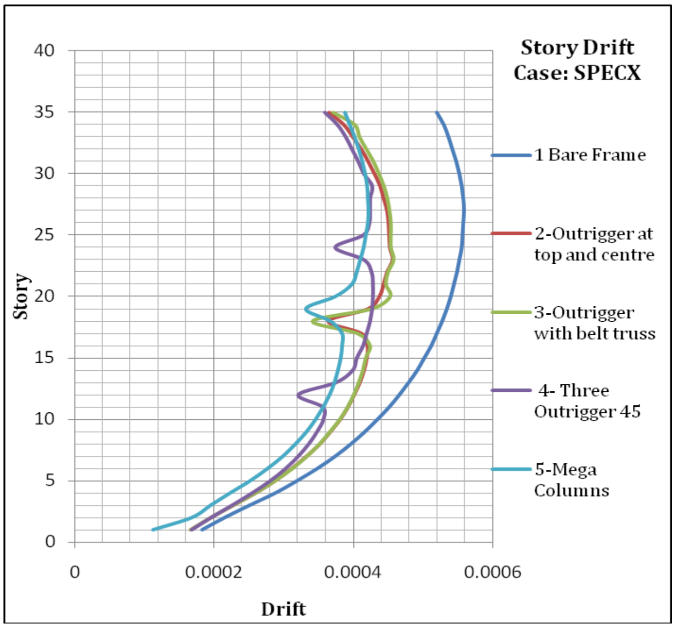

Chart -7: Inter-storey Drift of 35 storied models under load case Time History X

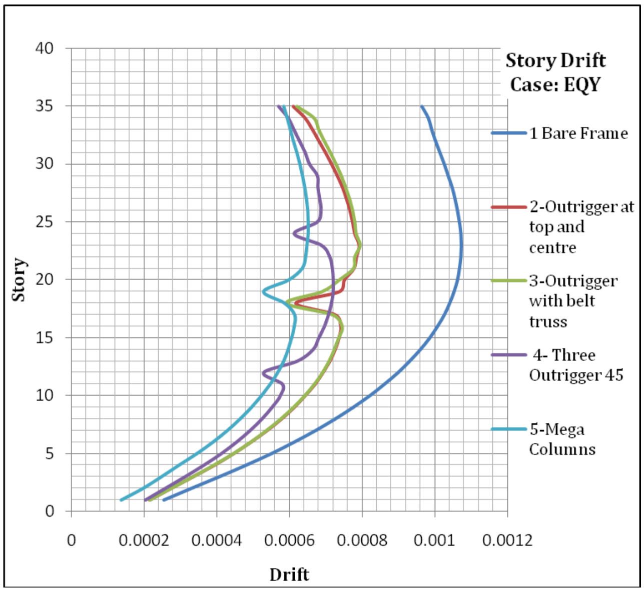

Chart -8: Inter-storey Drift of 35 storied models under load case EQY

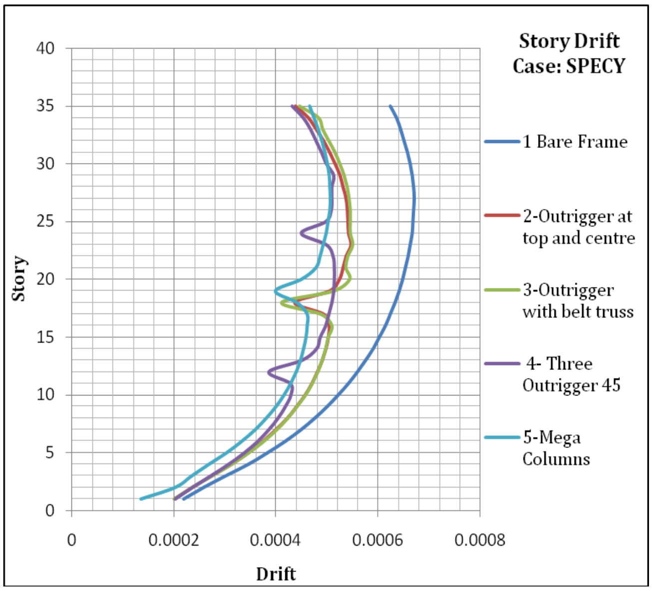

Chart -9: Inter-storey Drift of 35 storied models under load case Time History Y

Observations:

i. Story drift values significantly reduces at Outrigger locations as visible in graphs
ii. The huge reduction in story drift at Outriggers in turn reduces the slope of graph and eventually total displacement at top story
iii. For 35 stories models, difference between average drifts of Two outriggers is almost similar to models with Outriggers + belt truss
iv. Model with three outriggers gives significant reduction in average story drifts although maximum reduction is observed in case of model with Mega columns.

4. CONCLUSIONS

This research focused on studying Seismic behaviour of multi storied RC framed frames with Outriggers using ETABS program. Attempts are made in selecting the configurations which are distinct from each other so that a complete picture could be drawn to understand the performance of Outriggers under seismic loads.

The conclusions drawn from the thesis work are stated as follows;

i. In addition to the wind resistance offered by the outriggers, the resistance in deflection offered is not studied at large and is under appreciated
ii. The placement of outriggers in plan serves a great role in deciding its behaviour.
iii. Despite being square in shape, the frames gave lesser deflections and drift in X direction as compared to Y- direction. Such difference is because the Outriggers in X- direction are aligned on either side of the Shear wall core whereas; it is slightly staggered in Y- direction.
iv. The Non-linear Time History load case of El Centro earthquake generated lesser base shear then IS code's Equivalent static method.
v. Significant reduction in top story displacement is observed with Outriggers. Especially, reduction up to 31% is observed in top story displacement in Model 5- Outriggers with Mega columns. Reduction up to 26% was achieved in Model 4- Three Outriggers.
vi. The effect of Outriggers can be directly observed in kinks on Outriggered floors in Storey Drift plots. Reduction up to 39% in average drifts can be observed in model with Mega columns & 33% reduction observed in model with three outriggers.
vii. Addition of Belt truss to conventional outrigger system showed marginal benefit in the current set of models under study.
viii. Modal time period decreases by addition of Outriggers. Least modal time period is observed in model with Mega columns.
ix. Model 5- with two Outriggered stories provides better performance in terms of displacement and drift reduction as compared to Model 4- with Three Outriggered stories.

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