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ANALYSIS OF HIGH-RISE RCC STRUCTURE FOR INVESTIGATING OPTIMUM POSITION OF RCC OUTRIGGERS FOR DIFFERENT EARTHQUAKE ZONES AND TYPE OF SOILS

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Abstract— **Rapid growth of infrastructure to accommodate modern civilization is demanding tall structures in cities. As buildings become taller the problem of their lateral stability and sway needs to be tackled by engineering judgment. Outrigger systems have been successfully applied in reducing the lateral displacement of tall buildings under wind and earthquake forces. Numerous studies have been carried out for determining optimum positions of outriggers in high rise structures; however, effect of earthquake zones and soil types on optimum position of outriggers has not been adequately studied. In the present paper, an analysis of a 70 storied RCC high-rise structure provided with and without virtual outrigger system is carried out for determining optimum position of RCC outriggers. The structure has been analyzed to study its behavior under wind and earthquake forces, considering its location in different seismic zones (II, III. IV and V) and also in different types of soils (soft, medium and hard) using "ETAB" software. The virtual outriggers (RCC belt) were provided at seven different levels along the height structure (H/4, 3H/8, H/2, 5H/8, 3H/4, 7H/8 and H) with top level outrigger as fixed and others were varied for their locations. Thus, the structure has been analyzed considering it has been provided with two outriggers at a time, one at the top of structure (H) and the other at a specific level along the heights. Results of the analysis shows lower values for storey displacement, drift and base shear when the structure is considered with one outrigger at top (H) and other at 1/4th height (H/4) for all seismic zones (II, III, IV and V) and all soil conditions (soft, medium and hard). Thus, it is concluded that optimum position of outrigger lies at 1/4th height (H/4) along the height of structure and it goes well in agreement with the values found in literature.**

Keywords— **Outrigger system, High rise structures, Displacement, Base shear, Story drift, Optimum position of outrigger, Seismic zones**

I. INTRODUCTION

The growth of high-rise structure is rapidly rising in India and worldwide. In large cities where the population is growing together with a need of accommodation, high-rise structures are inevitable. The Indian territory is prone to earthquakes and is divided into four seismic zones viz. zone II, III, IV, and V as per the latest IS 1893 :2016 provisions. As the height of structure increases, it is necessary to analyse the structures according to the seismic zones and the soil types. Also, the structures get subjected to storey drift and lateral displacement due to earthquake forces. In such situations, controlling storey drift and lateral displacement of the structure becomes difficult unless some structural system is provided to withstand the effects of lateral forces such as earthquake and wind. The traditional techniques for controlling the storey drift and lateral displacement of tall structures include the structural systems viz bracings, outriggers, RC shear walls, shear cores, steel plate shear walls, box systems, base isolation, dampers etc. Among these available techniques, the outrigger structural system has been proved to be effective in resisting the effects of lateral forces.

The outrigger structural system is broadly classified into conventional and virtual outrigger system. In conventional outrigger system, outrigger trusses are connected directly to shear walls at the core and to the columns located at the periphery of the structure. However, in virtual outrigger system, only outer peripheral columns are connected by outrigger trusses and the shear wall remains unconnected.

Virtual outriggers are provided in the form of truss, RCC belt and composite materials. The complicated connection observed in conventional outrigger system between outrigger and core, which were avoided in virtual outrigger system. Floor space is saved in virtual outrigger system which is occupied by the outrigger truss members in conventional outrigger system Shah and Gore [1]. The number of outriggers depend on height of the structure i.e., height of the structure increases number of outriggers increases. Optimum responses of structure depend on optimum position of outrigger hence it becomes necessary to determine the optimum position of outrigger.

Many analytical and experimental research studies have been carried out to investigate the optimum position of outriggers in order to minimize structural responses (i.e., story drift, displacement and base shear) due to lateral forces such as wind and earthquake. Shivacharan et al. [2], analysed 30 storied high-rise structure in seismic zone V for medium type of soil and concluded that the optimum position of outrigger lies at 0.5 times the height of structure. Nanduri et al. [3], analysed 30 storied high rise reinforced concrete structure considering seismic zone I and hard type of soil under earthquake load and determined the optimum position of outrigger system with belt truss. The study indicated that the optimum location of the outrigger lies approximately at 0.5 times the height of structure. Kogilgeri and Shanthapriya [4], analysed 40 storied high rise steel structure under static, dynamic and wind load. The investigators concluded that optimum position of outrigger lies at 1/3rd height of the structure. Kian and Siahaan [5], determined optimum position of conventional outrigger in 40 and 60 storied high rise concrete structure subjected to earthquake load. Authors conclude that optimum position of the outrigger lies when first outrigger was provided at top and second outrigger at 0.55th height of the structure. Raut and Dahake [6], analysed a 30 storied structure with X bracing outrigger to study the structural responses viz. lateral displacement, story drift and time period using ETABS. Authors concluded that the optimum position of outrigger lies at 0.5th height of the structure. Osama and Omar [7], designed a 60 storied RCC structure with and without outrigger system subjected to earthquake load. The authors conclude that the outrigger system helps in reducing the lateral displacements up to 37% and hence decreases opportunities of the collapse of structure. Sathyanarayanan et al. [8], investigated the optimum position of outrigger for three multi-storied structures of 30m, 45m and 60m heights in seismic zone V for hard type of soil. Researchers concluded that optimum positions of outriggers for three multi-storied structures lies at 1/2, 1/2.5 and 1/2.85 height of the structures. Fawzia et al. (2010) [9], determined and compared deflection of 60 storied (H) composite structure by providing conventional outriggers at one (0.6H), two (H and 0.5H) and three (H, 2H/3 and H/3) levels. Authors concluded that deflection of the structure gets reduced by 34%, 41% and 51% for one, two and three outrigger levels respectively.

From the literature studies, it is observed that very few studies have been carried out with reference to the determination of optimum location of outriggers especially considering various seismic zones as well as different soil types. Further, the research studies also indicate that high rise structures up to a maximum of 60 stories are analysed for determining optimum positions of outriggers and that too for seismic zones I and V in hard and medium type soils. Therefore, in the present paper analysis of a 70 storied RCC high-rise building is carried out for determination of optimum position of virtual outrigger system considering various seismic zones viz. II, III, IV and V; and considering soft, medium and hard soils. The results are compared with the same structure but without providing the outrigger system. Study indicates that optimum position of outriggers lies at when one outrigger was provided at top of the structure height and second outrigger at 1/4th height of structure in all seismic zones and all type of soils and maximum % reduction in storey displacement, drift and % increment in base shear observed in all seismic zone and all types of soils without and with outrigger were 12.96, 8.67 to 9.61 and 5.36%.

II. METHODOLOGY

Analysis of 70 Storied High-Rise Structure

In the present study, analysis of a 70 storied RCC structure is carried out by assuming that it is located in the seismic zones II, III, IV and V; and in different type of soils viz. soft, medium and hard soil. The building structure provided with and without the virtual outriggers has been analysed considering the lateral forces viz. wind and earthquake. The analysis is performed using ETAB software and as per the recommendations of IS: 875 (Part 3) - 2015 [13] and IS: 1893 - 2016 [10]. Table - 1 shows geometrical data of the structure. The typical floor plan of the structure and its developed analytical model provided with and without the outriggers is shown in Fig. 1 (a) and Fig. 1 (b) respectively.

Geometrical Properties of Structure

Geometrical properties of structure and preliminary data considered for analysis is shown in Table - 1.

Table - 1 Geometrical properties of the Structure Considered for Analysis

Number of stories	G + 70	**RCC belt outrigger, location and grade of concrete**	3 m deep, 0.5 m thick 46-70 Storey - M60 16-45 Story - M50 6-15 Story - M60 Plinth-5 Story - M60
Total height of structure	210 m		

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<table>
<tr><td>Plan Dimensions</td><td>25 m x 25 m</td><td>Slab thickness and grade of concrete</td><td>0.150 m - M40</td></tr>
<tr><td>Floor to floor height</td><td>3 m</td><td>Wall thickness</td><td>0.230 m</td></tr>
<tr><td>Bottom story height</td><td>3.2 m</td><td>Live load
Floor load</td><td>2 kN/m^2 [12]
1.5 kN/m^2</td></tr>
<tr><td rowspan="4">Size of beam and grade of concrete</td><td rowspan="4">0.3 × 0.75 m, M40</td><td>Dead load
Wall load including plaster</td><td>11 kN/m [11]
3.45 kN/m</td></tr>
<tr><td>Seismic zones</td><td>II, III, IV, V</td></tr>
<tr><td>Wind force</td><td>55 m/s</td></tr>
<tr><td>Type of soil taken</td><td>Soft, Medium, Hard</td></tr>
<tr><td rowspan="2">Size of column and grade of concrete</td><td rowspan="2">0.8 m x 1.2 m (46-70 Story), M40
0.8 m x 1.4 m (16-45 Story), M50
0.8 m x 1.8 m (6-15 Story), M60
1.00 m x 1.8 m (Plinth-5 Story), M60</td><td>Earthquake load</td><td>As per IS 1893: 2016</td></tr>
<tr><td>Wind load</td><td>As per IS 875: 2015</td></tr>
</table>

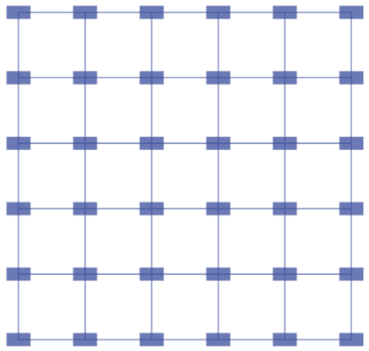

Fig. 1. (a) Typical Floor Plan of 70 storied structure

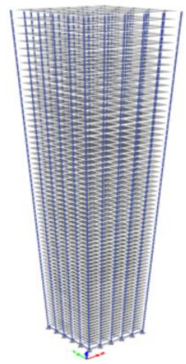

Fig. 1. (b) Analytical model provided without the outriggers

Modelling of the structure

The structure has been analysed by developing various models considering the outriggers at different locations along the height for determination of optimum location. Each model has been provided with two outriggers, one at the top of the structure (H) and the other at different locations along the height of structure viz. H/4, 3H/8, H/2, 5H/8, 3H/4, 7H/8. Thus, a total six structural models are developed for each seismic zone and soil type based on the location of outrigger sets (i.e., one at the top and other with varying height). The details of outrigger locations for these six structural models developed for each seismic zone and soil type are as given in Table - 2.

Table - 2 Outrigger Locations for a Structural Model with Varying Height of Second Outrigger

Model No.	1	2	3	4	5	6
Location of 1st outrigger	H	H	H	H	H	H
Location of 2nd outrigger	7H/8	3H/4	5H/8	H/2	3H/8	H/4

Table - 3 Nomenclatures Used for Designating Structural Models

Model –M, Seismic Zones – II, III, IV & V, Soft Soil – SS, Medium Soil – MS, Hard Soil – HS						
Type of Zones / Soil	**Without outrigger**			**With outrigger**		
	Soft	**Medium**	**Hard**	**Soft**	**Medium**	**Hard**
Zone II	M II - SS	M II - MS	M II - HS	M II SS - 1 to M II - SS - 6 (6 nos.)	M II MS - 1 to M II - MS - 6 (6 nos.)	M II HS - 1 to M II - HS - 6 (6 nos.)
Zone III	M III - SS	M III - MS	M III - HS	M III SS - 1 to M III - SS - 6 (6 nos.)	M II MS - 1 to M II – MS - 6 (6 nos.)	M III HS - 1 to M III - HS - 6 (6 nos.)
Zone IV	M IV - SS	M IV - MS	M IV - HS	M IV SS - 1 to M IV - SS	M IV MS - 1 to M IV -	M IV HS - 1 to M IV -

				- 6 (6 nos.)	MS - 6 (6 nos.)	HS - 6 (6 nos.)
Zone V	M V - SS	M V - MS	M V - HS	M V SS - 1 to M V - SS - 6 (6 nos.)	M V MS - 1 to M V - MS - 6 (6 nos.)	M V HS - 1 to M V - HS - 6 (6 nos.)
No. of Models (Total - 84)	04	04	04	24	24	24

Thus, for the structure under consideration, in all 84 models were developed. Of these 84 models 72 models were developed considering a particular seismic zone and a particular soil type with six different heights (i.e., 4 zones x 3 soil types x 6 heights) and remaining 12 models were developed for a particular seismic zone and a particular soil type but without any outrigger (i.e., 4 zones x 3 soil types). The first outrigger was provided at the top for all models, while the second was provided at six different heights. All these models are designated by using appropriate nomenclature as indicated in Table - 3.

Fig. 2 to 7 shows the structural models, each provided with two outriggers, one at top and other at different heights.

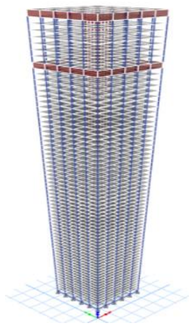
Fig. 2. Model with outriggers at H (top) and 7H/8


Fig. 3. Model with outriggers at H (top) and 3H/4


Fig. 4. Model with outriggers at H (top) and 5H/8

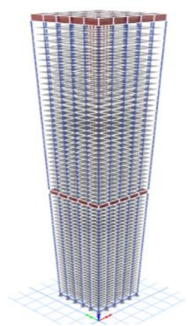
Fig. 5. Model with outriggers at H (top) and H/2

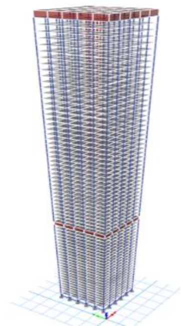
Fig. 6. Model with outriggers at H (top) and 3H/8


Fig. 7. Model with outriggers at H (top) and H/4

III. RESULT AND DISCUSSION

The analysis results for various responses of the structural models provided with and without outrigger are presented and discussed in following sections.

Analysis results of story displacement, drift and base shear - Structural models without outrigger

Results of storey displacement, drift and base shear of structural models without outrigger in seismic zone II, III, IV and V for soft, medium and hard soils are shown in Table - 4.

Model	**Displacement EQ Y**	**Drift EQ Y**	**Base Shear EQ Y**	**Model**	**Displacement EQ Y**	**Drift EQ Y**	**Base Shear EQ Y**
Seismic Zone II				Seismic Zone III			
M II - SS	151.45	0.000869	3356.05	M III - SS	242.28	0.001391	5369.68
M II - MS	123.31	0.000708	2733.07	M III - MS	197.30	0.001133	4372.92
M II - HS	90.67	0.000520	2009.61	M III - HS	145.07	0.000833	3215.38
Seismic Zone IV				Seismic Zone V			
M IV - SS	363.42	0.002086	8054.53	M V - SS	545.13	0.003129	12082.83
M IV - MS	295.95	0.001699	6559.38	M V - MS	443.93	0.002548	9839.07
M IV - HS	217.61	0.001249	4823.07	M V - HS	326.42	0.001874	7234.61

Table - 4 Displacement, Drift and Base Shear of Structure Without Outrigger

From the Table - 4 it is observed that, the storey displacement, drift and base shear values for models in zone II, III, IV and V for soft soil are found to be more by an average value of 44.92% when compared with values obtained for medium and hard soil in same zone.

Analysis results of story displacement, drift and base shear - Structural models with outrigger

Analysis results of storey displacement, drift and base shear of structural models with outrigger in seismic zone II, III, IV and V for soft, medium and hard soils are shown in Table - 5 to 7.

A. Structural Models in Soft Soil

Results of storey displacement, drift and base shear of structural model with outrigger system for seismic zone II, III, IV and V in soft soils are shown in Table - 5.

Model	Displacement EQ Y	Drift EQ Y	Base Shear EQ Y	Model	Displacement EQ Y	Drift EQ Y	Base Shear EQ Y
Seismic Zone II				Seismic Zone III			
M II SS - 1	136.29	0.000805	3546.25	M III SS - 1	218.07	0.001287	5674.00
M II SS - 2	134.63	0.000799	3546.12	M III SS - 2	215.41	0.001279	5673.80
M II SS - 3	133.40	0.000801	3546.18	M III SS - 3	213.44	0.001281	5673.89
M II SS - 4	132.26	0.000812	3546.18	M III SS - 4	211.62	0.001300	5673.89
M II SS - 5	131.82	0.000799	3546.18	M III SS - 5	210.91	0.001278	5673.89
M II SS - 6	131.79	0.000790	3546.18	M III SS - 6	210.88	0.001264	5673.89
Seismic Zone IV				Seismic Zone V			
M IV SS - 1	327.11	0.001931	8511.00	M V SS - 1	490.67	0.002896	12767
M IV SS - 2	323.11	0.001918	8510.70	M V SS - 2	484.67	0.002877	12766
M IV SS - 3	320.16	0.001921	8510.84	M V SS - 3	480.24	0.002882	12766
M IV SS - 4	317.43	0.001949	8510.84	M V SS - 4	476.15	0.002924	12766
M IV SS - 5	316.37	0.001917	8510.84	M V SS - 5	474.56	0.002875	12766
M IV SS - 6	316.30	0.001896	8510.84	M V SS - 6	474.45	0.002844	12766

Table - 5 Displacement, Drift and Base Shear of Structure with Outrigger in Soft Soil

From Table - 5 it is observed that displacement, drift and base shear values are found to be lesser for M II SS - 6, M III SS - 6, M IV SS - 6 and M V SS - 6 for outrigger provided at H and H/4.

B. Structural Models in Medium Soil

Results of storey displacement, drift and base shear of structural model with outrigger system for seismic zone II, III, IV and V in medium soils are shown in Table - 6.

Model	Displacement EQ Y	Drift EQ Y	Base Shear EQ Y	Model	Displacement EQ Y	Drift EQ Y	Base Shear EQ Y
Seismic Zone II				Seismic Zone III			
M II MS - 1	110.99	0.000655	2887.96	M III MS - 1	177.59	0.001048	4620.74
M II MS - 2	109.64	0.000651	2887.86	M III MS - 2	175.42	0.001041	4620.58
M II MS - 3	108.63	0.000652	2887.91	M III MS - 3	173.82	0.001043	4620.66
M II MS - 4	107.71	0.000661	2887.91	M III MS - 4	172.33	0.001058	4620.66
M II MS - 5	107.35	0.000650	2887.91	M III MS - 5	171.76	0.001041	4620.66
M II MS - 6	107.32	0.000643	2887.91	M III MS - 6	171.72	0.001030	4620.66
Seismic Zone IV				Seismic Zone V			
M IV MS - 1	266.39	0.001572	6931.11	M V MS - 1	399.59	0.002359	10397
M IV MS - 2	263.13	0.001562	6930.84	M V MS - 2	394.70	0.002343	10396
M IV MS - 3	260.73	0.001565	6930.99	M V MS - 3	391.09	0.002343	10396
M IV MS - 4	258.50	0.001587	6930.99	M V MS - 4	387.76	0.002381	10396
M IV MS - 5	257.64	0.001561	6930.99	M V MS - 5	386.46	0.002341	10396
M IV MS - 6	257.58	0.001544	6930.99	M V MS - 6	386.38	0.002316	10396

Table - 6 Displacement, Drift and Base Shear of Structure with Outriggers in Medium Soil

From Table - 6 it is observed that displacement, drift and base shear values are found to be lesser for M II MS - 6, M III MS - 6, M IV MS - 6 and M V MS - 6 for outrigger provided at H and H/4.

C. Structural Models in Hard Soil

Results of storey displacement, drift and base shear of structural model with outrigger system for seismic zone II, III, IV and V in hard soils are shown in Table - 7.

Model	Displacement EQ Y	Drift EQ Y	Base Shear EQ Y	Model	Displacement EQ Y	Drift EQ Y	Base Shear EQ Y
Seismic Zone II				Seismic Zone III			
M II HS - 1	81.61	0.000482	2123.50	M III HS - 1	130.58	0.000771	3397.60
M II HS - 2	80.61	0.000479	2123.42	M III HS - 2	128.98	0.000766	3397.48
M II HS - 3	79.88	0.000479	2123.46	M III HS - 3	127.80	0.000767	3397.54
M II HS - 4	79.20	0.000486	2123.46	M III HS - 4	126.72	0.000778	3397.54
M II HS - 5	78.93	0.000478	2123.46	M III HS - 5	126.29	0.000765	3397.54
M II HS - 6	78.81	0.000473	2123.46	M III HS - 6	126.26	0.000757	3397.54
Seismic Zone IV				Seismic Zone V			
M IV HS - 1	195.87	0.001156	5096.40	M V HS - 1	293.81	0.001734	7644.61
M IV HS - 2	193.48	0.001149	5096.26	M V HS - 2	290.22	0.001723	7644.34
M IV HS - 3	191.71	0.001151	5096.31	M V HS - 3	287.57	0.001726	7644.47
M IV HS - 4	190.08	0.001167	5096.31	M V HS - 4	285.12	0.001751	7644.47
M IV HS - 5	189.44	0.001148	5096.31	M V HS - 5	284.16	0.001722	7644.47
M IV HS - 6	189.40	0.001136	5096.31	M V HS - 6	284.10	0.001703	7644.47

Table - 7 Displacement, Drift and Base Shear of Structure with Outriggers in Hard Soil

From Table - 7 it is observed that displacement, drift and base shear values are found to be lesser for M II HS - 6, M III HS - 6, M IV HS - 6 and M V HS - 6 for outrigger provided at H and H/4.

Comparison of responses of structural models without and with outrigger at optimum location

Comparison of storey displacement, drift and base shear of structural models without and with outrigger at optimum location in seismic zone II, III, IV and V for soft, medium and hard soil are shown in Table - 8 and Fig. 8 to 10.

Seismic Zone	Soil Type	Without outrigger				With outrigger			
		Model	Displacement (mm)	Drift	Base Shear (kN)	Model	Displacement (mm)	Drift	Base Shear (kN)
II	Soft	M II - SS	151.45	0.00086	3356.05	M II SS - 6	131.79	0.00079	3546.18
III	Soft	M III - SS	242.88	0.00139	5369.68	M III SS - 6	210.88	0.00126	5673.88
IV	Soft	M IV - SS	363.42	0.00208	8054.53	M IV SS - 6	316.30	0.00189	8510.84
V	Soft	M V - SS	545.13	0.00312	12082.8	M V SS - 6	474.45	0.00284	12766
II	Medium	M II - MS	123.31	0.00070	2733.07	M II MS - 6	107.32	0.00064	2887.91
III	Medium	M III - MS	197.30	0.00113	4372.92	M III MS - 6	171.72	0.00103	4620.66
IV	Medium	M IV - MS	295.95	0.00169	6559.38	M IV MS - 6	257.58	0.00154	6930.99
V	Medium	M V - MS	443.93	0.00254	9839.07	M V MS - 6	386.38	0.00231	10396
II	Hard	M II - HS	90.67	0.00052	2009.61	M II HS - 6	78.81	0.00047	2123.46
III	Hard	M III - HS	145.07	0.00083	3215.38	M III HS - 6	126.26	0.00075	3397.54
IV	Hard	M IV - HS	217.61	0.00124	4823.07	M IV HS - 6	189.40	0.00113	5096.31
V	Hard	M V - HS	326.42	0.00187	7234.61	M V HS - 6	284.10	0.00170	7644.47

Table - 8 Responses of Structural Models Without and With Outrigger at Optimum Location

Fig. 8 to 10 shows graphical representation of storey displacement, drift and base shear of structural models without and with outrigger at optimum location outrigger in seismic zone II, III, IV and V for soft, medium and hard soil.

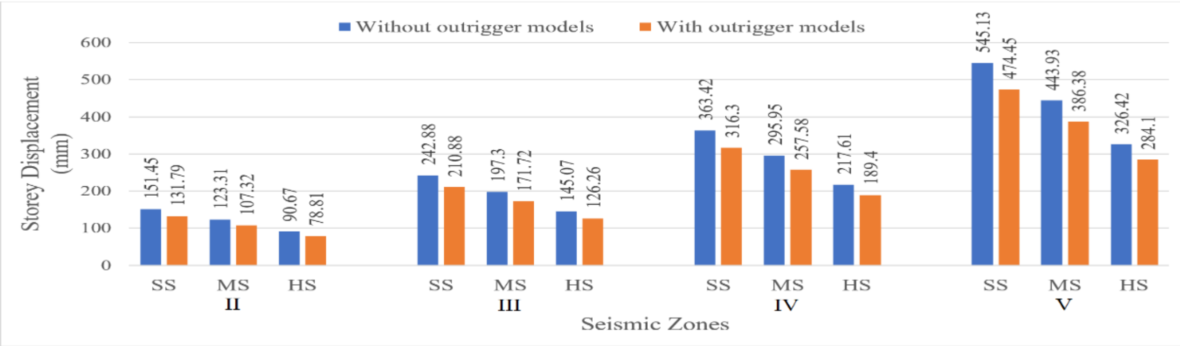

Fig. 8. Story displacement of structural models without and with outrigger at optimum location

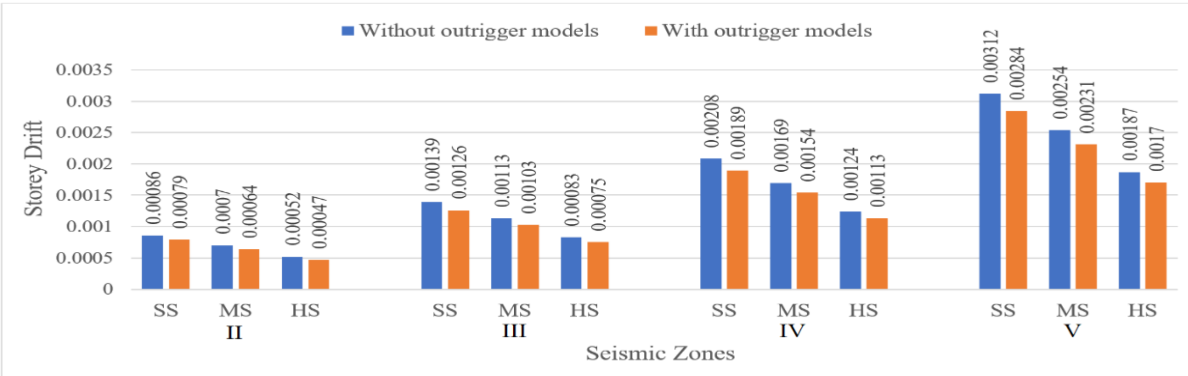

Fig. 9. Story drift of structural models without and with outrigger at optimum location

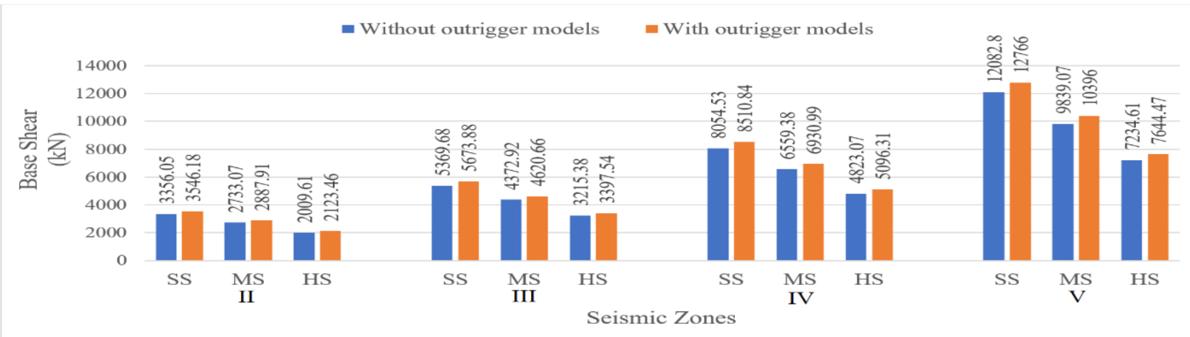

Fig. 10. Base shear of structural models without and with outrigger at optimum location

From Fig. 8 to 10 it is seen that for structural models provided with outriggers in all seismic zones and types of soils shows a reduction of 12.96% in the storey displacement and an average reduction of 9.14% in storey drift when compared with structural models without outriggers. However, an increment of 5.36% is observed in base shear values for the structural models provided with outriggers when compared with the structural models without outriggers.

IV. CONCLUSIONS

The following conclusions are drawn from the study –

1) The storey displacement, drift and base shear values for models in zone II, III, IV and V for soft soil are found to be more by an average value of 44.92% when compared with values obtained for medium and hard soil in same zone.

2) The values of storey displacement, drift and base shear get increases by an average value of 52.5 % for all types of soils as the seismic zone changes from II to V.
3) The optimum position of RCC outriggers is found to be same for all types of soils and in all seismic zones. Thus, for the structure under consideration the location of the outrigger is found to be optimum when first outrigger is placed at top (H) and the other at H/4 height.

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