STUDY OF BEHAVIOR OF OUTRIGGERS IN A HIGH RISE BUILDING UNDER SEISMIC LOADING

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Abstract - *The lateral seismic forces acting on the structure is effectively resisted by using outrigger lateral system. In the present study a 30 storey model is modelled using ETABS 2015 software. The optimum location of the outriggers is determined by the varying the location of outriggers throughout the height of the structure. Response spectrum analysis is made by considering building situated in zone III. Time history analysis of the building is carried out for elcentro earthquake data. And pushover analysis is carried out and performance point of the building is determined. The response of the building is determined for lateral seismic forces.*

Key Words*: *: Response spectrum, outriggers, time history, pushover analysis.

1.INTRODUCTION

The introduction of tall buildings was mainly seen in the later part of the nineteen century. In recent years there is a faster growth of tall buildings. The main reason for the growth tall buildings is the economy of the country and people flowing into the major cities. The majority of the tall buildings are now found in Asian countries.

Due to the race to achieve higher heights the buildings are getting more taller and more slender and hence becoming more complicated to design these slender buildings. And this lead to new advanced technologies and design softwares. But the understanding of the basic concept along with the use of softwares is necessary for better design of building.

The factors that influence the functioning of tall buildings are mainly serviceability, strength and stability. The main forces that the tall buildings have to resist are the wind and seismic forces. And as the height of the building increases the then drift of the building becomes important. Some of the lateral load resisting structures are shear wall structures , framed structures, tubular structures, outriggers etc. out of these structures outriggers are found to resist drift more significantly.

Outrigger systems

Outriggers are one of the most effective lateral load resisting systems commonly used nowadays in tall structures. Earlier the concept of outriggers was used in ships to strengthen the mast of the ships to resist against wind forces. The core of the tall structure is similar to the mast of the ship and outriggers are extend in one direction from the core or in both directions of the core. Hence they are the horizontal members of the structure that connects the core wall of the structure to the columns at the outer edges of the building. The core can be a bracings or shear wall.

The outriggers can be of reinforced concrete or of steel trusses. Outrigger beam are almost one to two floor deep. The outriggers increase the stiffness of the buildings which is important to control the drift of the structure. The deflection of the structure is also significantly reduced by the use of outriggers.

The outriggers makes better use of the structural components by increasing the axial strength of the outrigger columns and also its stiffness which helps in carrying a certain amount of the overturning moment induced on the core. When the lateral forces act on the building the columns in the windward sides undergo tension and the columns in leeward side undergo compression. And this leads to formation of a couple force which acts against seismic and wind forces. And hence reduces the deflection at the top storey and also drift is controlled. And it also decreases the amount of moment resisted by the core.

The outer columns other than the outrigger columns can also be involved in resisting the lateral loads by using belt truss. These belt trusses connect the all the outer columns and hence the system becomes more stiff.

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2. ANALYSIS OF OUTRIGGER STRUCTURE USING RESPONSE SPECTRUM METHOD

When the structure is subjected to a seismic force then the structure responds in the form of displacement, velocity and acceleration. The plot of highest value of response of the structure to specific seismic force which causes the

movement of the ground against the time period is called a response spectrum curve.
The response spectrum method gives the highest response the structure can have and hence it helps to determine the forces generated in the structure due to seismic ground motion. And thus it helps in the design of structures capable of withstanding the earthquake. It a linear analysis and hence the responses will be in the elastic range.

A 30 storey high rise building is considered. The core consists of shear wall made up of concrete. The outriggers provided are steel beams with bracings. Here for earthquake loading IS 1893 (PART 1): 2002 was considered. Here ETABS software was used for analysis.

Table -2.1: Properties of Materials

MATERIALS	PROPERTIES
CONCRETE	GRADE M40, Density 24.9926 KN/m3, Modulus of elasticity 31622.78 MPa, Shear modulus 13176.16 MPa, Poisson's ratio 0.2
STEEL	HYSD-500, Density 76.9729 KN/m3, Modulus of elasticity 200000 MPA, Fe-345, Poisson's ratio 0.3, Shear modulus 80769.2MPA.

Table 2.2: Sections of column, beams and bracings

CONCRETE		STEEL	
Beams (mm)	Columns(mm)	Beams	Bracings
300X300	400X400	ISMB350 BUILTUP	ISMB300 BUILTUP

2.1 METHODOLOGY

A 30 storey building is modelled with the height of all stories being same by using ETABS software. The height of each storey is 3.1 meters. The depth of slab is 150 mm. Shear wall of thickness 75 mm is provided. The zone considered is III with a zone factor of 0.16 . And soil condition taken is medium. Response reduction factor is 5. And importance factor is 1.

Here two models are modelled . First model is without outriggers with concrete shear wall core. Second model consists of outriggers with concrete shear wall core.

Table 2.3: Load Combination

1.5 (DL +LL)	1.5 (DL - EQX)
1.2 (DL + LL + EQX)	1.5 (DL - EQY)
1.2 (DL + LL + EQY)	0.9 DL + 1.5 EQX
1.2 (DL +LL - EQX)	0.9 DL + 1.5 EQY
1.2 (DL + LL - EQY)	0.9 DL - 1.5 EQX
1.5 (DL + EQX)	0.9 DL - 1.5 EQY
1.5 (DL + EQY)	

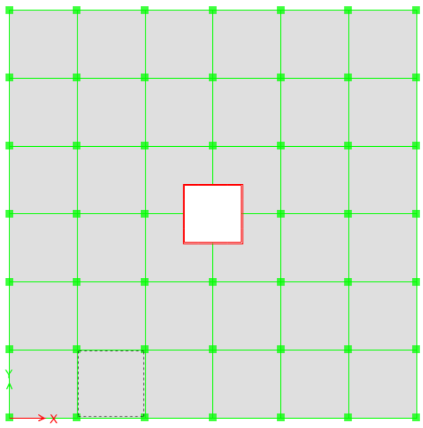

Fig 2.1: Plan of building without outrigger

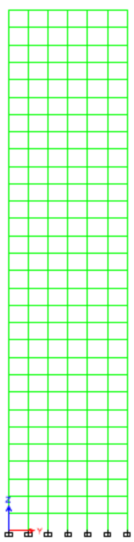

Fig 2.2: Elevation of building without outrigger

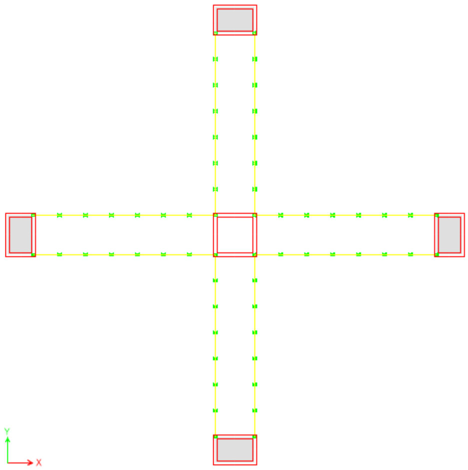

Fig 2.3: Plan of building with outrigger

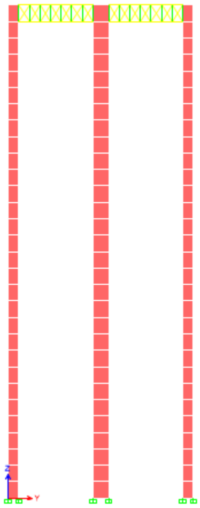

Fig 2.4 : Elevation of building with outrigger

RESULTS:

The results obtained are in X direction and response in Y direction are neglected in the following figures below.

DISPLACEMENT:

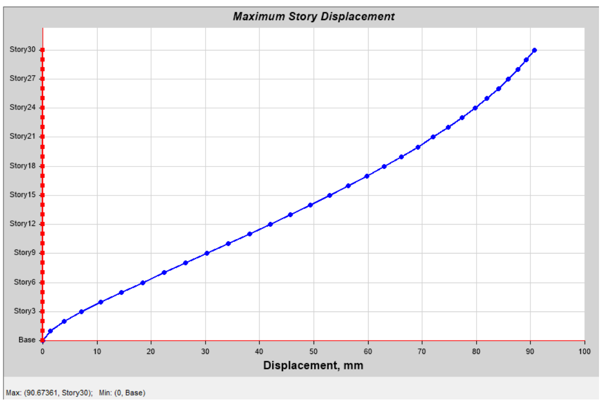

Fig 2.5: Maximun storey displacement without outrigger

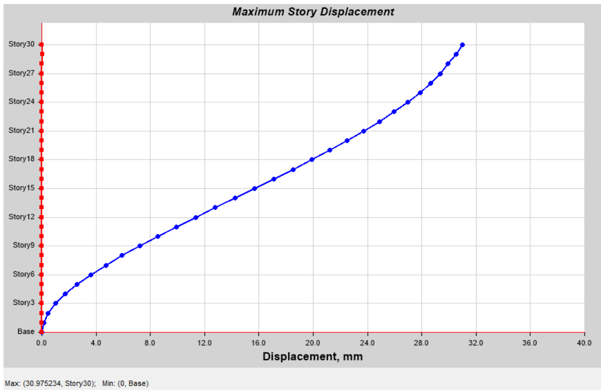

Fig 2.6: Maximun storey displacement with outrigger

STOREY DRIFT:

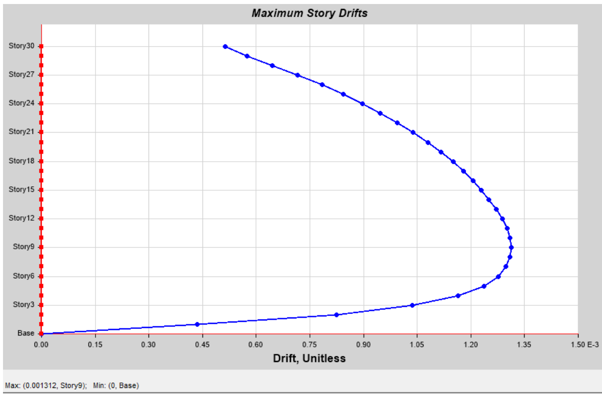

Fig 2.7: Maximun storey drifts without outrigger

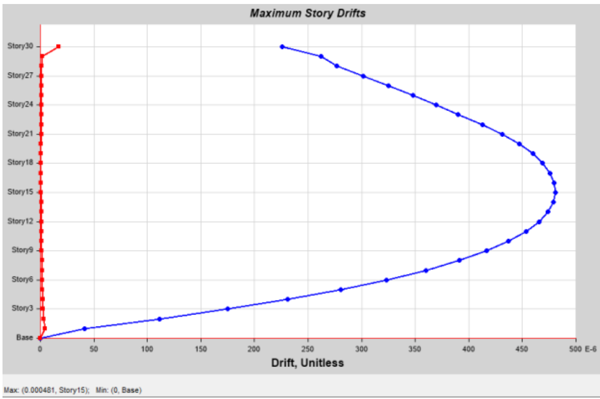

Fig 2.8: Maximun storey drifts with outrigger

STOREY SHEAR:

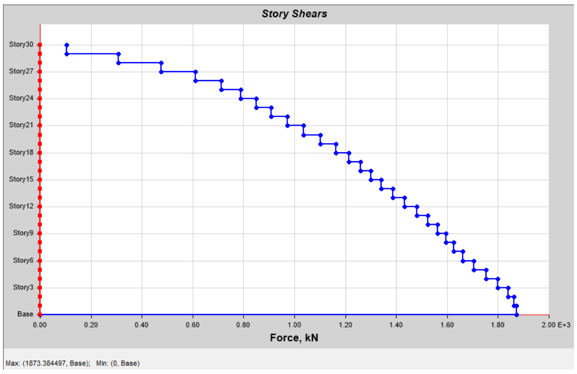

Fig 2.9: Storey shear without outrigger

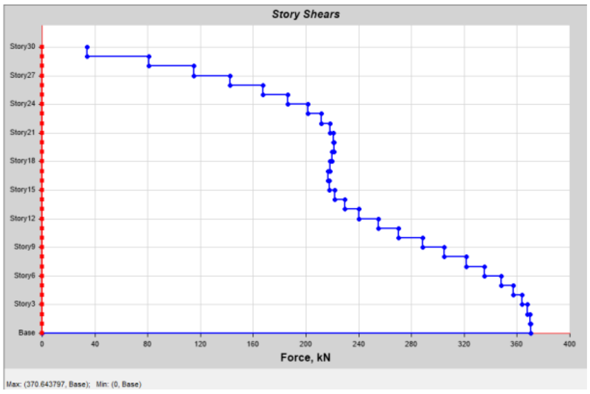

Fig 2.10: Storey shear with outrigger

STOREY OVERTURNING MOMENT :

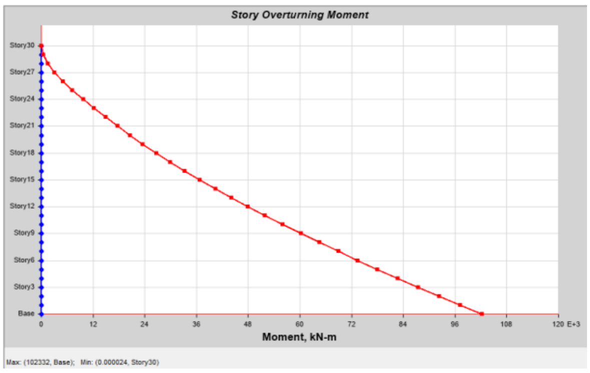

Fig 2.11: Storey overturning moment without outrigger

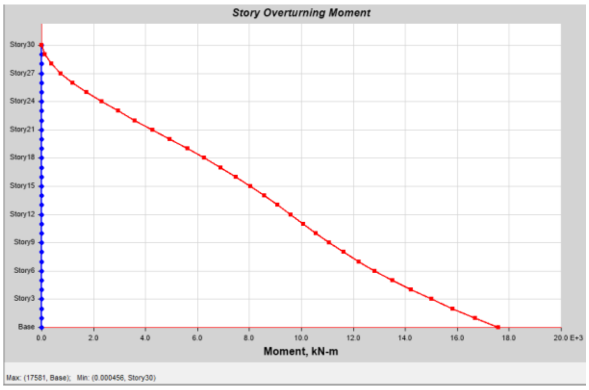

Fig 2.12 : Storey overturning moment with outrigger

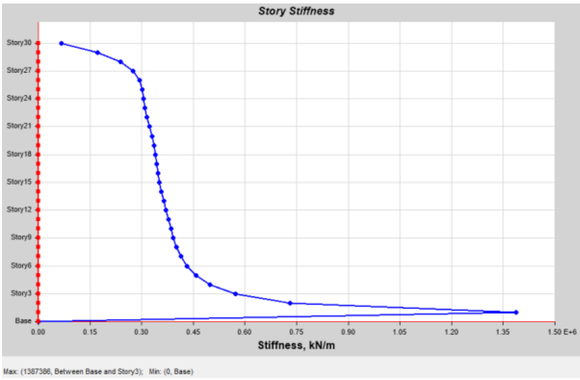

Fig 2.13: Storey stiffness without outrigger

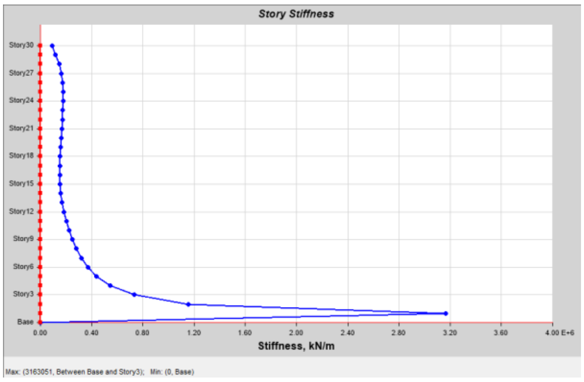

Fig 2.14: Storey stiffness with outrigger

Table 2.4: Storey Displacement, Drift, Shear, Overturning moment

Outriggers	Storey Displacement (mm)	Storey Drift	Storey Shear (KN)	Storey Overturning Moment (KN-m)	Storey Stiffness (KN/m)
Without Outrigger	90.67	0.001312	1873.38	102332	1387386
With Outrigger	30.97	0.000481	370.64	17581	3163051

DISCUSSION:

The maximum storey displacement in the building with the use of outriggers at the top most storey is reduced by 34.1% as compared to the one without outrigger, storey shear is reduced by 19.78% when compared to the one without outrigger, storey overturning moment is reduced by 17.18% as compared to the one without outrigger and storey stiffness is increased by 2.27 times storey stiffness of the building without the use of outriggers.

3. OPTIMUM LOCATION OF OUTRIGGER SYSTEM IN THE STRUCTURE

Here 30 models of 30 storey high rise building are modelled. The core consists of shear wall made up of concrete. The outriggers provided are steel beams with bracings at each storey level. And positon of outrigger is varied along storey height. Here for earthquake loading IS 1893 (PART 1) : 2002 was considered. Here ETABS software was used for analysis.

3.1 METHODOLOGY

A 30 storey building is modelled with the height of all stories being same by using ETABS software. The height of each storey is 3.1 meters. The depth of slab is 150 mm. Shear wall of thickness 75 mm is provided. The zone considered is III with a zone factor of 0.16. And soil condition taken is medium. Response reduction factor is 5. And importance factor is 1.

Here 30 models are modelled. The positions of outriggers are varied along the height of the structure.

RESULTS:

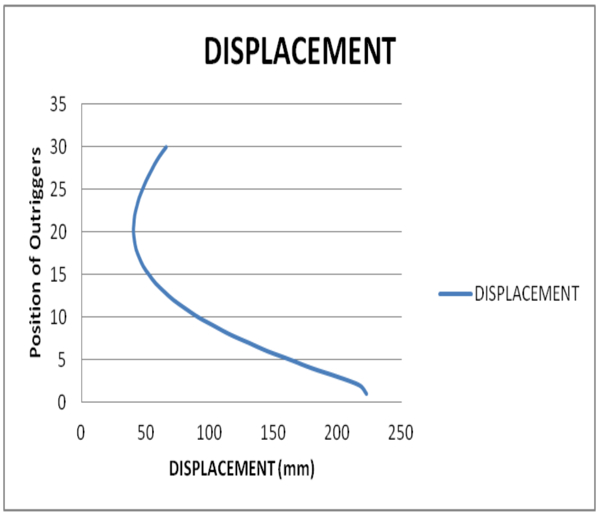

Fig 3.1: Storey Displacement

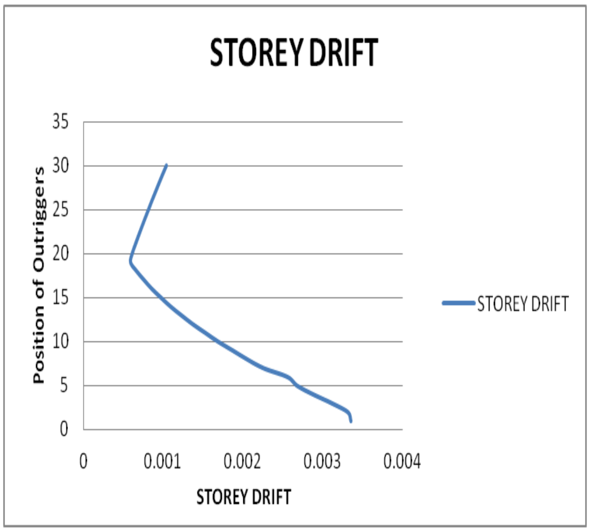

Fig 3.2: Storey Drift

Table 3.1: Maximum Storey Displacement , Storey Drift

STOREY	DISPLACEMENT (MM)	STOREY DRIFT
1	222.47	0.003353
2	216.956	0.003316
3	199.863	0.00312
4	179.97	0.002887
5	163.09	0.00268
6	145.361	0.00256
7	130.585	0.002259
8	115.686	0.002054
9	103.362	0.001873
10	91.308	0.00169
11	81.501	0.001529
12	72.162	0.001369
13	64.795	0.001228
14	57.974	0.001091
15	52.882	0.000972
16	48.34	0.000858
17	45.304	0.00076
18	42.773	0.000667
19	41.541	0.00059
20	40.741	0.00061
21	41.046	0.000648
22	41.698	0.000688
23	43.273	0.000729
24	45.105	0.000771
25	47.693	0.000814
26	50.452	0.000857
27	53.818	0.000902
28	57.281	0.000946
29	61.288	0.000992
30	66.247	0.001039

DISCUSSION:

The maximum storey displacement at the top of the structure is 40.741 mm when the outrigger is located at the 20th storey which is lowest compared to the maximum displacement for all other outrigger locations.

Similarly the maximum storey drift is 0.00059 when the outrigger is located at the 19th storey which is lowest compared to the maximum drift for all other outrigger locations.

4. ANALYSIS OF OUTRIGGER STRUCTURE USING TIME HISTORY METHOD

When severe earthquake forces hits a building then the building undergoes deformation in plastic range. And hence while designing the building for seismic forces the inelastic deformation or non linear deformation of the building has to be considered for a safe design of the building. Hence time history analysis is non linear analysis carried out to determine the state of structure to particular seismic forces. And hence helps in the efficient seismic design of the structure.

A 30 storey high rise building is considered. The core consists of shear wall made up of concrete. The outriggers provided are steel beams with bracings. Here for earthquake loading IS 1893 (PART 1): 2002 was considered. Here ETABS software was used for analysis.

4.1 METHODOLOGY

A 30 storey building is modelled with the height of all stories being same by using ETABS software. The height of each storey is 3.1 meters. The depth of slab is 150 mm. Shear wall of thickness 75 mm is provided. The zone considered is III with a zone factor of 0.16. And soil condition taken is medium. Response reduction factor is 5. And importance factor is 1. Elcentro earthquake is considered for time history analysis.

Here 5 models are modelled. First model is without outriggers with concrete shear wall core. For other models outriggers are placed at various locations.

RESULTS:

The results obtained are in X direction and response in Y direction are neglected in the following figures below

DISPLACEMENT:

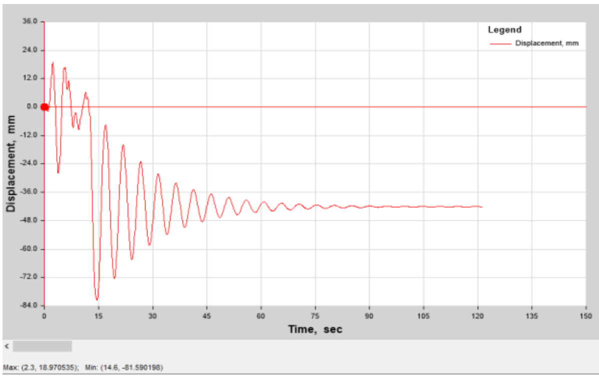

Fig 4.1: Displacement vs Time without Outrigger

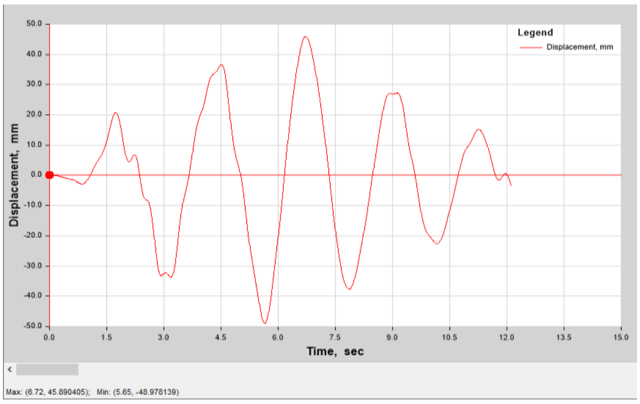

Fig 4.2: Displacement vs Time with Outrigger at 5th storey

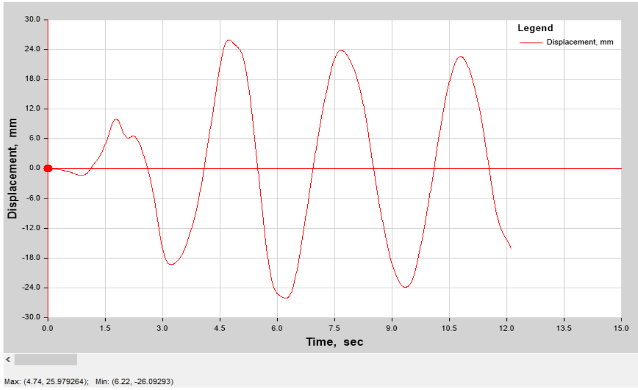

Fig 4.5: Displacement vs Time with Outrigger at 30th storey

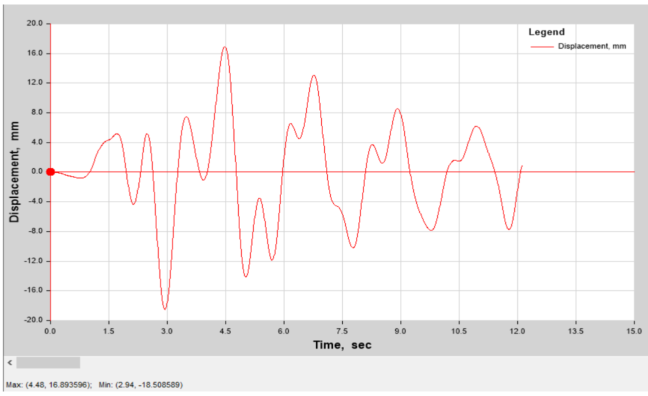

Fig 4.3: Displacement vs Time with Outrigger at 15th storey

VELOCITY:

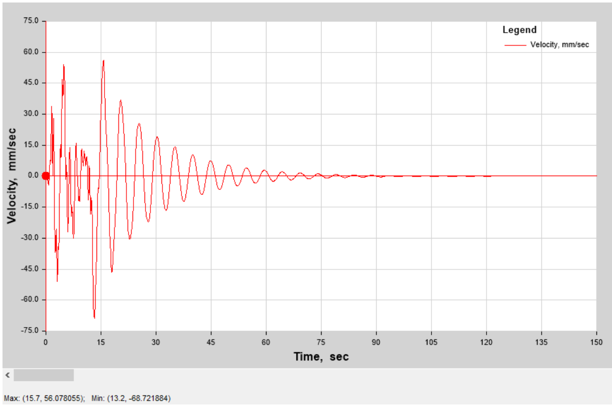

Fig 4.6: Velocity vs Time without Outrigger

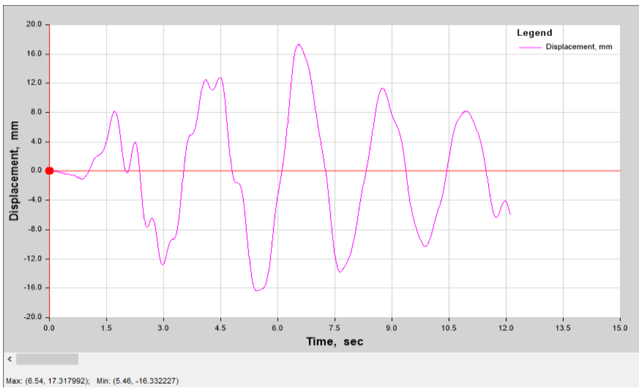

Fig 4.4: Displacement vs Time with Outrigger at 20th storey

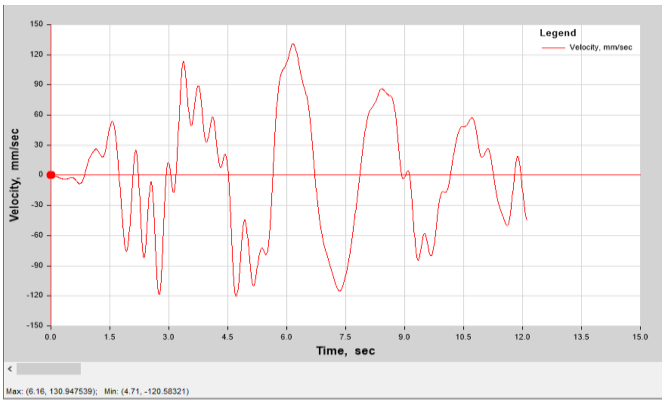

Fig 4.7: Velocity vs Time with Outrigger at 5th storey

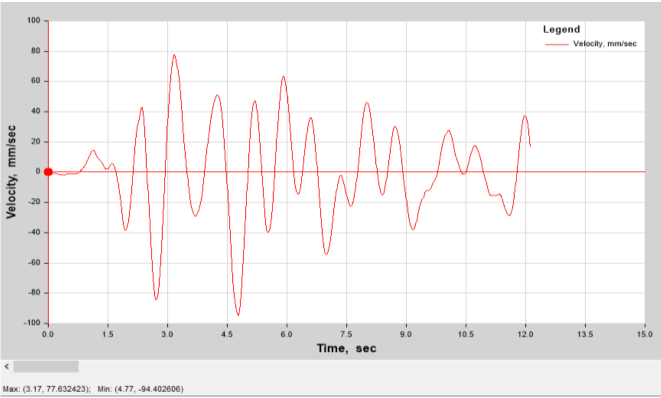

Fig 4.8: Velocity vs Time with Outrigger at 15th storey

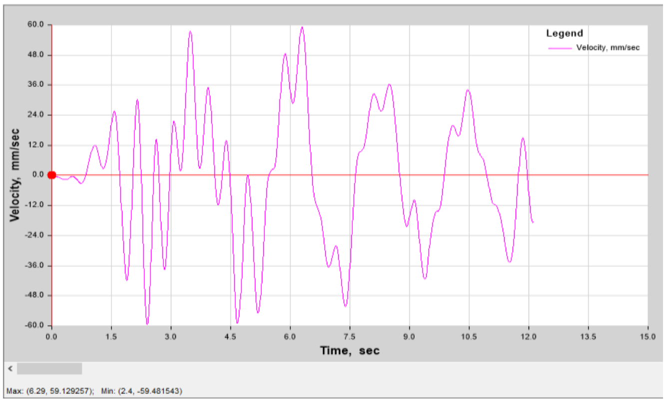

Fig 4.9: Velocity vs Time with Outrigger at 20th storey

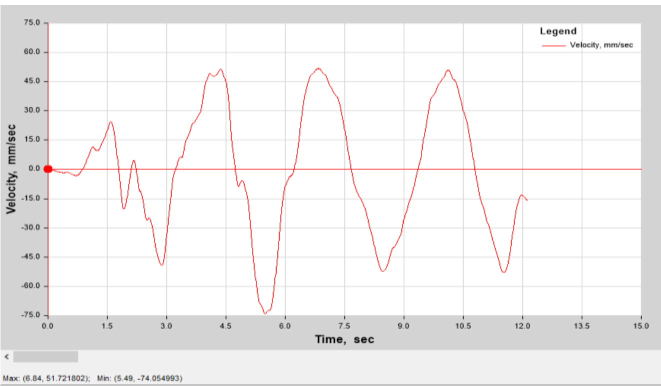

Fig 4.10: Velocity vs Time with Outrigger at 30th storey

ACCELERATION:

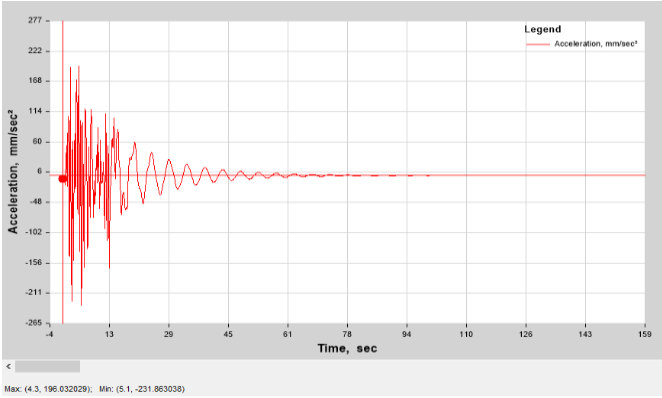

Fig 4.11: Acceleration vs Time without Outrigger

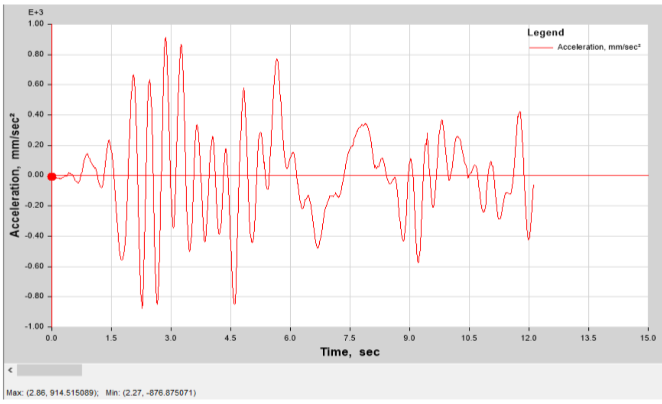

Fig 4.12: Acceleration vs Time with Outrigger at 5th Storey

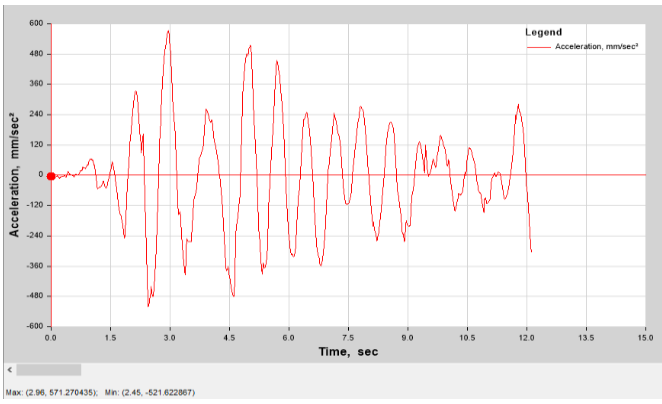

Fig 4.13: Acceleration vs Time with Outrigger at 15th Storey

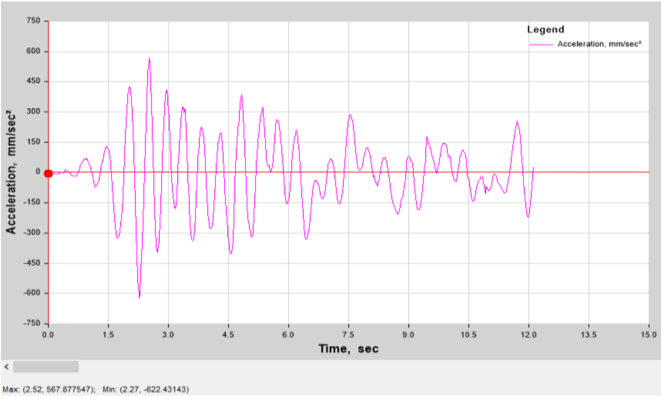

Fig 4.14: Acceleration vs Time with Outrigger at 20th Storey

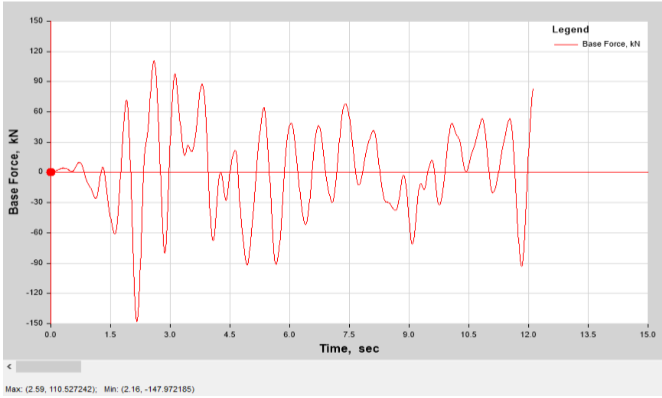

Fig 4.17: Base Force vs Time with Outrigger at 5th Storey

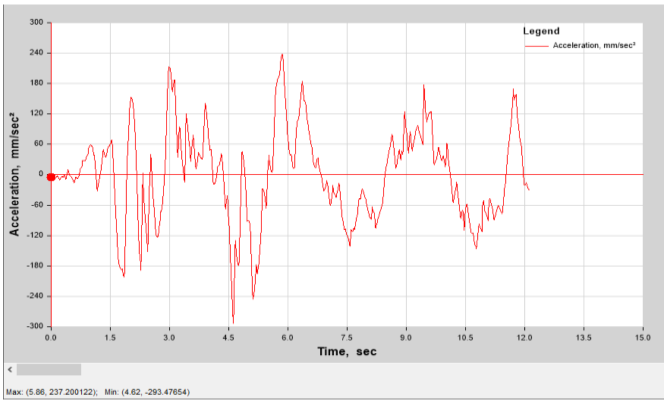

Fig 4.15: Acceleration vs Time with Outrigger at 30th Storey

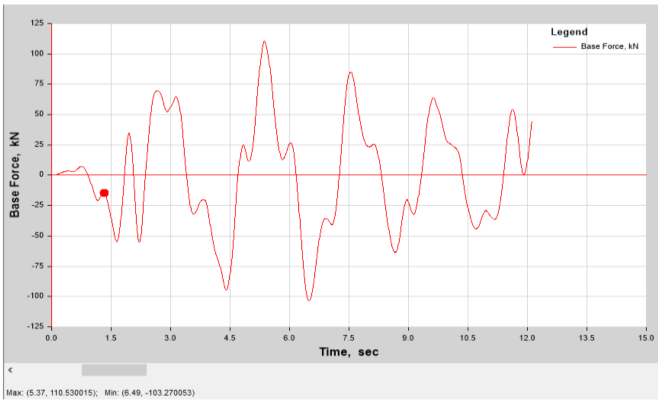

Fig 4.18: Base Force vs Time with Outrigger at 15th Storey

BASE FORCE:

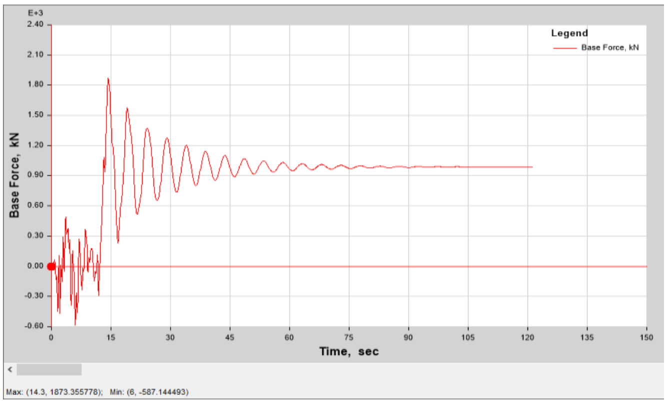

Fig 4.16: Base Force vs Time without Outrigger

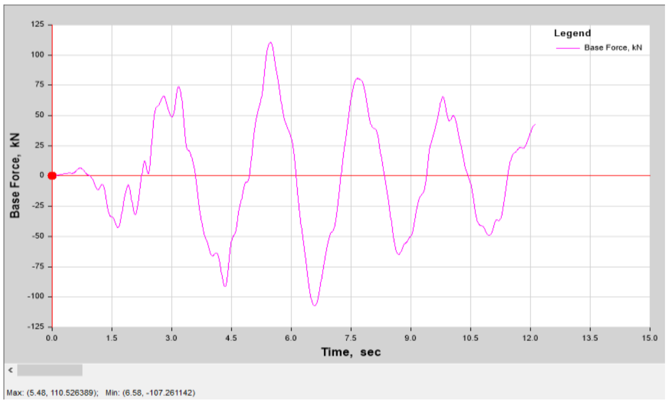

Fig 4.19: Base Force vs Time with Outrigger at 20th Storey

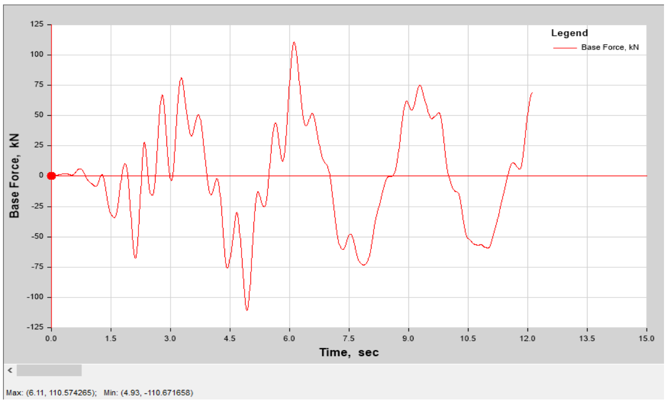

Fig 4.20: Base Force vs Time with Outrigger at 30th Storey

Table 4.1: Displacement, Velocity, Acceleration, Base Force

Storey	Displacement (mm)	Velocity (mm/sec)	Acceleration (mm/sec2)	Base Force (KN)
Without outrigger	81.59	68.72	231.86	1873.35
5	48.97	130.94	914.51	147.97
15	18.51	94.40	571.27	110.53
20	17.31	59.48	622.43	110.52
30	26.09	74.05	293.47	110.67

DISCUSSION:

The outriggers were placed at 5th, 15th, 20th, 30th stories. The maximum displacement in the building was found to be minimum when outrigger was placed at the 20th storey and it was reduced to 17.31 mm from 81.59 mm when no outriggers were used. The velocity was reduced to 59.48 mm/sec from 68.72 mm/sec when no outriggers were used. The acceleration was increased to 622.43 mm/sec^2 from 231.86 mm/sec^2 when no outriggers were used. The base force was decreased to 110.52 kN from 1873.35 kN when no outriggers were used.

5. ANALYSIS OF OUTRIGGER STRUCTURE USING CAPACITY SPECTRUM METHOD

The seismic response of a building is determined by a non linear static analysis also called as pushover analysis. It is an approximate method of analysis. It is a graphical method which comprises of push over curve and the demand curve.

From pushover analysis we get pushover curve. Pushover curve is a plot of displacement at the top to shear forces at the base. This displacement is changed to spectral displacement and base force is changed to spectral acceleration. And hence capacity spectrum is formed. The demand spectrum is the demand of the structure to the seismic forces. The point where this demand curve and the capacity curve coincides is the performance point of the structure. And hence the capacity of the structure is determined.

A 30 storey high rise building is considered. The core consists of shear wall made up of concrete. The outriggers provided are steel beams with bracings. Here for earthquake loading IS 1893 (PART 1) : 2002 was considered.

5.1 METHODOLOGY

A 30 storey building is modelled with the height of all stories being same by using ETABS software. The height of each storey is 3.1 meters. The depth of slab is 150 mm. Shear wall of thickness 75 mm is provided. The zone considered is III with a zone factor of 0.16. And soil condition taken is medium. Response reduction factor is 5. And importance factor is 1.

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RESULTS:

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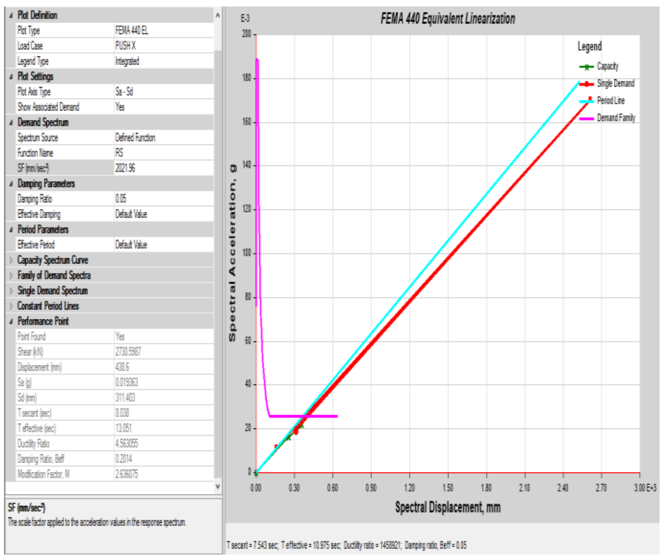

Fig 5.1: Capacity Spectrum Curve without outrigger

The performance point of the building in the fig.5.1 had a base force of 2730.59 kN and displacement of 438.6 mm.

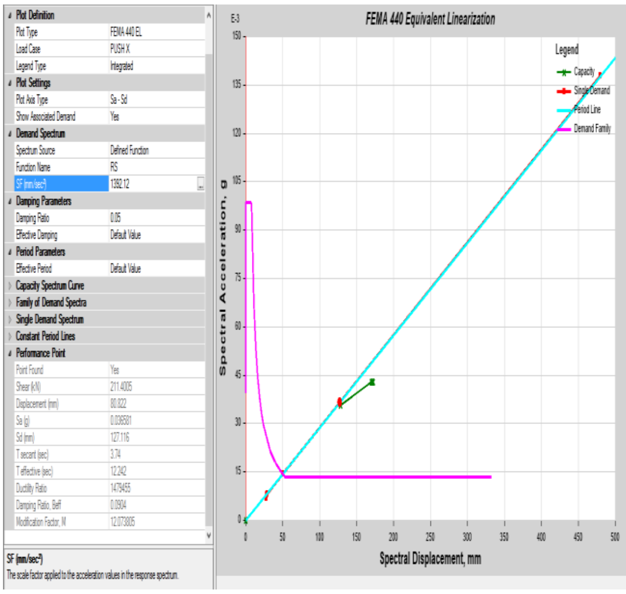

Fig 5.2:Capacity Spectrum Curve with outrigger at 5th storey

The performance point of the building in the fig 5.2 had a base force of 211.4 kN and displacement of 80.82 mm.

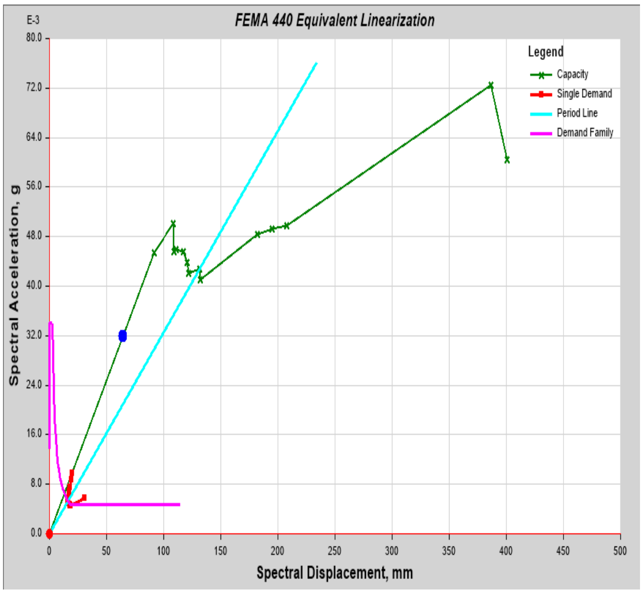

Fig 5.4 : Capacity Spectrum Curve with outrigger at 20th storey

The performance point of the building in the fig 5.4 had a base force of 388.34 kN and displacement of 109.49 mm.

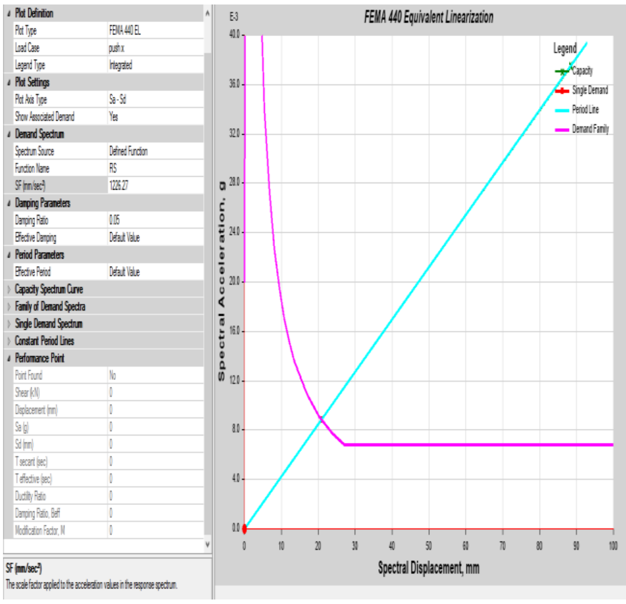

Fig 5.3: Capacity Spectrum Curve with outrigger at 15th storey

The performance point of the building in the fig 5.3 had a base force of 128.2 kN and displacement of 60.1 mm.

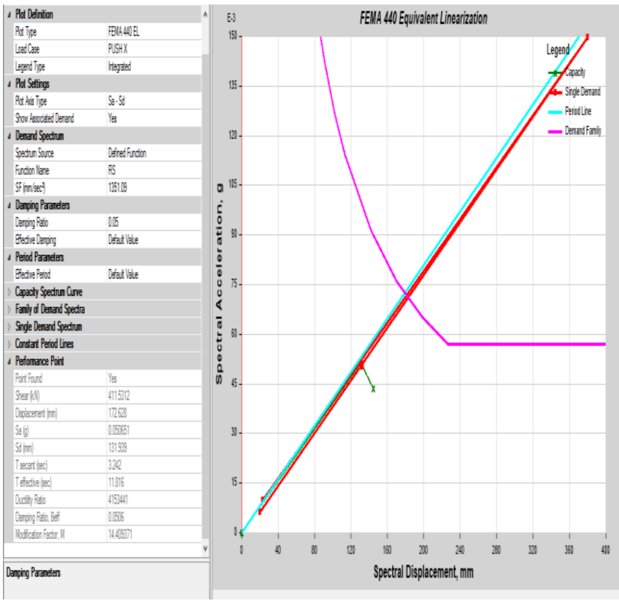

Fig 5.5: Capacity Spectrum Curve with outrigger at 30th storey

The performance point of the building in the fig 5.5 had a base force of 411.53 kN and displacement of 172.62 mm.

Fig 5.6: Pushover Curve without outrigger

Fig 5.9: Pushover Curve with outrigger at 20th storey

Fig 5.7: Pushover Curve with outrigger at 5th storey

Fig 5.10: Pushover Curve with outrigger at 30th storey

Fig 5.8: Pushover Curve with outrigger at 15th storey

Table 5.1: Displacement and Base Shear

Storey	Displacement (mm)	Base Shear (KN)
Without Outrigger	502.77	3110.63
5	97.79	249.18
15	60.13	128.22
20	544.93	657.53
30	170.98	415.87

DISCUSSION:

Outriggers placed at 15th storey the base force of 128.2 kN and displacement of 60.1 mm at performance point was found to be minimum when compared to base force and displacement at performance when outriggers were placed at 5th, 20th, 30th and when no outriggers were used.

And maximum displacement in the building which is 502.77 mm and maximum base force of 3110.63 kN when no outriggers were used was reduced to a displacement of 60.13 mm and base force of 128.22 kN when outrigger was placed at 15th storey.

CONCLUSIONS

The outriggers were placed at 5th ,15th ,20th ,30th stories for time history analysis. The displacement in the building was found to be minimum when outrigger was placed at the 20th storey and it was reduced to 17.31 mm from 81.59 mm when no outriggers were used. The velocity was reduced to 59.48 mm/sec from 68.72 mm/sec when no outriggers were used. The acceleration was increased to 622.43 mm/sec^2 from 231.86 mm/sec^2 when no outriggers were used. The base force was decreased to 110.52 kN from 1873.35 kN when no outriggers were used.

The storey stiffness is increased by 2.27 times storey stiffness of the building without the use of outriggers. The maximum storey displacement in the building with the use of outriggers at the top most storey is reduced by 34.1% as compared to the one without outrigger while the storey shear is reduced by 19.78% when compared to the one without outrigger. The storey overturning moment is reduced by 17.18% as compared to the one without outrigger.

The optimum location of outrigger is found to be at 0.66 times the height of the building from the bottom.

When outriggers are placed at 15th storey the base force of 128.2 kN and displacement of 60.1 mm at performance point was found to be lowest when compared to base force and displacement at performance when outriggers were placed at 5th, 20th, 30th and when no outriggers were used.

The maximum displacement in the building which is 502.77 mm and maximum base force of 3110.63 kN when no outriggers were used was reduced to a displacement of 60.13 mm and base force of 128.22 kN when outrigger was placed at 15th storey.

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