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RC Building behaviour Subjected to Earthquake and Wind Effect with Outrigger System

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ABSTRACT

The outrigger and belt truss system is commonly used as one of the structural system to effectively control the excessive drift due to lateral load, so that at the time of small or medium lateral load due to either wind or earthquake load, the risk of structural and non-structural damage can be minimized. For high-rise buildings, particularly in seismic active zone or wind load dominant, this system can be chosen as an appropriate structure. This paper studies the use of outrigger and belt truss system for high-rise concrete building subjected to wind or earthquake load. In this thesis 50, 55 and 60 storey two dimensional models of outrigger and are subjected to wind load. For the two dimensional 50 storey model, 65% maximum displacement reduction can be achieved by providing first outrigger at the top and second outrigger at the middle of the structure height. For the two dimensional 60 storey structural model subjected to the earthquake load, about 18 % reduction in maximum displacement can be achieved with optimum location of the outrigger truss placed at the top and the 33rd level. It has been observed that the maximum reaction has been generated in the soil type III (Soft soil) for all three structures (G+50, G+55 & G+60). It can be concluded after reviewing the values in table of base shear that Gust Factor load case governs the analysis as well as design for the soil type I (Hard Soil). The base shear generated by the Gust Factor load case is maximum among all the load cases in soil type I. It is safer to build tall structure on the soil type I (hard soil) rather than soil type II, (medium soil) and soil type III (soft soil).

1. INTRODUCTION

1.1 General

Now a days it is the most common trend in the world of structures to go for the tall buildings, this trend has raised many issues with it to be taken into consideration, the major issue that affects the design of tall structures, is its sensitivity to the lateral load. One of the important criteria for the design of tall buildings is lateral sway (deflection) and storey drift together along with the strength criteria. Now the question is how to ensure that the considered structure is safe and stable from the deflection and drift point of view, to ensure this IS code has laid some guidelines.

1.1.1 Outrigger Systems

What is outrigger - Outrigger is deep, stiff beam which connects the central core to the exterior column which helps in keeping the column at their position and further in reducing the lateral sway of the structure as a whole.

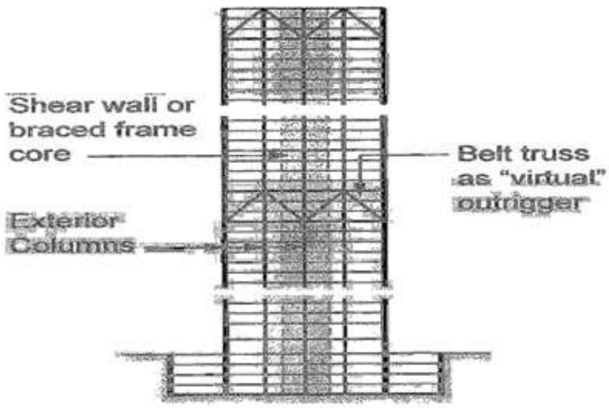


Fig. 1.1 Outrigger System

1.1.2 Historical Background and development of Outrigger system

Outriggers have been used in tall narrow buildings for nearly half a century, but the design principles has been used for millennia, the oldest "outriggers' were horizontal beams connecting the main canoe shaped hulls of Polynesian oceangoing boats to outer stabilizing floats or "amass". A rustic contemporary version of this vessel type illustrates key about building outrigger systems:

1.1.3 Structural concepts

The structural system of a narrow tall building can be considered as a beam cantilevering from the earth, the lateral force generated, either due to wind blowing against the building or due to the inertia force exerted by ground shaking during earthquake, tends both to snap(shear) the building and bend the building.

1.1.4 Introduction to Outrigger

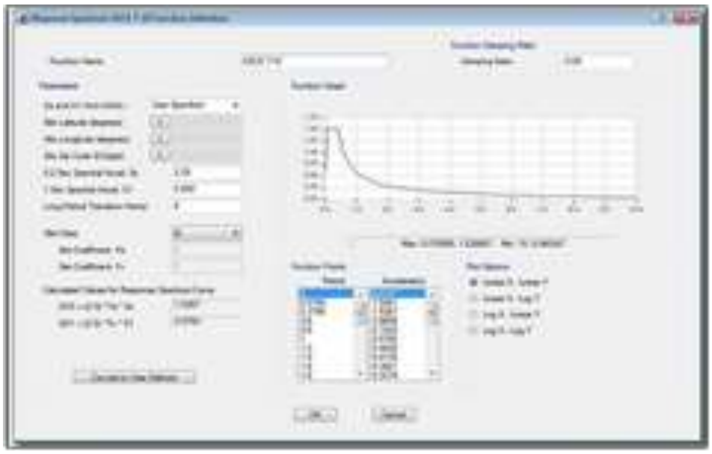
The outrigger and belt truss system is one of the effective lateral loads resisting system in which the external columns are tied to the central core wall with very stiff outriggers. The outrigger and belt truss system is commonly used as one of the structural system to effectively control the excessive drift due to lateral load, so that, during small or medium lateral load due to either wind or earthquake load, the risk of structural and non-structural damage can be minimized. For high-rise buildings, particularly in seismic active zone or wind load dominant, this system can be chosen as an appropriate structural system.

The great sailing ships use outriggers to help resist the wind forces in their sail.

Same as ship, the core in the tall building can be considered to the mast of the ship, the outrigger acts like the spreaders and the exterior columns like the stays or shroud of the ship.

1.1.5 The Use of Outriggers in High-rise Buildings to Control the lateral Force

The use of an outrigger which connects the two elements together provides a stiffer component which act together to resist the overturning lateral seismic or wind forces. When an outrigger-braced building deflects under wind or seismic load, the outrigger which connects to the core wall and the exterior columns, makes the whole system to act as a unit in resisting the lateral load.



MODEL DESCRIPTION

5.1 Introduction

Finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations. It uses subdivision of a whole problem domain into simpler parts, called finite elements, and variational methods from the calculus of variations to solve the problem by minimizing an associated error function. Analogous to the idea that connecting many tiny straight lines can approximate a larger circle, FEM encompasses methods for connecting many simple element equations over many small sub domains, named finite elements, to approximate a more complex equation over a larger domain.

5.1.1 Programme/software selection

For the analysis work ETABS 15.2.0 has been selected, the reason is, ETABS

15.2.0 is the most popular amongst structural design engineer, for their analysis work. ETABS 15.2.0 is the ultimate integrated software package for the structural analysis and design of buildings. Incorporating 40 years of continuous research and development, this latest ETABS offers unmatched 3D object based modelling and visualization tools, blazingly fast linear and nonlinear analytical power, sophisticated and comprehensive design capabilities for a wide-range of materials, and insightful graphic displays, reports, and schematic drawings that allow users to quickly and easily decipher and understand analysis and design results.

5.1.2.1 Response Spectrum analysis solver

Response-spectrum analysis solver (Figure 5.2) determines the statistically likely response of a structure to seismic loading. This linear type of analysis uses response-spectrum ground-acceleration records based on the seismic load and site conditions, rather than time-history ground motion records. This method is extremely efficient and takes into account the dynamical behavior of the structure.

RESULTS AND DISCUSSION

6.1.1 Time Period

Time period has been calculated using two methods, in the first method using formula T = (0.075) x H(0.75) as mentioned in clause 7.6.2 of IS 1893:2002, and in the second method as per modal analysis suggested by IS 1893:2002.

Table 6.1 Time period of structures

Time Period of Structure (sec)						
Types of analysis	**G+50-C**	**G+50- OUT**	**G+55-C**	**G+55- OUT**	**G+60-C**	**G+60- OUT**
E.S.A	3.302	3.302	3.538	3.538	3.769	3.769
M. A.	6.700	4.578	7.621	5.337	8.585	6.198
% REDUCTION IN M. A. TIME PERIOD	32%		30%		28%	
E. S. A-Equivalent Static Analysis, M. A. -Modal Analysis						

6.1 shows the comparison of the time period of structures dealt with, throughout the thesis work, and it shows that the time period has been reduced by 32% for G+50, 30% for G+55 and 28% for G+60, adding outrigger increases the stiffness of structure and which helps in reducing the overall lateral displacement of the structure.

Above table shows the time period from modal analysis, the maximum time period is 8.585 second for G+60 in conventional modal and which gets reduced to

6.198 second after adding outriggers to the structure, and by this we can say that adding outriggers increases the stiffness of structure as a whole, makes the structure more stiff compared to conventional structure.

6.1.2 Base Shear& Base moment

Base shear is the maximum lateral force generated at the base of structure.

Table 6.3 Base Shear (FX) and Base Moment (MY), X-Direction, kN-m

TABLE: Base Shear (FX) and Base Moment(MY), X-Direction, kN, m						
Load Case	**FX**	**MY**	**FX**	**MY**	**FX**	**MY**
	G+50-I-CON		G+50-II-CON		G+50-III-CON	
EQ X	34467.5	4619703.0	46875.8	6282796.0	57560.7	7714903.0
GUST X	31153.6	2997135.0	31153.6	2997135.0	31153.6	2997135.0
TIME HISTORY X	22889.5	1703162.0	30061.0	1887713.0	30274.1	2657020.0
Wind X	21491.8	2100384.0	21491.8	2100384.0	21491.8	2100384.0
	G+50-I-OUT		G+50-II-OUT		G+50-III-OUT	
EQ X	34210.7	4296162.0	46526.6	5842781.0	57117.4	7172334.0

GUST X	31153.6	2816457.0	31153.6	2816457.0	31153.6	2816406.0
TIME HISTORY X	30820.0	2320019.0	40715.7	2995729.0	37370.1	3064399.0
Wind X	21491.8	1974013.0	21491.8	1974013.0	21491.8	1973978.0

Table 6.4 Base Shear (FY) and Base Moment (MX), Y-Direction, kN-m

TABLE: Base Shear(FY) and Base Moment(MX), Y-Direction, kN, m						
Load Case	**FY**	**MX**	**FY**	**MX**	**FY**	**MX**
	G+50-I-CON		G+50-II-CON		G+50-III-CON	
EQ Y	34467.5	4207671.0	46875.8	5722432.0	57560.7	7026810.0
GUST Y	34268.9	2999704.0	34268.9	2999704.0	34268.9	2999704.0
TIME HISTORY Y	34558.8	2790444.0	45456.4	4157409.0	62967.8	4520881.0
Wind Y	23641.0	2101979.0	23641.0	2101979.0	23641.0	2101979.0
	G+50-I-OUT		G+50-II-OUT		G+50-III-OUT	
EQ Y	34210.7	4122729.0	46526.6	5606911.0	57117.4	6883076.0
GUST Y	34268.9	2961084.0	34268.9	2961084.0	34268.9	2961153.0
TIME HISTORY Y	57136.0	2762150.0	62643.9	4582462.0	91219.6	5414568.0
Wind Y	23641.0	2075003.0	23641.0	2075003.0	23641.0	2075052.0
	G+55-I-CON		G+55-II-CON		G+55-III-CON	
EQ Y	35280.1	4761849.0	47980.9	6476114.0	58917.8	7952287.0
GUST Y	39455.6	3826361.0	39455.6	3826361.0	39455.6	3826361.0
TIME HISTORY Y	35512.3	2754944.0	51828.8	4515414.0	48021.0	4048689.0
Wind Y	26366.3	2587813.0	26366.3	2587813.0	26366.3	2587813.0
	G+55-I-OUT		G+55-II-OUT		G+55-III-OUT	
EQ Y	35040.4	4653407.0	47654.9	6328634.0	58515.3	7770852.0
GUST Y	39455.6	3766696.0	39455.6	3766696.0	39455.6	3766698.0
TIME HISTORY Y	46845.4	3307251.0	49046.6	4985498.0	73357.5	5948808.0
Wind Y	26366.3	2547608.0	26366.3	2547608.0	26366.3	2547609.0
	G+60-I-CON		G+60-II-CON		G+60-III-CON	
EQ Y	36029.7	5340959.0	49000.4	7263705.0	60169.6	8919402.0
GUST Y	44997.7	4801692.0	44997.7	4801692.0	44997.7	4801692.0
TIME HISTORY Y	43726.1	3274301.0	56367.2	4809487.0	42671.9	4501758.0
Wind Y	29132.0	3135448.0	29132.0	3135448.0	29132.0	3135448.0
	G+60-I-OUT		G+60-II-OUT		G+60-III-OUT	
EQ Y	35766.5	5201228.0	48642.5	7073670.0	59730.1	8686051.0
GUST Y	44997.8	4714343.0	44997.8	4714343.0	44997.8	4714343.0
TIME HISTORY Y	40010.8	3667287.0	60491.1	5357021.0	67462.9	5596786.0
Wind Y	29132.0	3078650.0	29132.0	3078650.0	29132.0	3078650.0

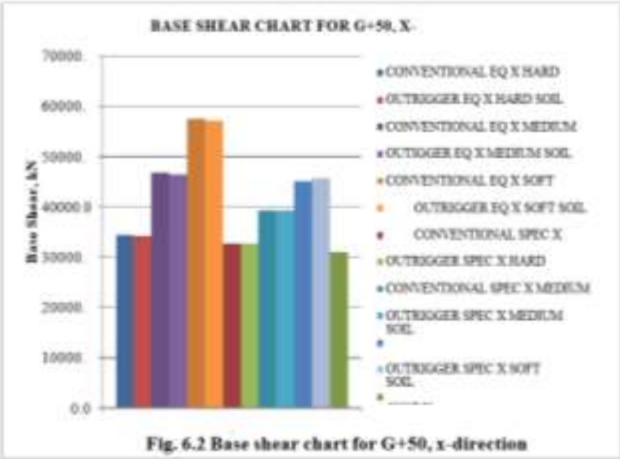


Fig. 6.2 Base shear chart for G+50, x-direction

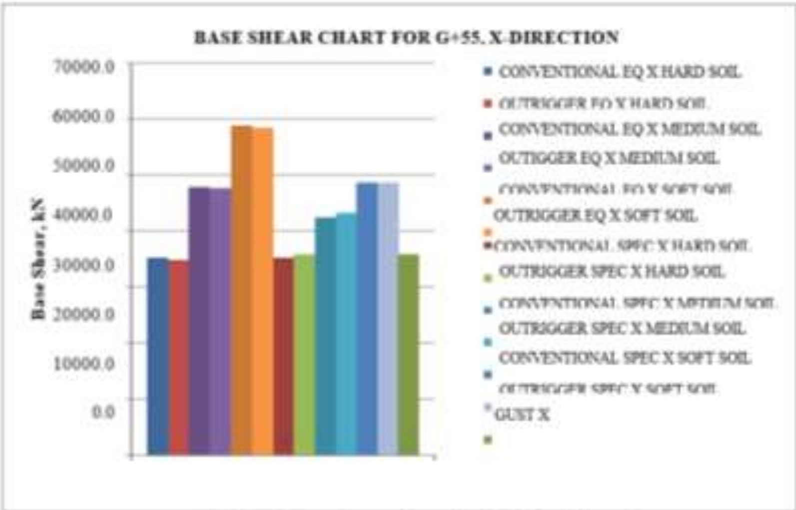


Fig. 6.3 Base shear chart for G+55, x-direction.

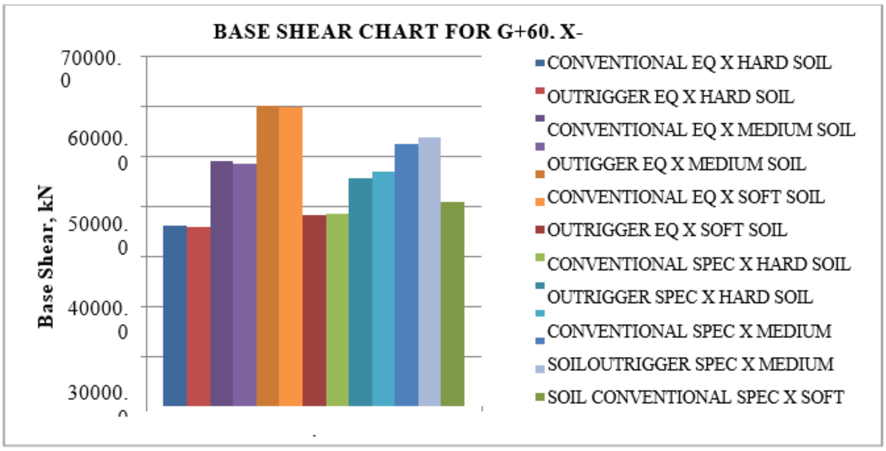


Fig. 6.4 Base shear chart for G+60, x-direction.

Base shear has been presented in above graphs and table maximum base shear is generated when the structures have been analysed with soft soil, equivalent static analysis governs all the cases.

6.1.3 Base Moment

Base Moment is the maximum moment generated at the base of structure, for analysis the structure has been fixed a base that is at foundation level.

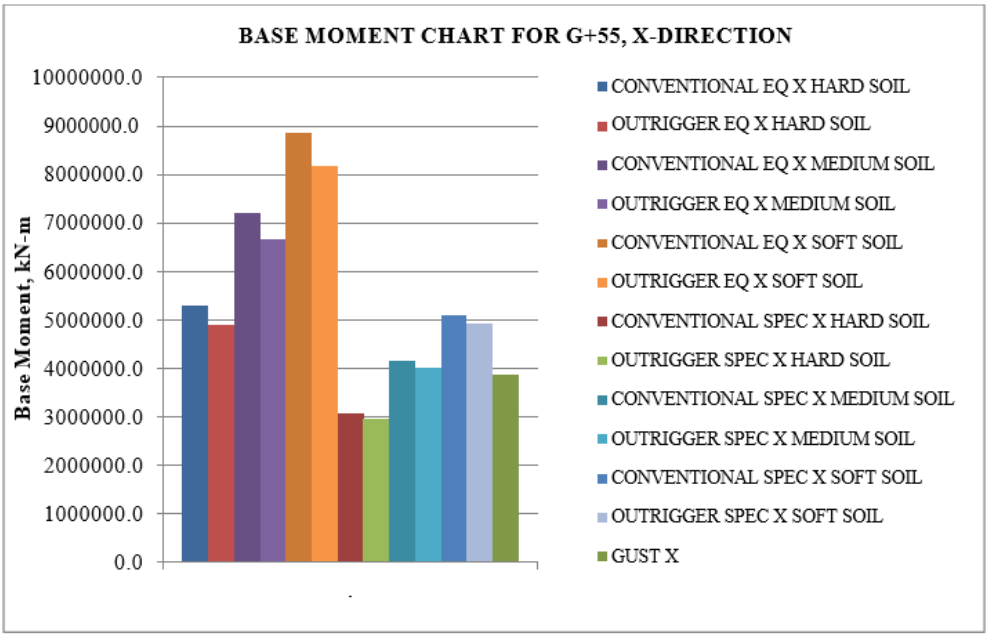


Fig. 6.6 Base moment chart for G+55, x-direction.

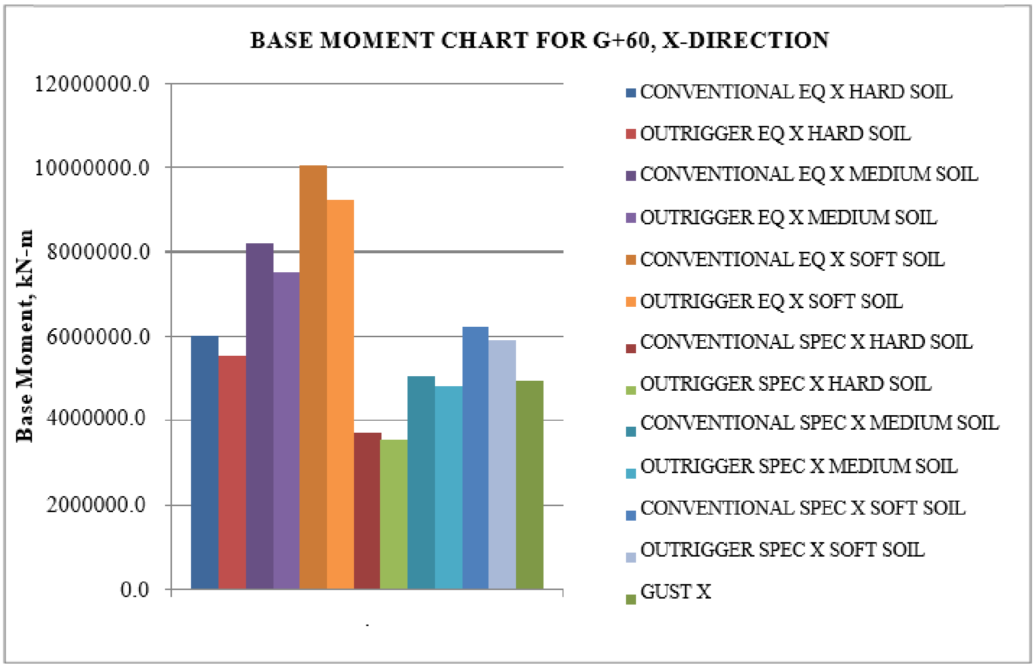


Fig. 6.7 Base moment chart for G+60, x-direction.

Base moment has been presented here for all the structures, the base moments is getting reduced after adding the outrigger, and this proves the concept of outrigger, without outrigger the structure acts like a pure cantilever beam projecting from earth.

Top Storey Displacement

Storey shear is the lateral force generated at the storey of a structure.

Table 6.5 Top Storey Displacement, X-Direction, mm

Top Storey Displacement, X-Direction, mm			
Load Case	**UX**	**UX**	**UX**
	G+50-I-CON	**G+50-II-CON**	**G+50-III-CON**
EQ X	334.395	454.778	558.44
GUST X	202.783	202.783	202.783
TIME HISTORY X	160.044	208.592	192.794
Wind X	141.875	141.875	141.875
	G+50-I-OUT	G+50-II-OUT	G+50-III-OUT
EQ X	139.745	190.053	233.323
GUST X	89.636	89.636	89.642
TIME HISTORY X	81.175	99.416	117.234
Wind X	62.834	62.834	62.838
	G+55-I-CON	G+55-II-CON	G+55-III-CON
EQ X	399.249	542.978	666.745
GUST X	274.175	274.175	274.175
TIME HISTORY X	177.093	221.088	205.403
Wind X	185.098	185.098	185.098
	G+55-I-OUT	G+55-II-OUT	G+55-III-OUT
EQ X	177.487	241.382	296.391
GUST X	128.398	128.398	128.398
TIME HISTORY X	103.42	125.35	143.827
Wind X	86.852	86.852	86.853
	G+60-I-CON	G+60-II-CON	G+60-III-CON
EQ X	470.727	640.189	786.114
GUST X	363.307	363.307	363.307
TIME HISTORY X	194.991	225.614	205.251
Wind X	236.762	236.762	236.762
	G+60-I-OUT	G+60-II-OUT	G+60-III-OUT
EQ X	224.774	305.692	375.372
GUST X	182.139	182.139	182.139
TIME HISTORY X	131.719	164.207	170.668
Wind X	118.93	118.93	118.93

Table 6.6 % Reduction in top storey displacement, x-direction, mm

% REDUCTION IN TOP STOREY DISPLACEMENT, X-Direction, mm			
Load Case	**UX**	**UX**	**UX**
	G+50-SOIL-I	**G+50-SOIL-II**	**G+50-SOIL-III**
EQ X	58%	58%	58%
GUST X	56%	56%	56%
TIME HISTORY X	49%	52%	39%
Wind X	56%	56%	56%
	G+55-SOIL-I	G+55-SOIL-II	G+55-SOIL-III
EQ X	56%	56%	56%
GUST X	53%	53%	53%
TIME HISTORY X	42%	43%	30%
Wind X	53%	53%	53%
	G+60-SOIL-I	G+60-SOIL-II	G+60-SOIL-III
EQ X	52%	52%	52%
GUST X	50%	50%	50%
TIME HISTORY X	32%	27%	17%
Wind X	50%	50%	50%

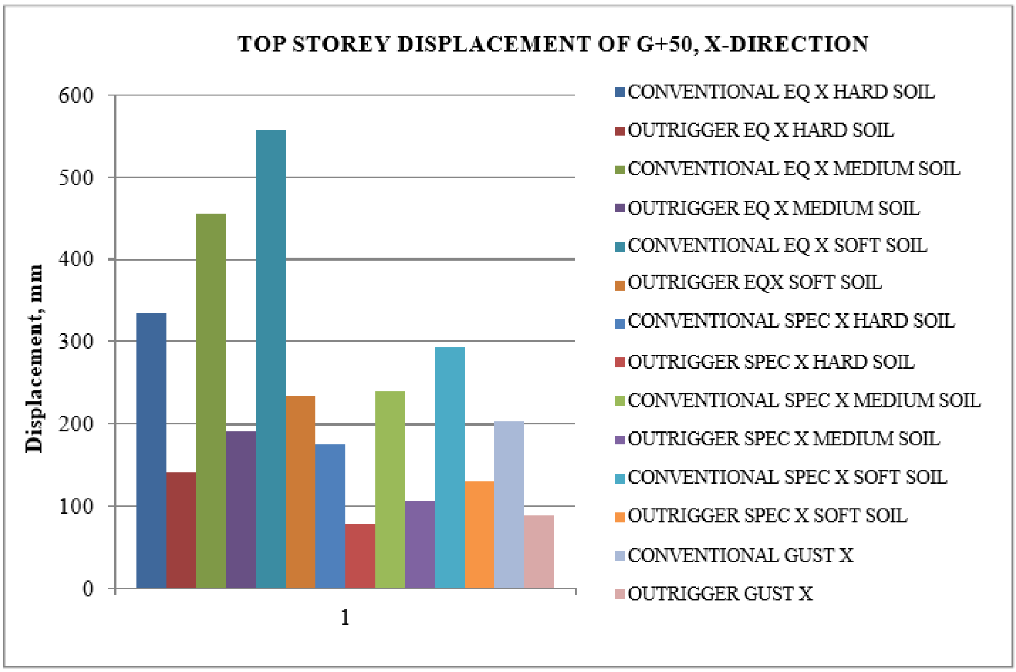


Fig. 6.8 Top storey displacement of G+50, x-direction.

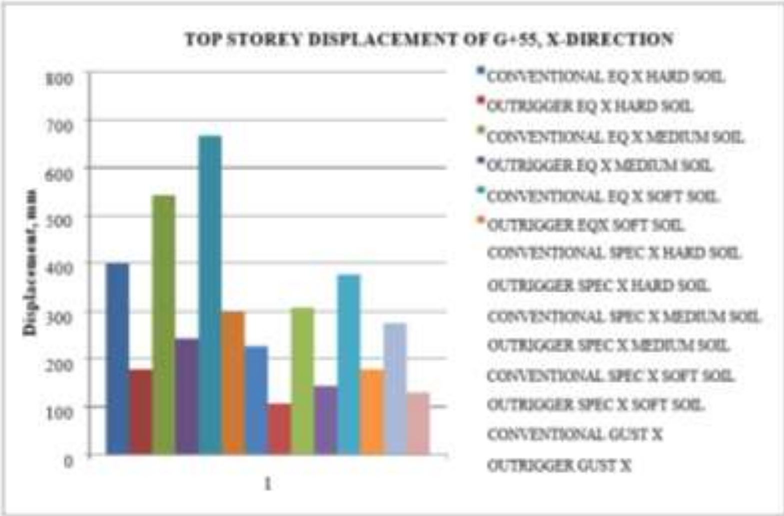


Fig. 6.9 Top storey displacement of G+55, x-direction.

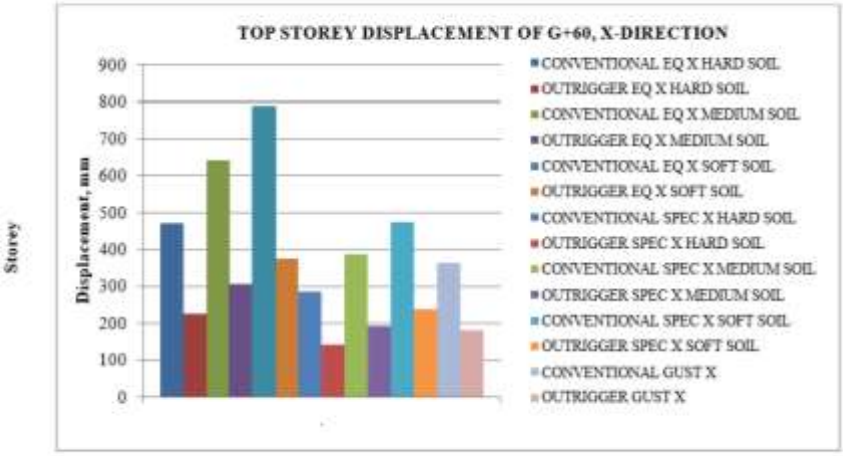


Fig. 6.10 Top storey displacement of G+60, x-direction.

From the results presented in the table 4.7 and 4.8, the reduction in top storey displacement is getting reduced by about 50% in x-direction and it clearly shows the benefit of adding outriggers to the structure.

6.1.4 Storey Displacement

Storey displacement is the displacement at the storey of the structure, shows the distribution of shear force along the storey of the structure.

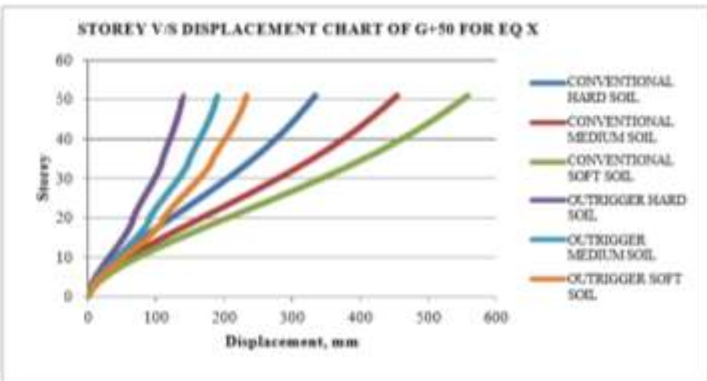


Fig. 6.11 Storey v/s displacement chart of G+50, for EQX.

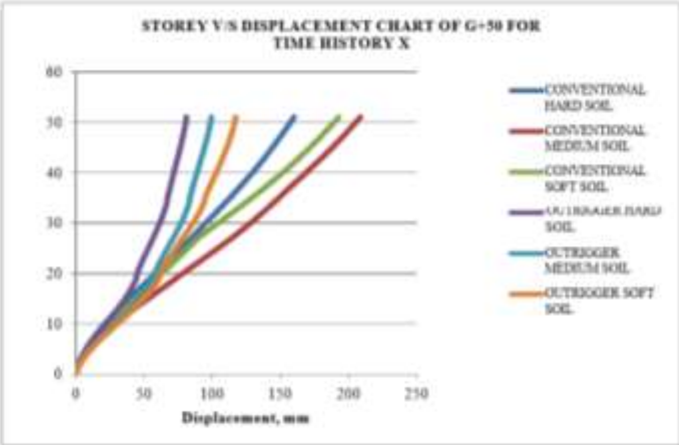


Fig. 6.12 Storey v/s displacement chart of G+50, for TIME HISTORY X.

Fig. 6.13 Storey v/s displacement chart of G+50, for GUST X.

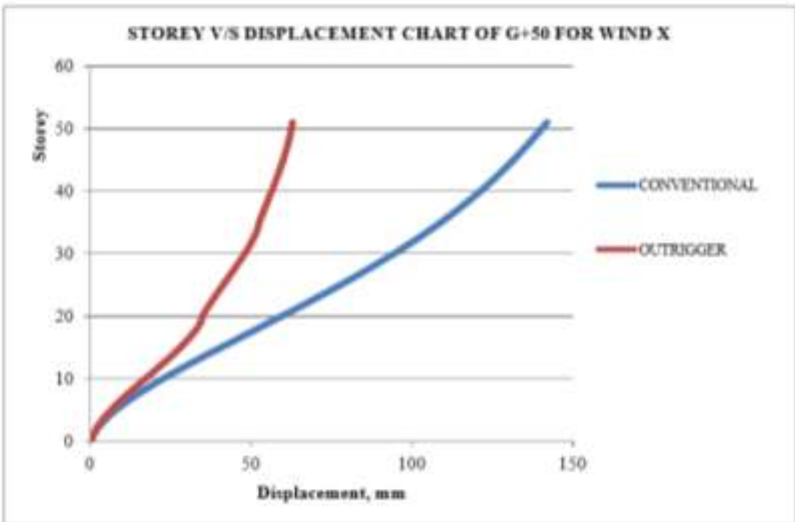


Fig. 6.14 Storey v/s displacement chart of G+50, for WIND X.

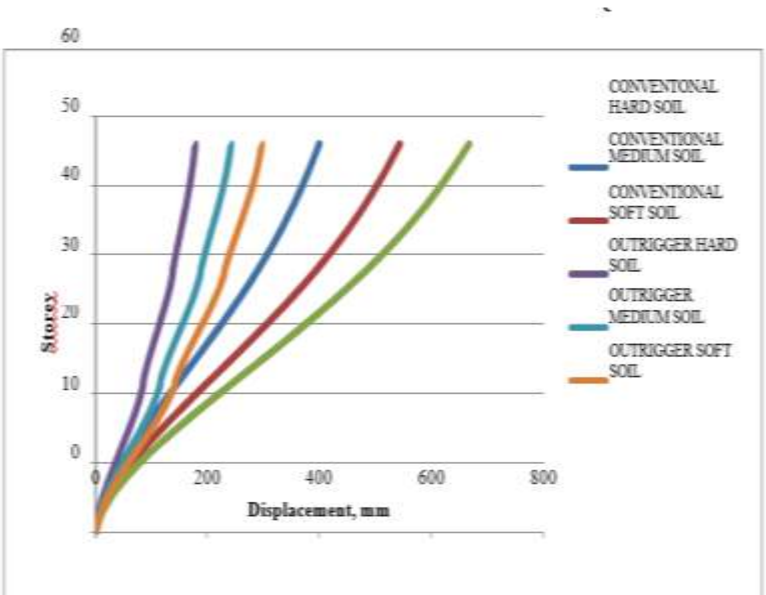


Fig. 6.15 Storey v/s displacement chart of G+55, for EQ X.

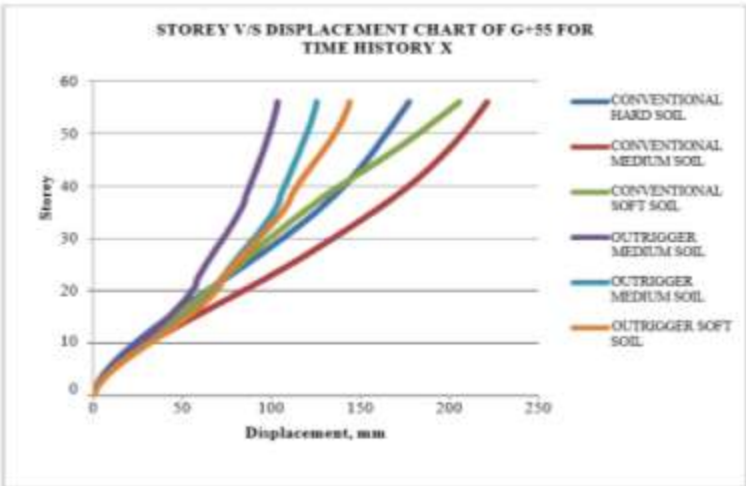


Fig. 6.16 Storey v/s displacement chart of G+55, for Time History X.

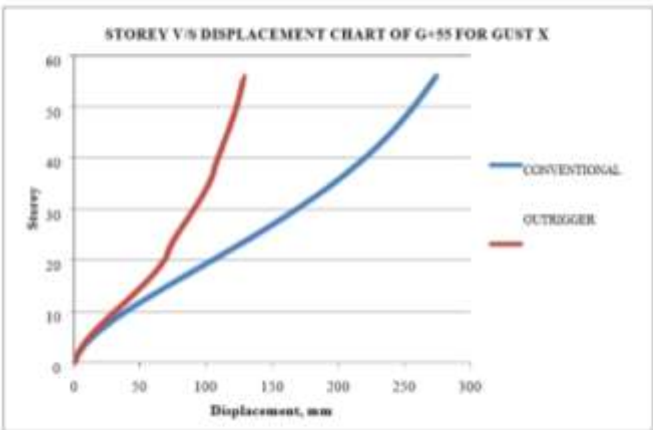


Fig. 6.17 Storey v/s displacement chart of G+55, for GUST X.

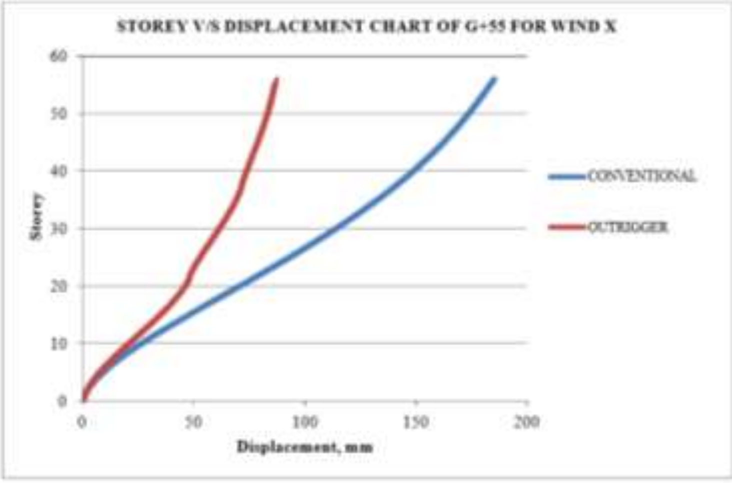


Fig. 6.18 Storey v/s displacement chart of G+55, for WIND X.

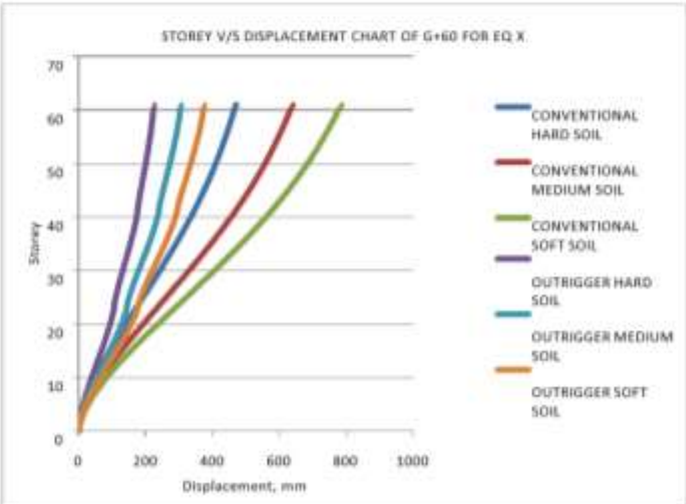


Fig. 6.19 Storey v/s displacement chart of G+60 for EQ X.

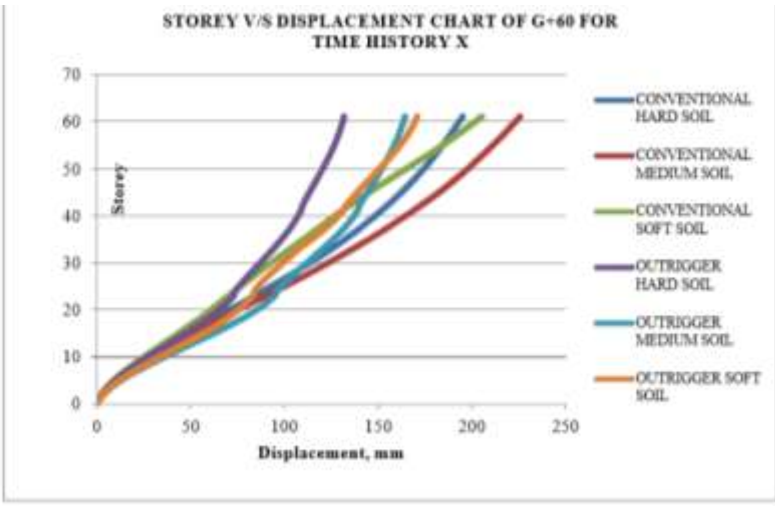


Fig. 6.20 Storey v/s displacement chart of G+60 for TIME HISTORY X.

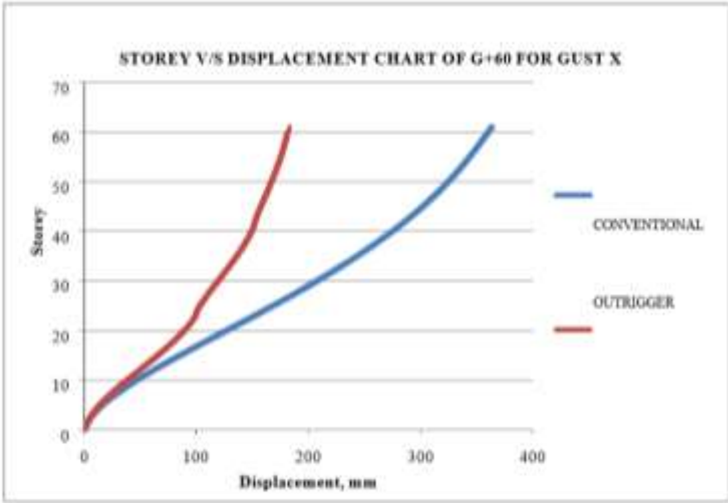


Fig. 6.21 Storey v/s displacement chart of G+60 for GUST X.

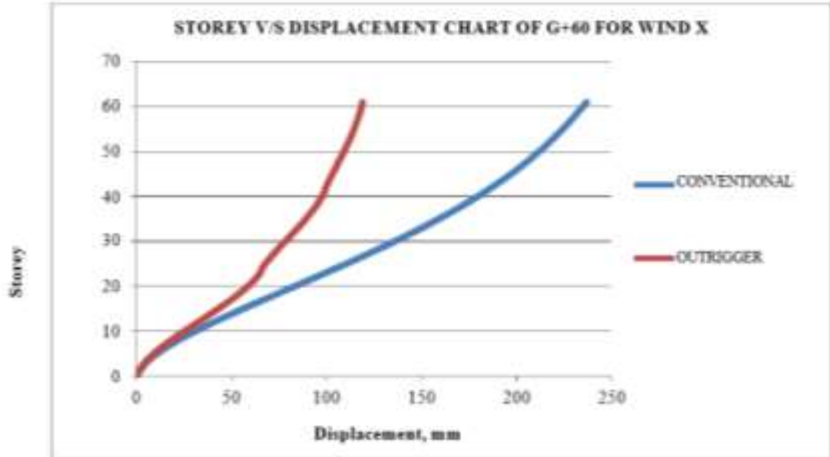


Fig. 6.22 Storey v/s displacement chart of G+60 for WIND X.

In all the graphs presented above under the topic storey displacement, the structure with outrigger deflects less than the structure without outriggers, and it shows the benefits of adding the outrigger to the structure.

6.1.5Storey Drift

Storey drift is the representation of drift along the storey of the structure.

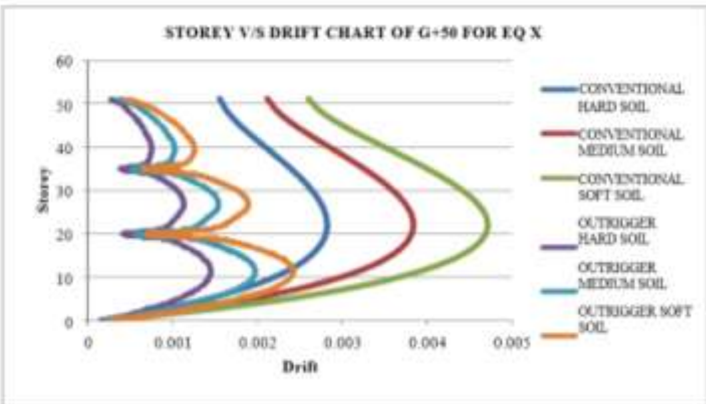


Fig. 6.23 Storey v/s drift chart of G+50 for EQ X

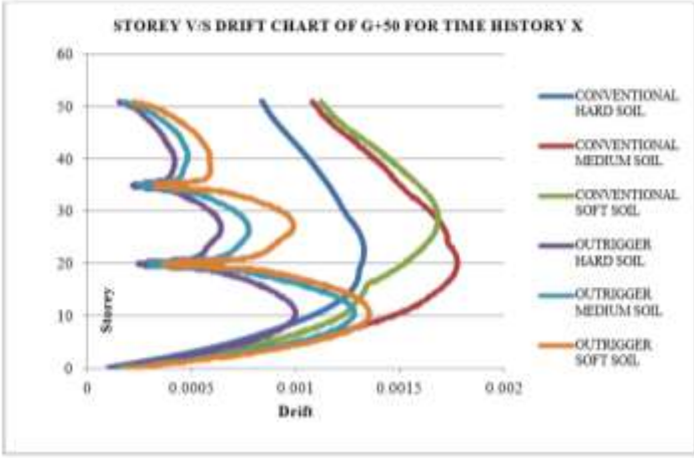


Fig. 6.24 Storey v/s drift chart of G+50 for TIME HISTORY X.

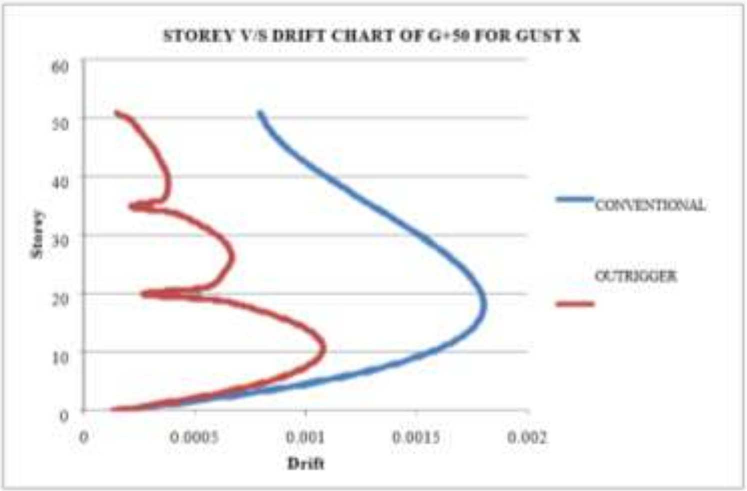


Fig. 6.25 Storey v/s drift chart of G+50 for GUST X.

Conclusion

Following conclusions can be drawn after completing the present thesis work

1. Little information is available on the Behaviour of tall RC structure with outrigger systems supported on the different types of soils and subjected to wind loading.
2. By studying the literature review of this thesis, the optimum location of outrigger system varies from 0.4H to 0.7H, Where H is the height of the building.
3. In geometrically regular and symmetrical structure with simple grid plan it was proved that by considering the previous earthquake records of acceleration velocity ratio, the structure was optimized when outrigger were placed at 22-24 level in 50 storey high-rise building therefore optimum location of outrigger is between 0.44-0.48 times of its height. Significant reduction and possibly the complete elimination of uplift and net tension forces throughout the column and the foundation systems.
4. The exterior column spacing is not driven by structural considerations and can easily mesh with aesthetic and functional considerations.
5. For rectangular buildings, outriggers can engage the middle columns on the long faces of the building under the application of wind loads in the more critical direction.
6. In core-alone and tubular systems, these columns which carry significant gravity load are either not incorporated or under-utilized.
7. The use of outrigger system in tall structure increases the stiffness and makes the structure more efficient under seismic and wind loading.
8. The reduction in displacement is more than 40%, after adding outriggers at 0.4H, 0.7H & 1H, where H is the height of structure.
9. The reduction in drift is more than 50% at the level where outriggers are added.
10. It has been observed that the base moment gets reduced when outriggers are added, and it is advantageous for the structural engineers.

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