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Study of Rigid Frame, Core and Outrigger Structural Systems under Variable Heights as Per IS: 1893-2016

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Abstract: The structural efficiency of high rise buildings depends heavily on its resisting capacity and lateral stiffness. With the rise in height of the building, the requirement of new structural system arises in order to increase its performance under lateral loads. This paper presents seismic analysis of different lateral load resisting systems such as Rigid Frame system, Core and Outrigger system under 10,15 and 20 story building for seismic zone IV for soil type III. Models are analysed using Response Spectrum Method in ETABS V18.0.0 software package as per IS 1893(Part 1):2016. The performance of structural systems are analysed considering parameters such as the top story displacement, base shear, axial force and bending moment of critical columns at base. The objective of present work is to check the effectiveness of Rigid Frame system, Core system and Outrigger structural system placed at various positions under increasing height.
Keywords: Core system, Outrigger structural system, Response Spectrum Method, Rigid Frame system and Structural systems.

I. INTRODUCTION

Reaching to top of the sky is setting the new benchmark for the Structural Engineering. The scarcity of land and increase in population, lead to the development of tall buildings. Tall structures analysis and design needs appropriate analytical methods and precise design concepts to resist the lateral loads, so that the structure is safe. Developments of design in the tall building frames have ensured the importance of limiting the sideway under the action of lateral loads. By using various structural systems such as Rigid frame system, core system, flat-slab system, outrigger system, braced frame system etc., the lateral load carrying capacity of structure could be increased to a certain extent. Bare Frame case produces larger lateral displacements and drifts[6].

A. Core and Outrigger Structural System

A core wall is an open core that is converted into a partially closed core by using floor beams and slabs so that lateral and torsional stiffness of the building will be increased.

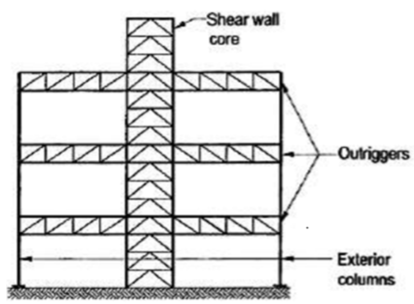

Fig. i : Outrigger with central core

The Outrigger structural system is a lateral load resisting system in which outer peripheral columns are tied to the central core at one or more levels throughout the height of the building. Outrigger acts as stiff horizontal member connected to the core and when lateral load acts upon core, it tries to resist its rotation .The various factors affecting the effectiveness of Outrigger are stiffness and location of the Outrigger truss system, geometry of the building, floor-to-floor height and shape of the tall building, type of outrigger, number of outriggers and its positioning etc. With the increase in height, then the necessity of new structural system arises. In the present study, the performance of rigid frame, core and outrigger structural systems are studied at 10,15 and 20 story's under seismic zone IV. From [13] The permissible lateral top story displacement is $^{H}/_{500}$, i.e., ratio of height of the building from base to 500. Hence based on permissible lateral displacement, the efficient lateral load resisting system and the optimum positioning of outrigger are decided with increase in height.

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II. MODELING DETAILS

A. *General Considerations*

The frame selected for analysis is symmetrical in plan with plan size 42mx42m and floor to floor height is 3m. Here, 10,15 and 20 story models are anlysed for seismic zone IV and soil type III. Centre to center spacing of columns is 6m.Top story displacement, base shear, and axial force and bending moments of critical column C1 and C4 are extracted. The thickness of slab, wall and shear wall are 150mm,200mm and 250mm respectively. The type of outrigger system used is Conventional outrigger without belt truss. Response of building from earthquake considered by load combination as per IS 456:2000, Table 18 and the analysis is carried out as per IS 1893-2016 using Response spectrum method.

B. *Load Definition*

Table. i:Gravity and lateral load considered

Gravity load	
Dead load	Weight of structure
Live load on floor	2 kN/m^2
Live load at roof	1.5 kN/m^2
Floor finish	1.5 kN/m^2
Seismic load	
Soil condition	Soft soil (Soil type III)
Importance factor	1.2
Response reduction factor	5(SMRF)
Seismic zone	IV

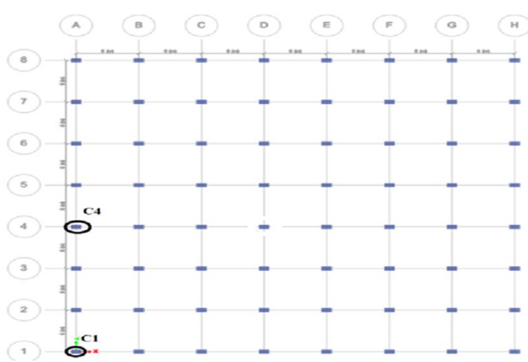
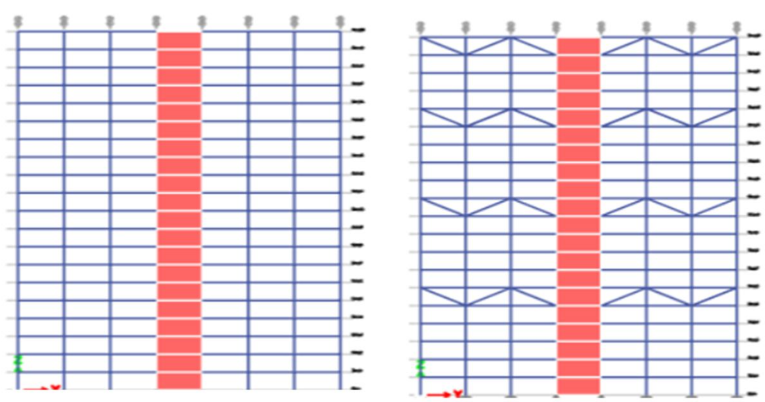


Fig ii:Plan considered for the project work and marked critical column C1 and C4.



(a) (b)

Fig iii: Section view for 20 story (a)core wall and (b) outrigger palced at 0.25H, 0.5H, 0.75H and H.

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III. RESULTS AND DISCUSSIONS

The permissible top story displacement is 60mm, 90mm and 120mm for 10, 15 and 20 story respectively. Initially rigid frame system is checked for top story displacement and if it fails to satisfy the permissible criteria, then core system is analysed and if the displacement is within the limit, then it is adopted ; if core system fails then various positions of outrigger placed 1 number, 2 number, 3 number and 4 number are analysed.

A. 10 Story

Grade of concrete is M30 from story 1 to 5 and M25 from story 6 to 10 and of rebar is Fe500 throughout. The sizes of beam , column and outrigger are 300mmx600mm, 450mmx1000mm and 400mmx600mm respectively.

Table ii : Summary of results

Parameters	Roof displacement (mm)	Column forces at base				Base shear (kN)
		C1		C4		
Model		Axial force (KN)	BM (kN-m)	Axial force (KN)	BM (kN-m)	
Rigid Frame	306.6	2243.2	2469.4	4455.4	2455.6	23422
Core System	110.5	3113.9	1150.5	5318.2	1736.8	22350
Outrigger at 0.25H	59.7	3257.3	1036.8	5611.7	1024.6	23354
Outrigger at 0.5H	54.9	3246.1	1021.5	5582.1	1007.5	23389
Outrigger at 0.75H	64.1	3294.6	1051.7	5676.3	998.6	23411
Outrigger at H	72.6	3313.8	1088.5	5734.6	971.3	23419

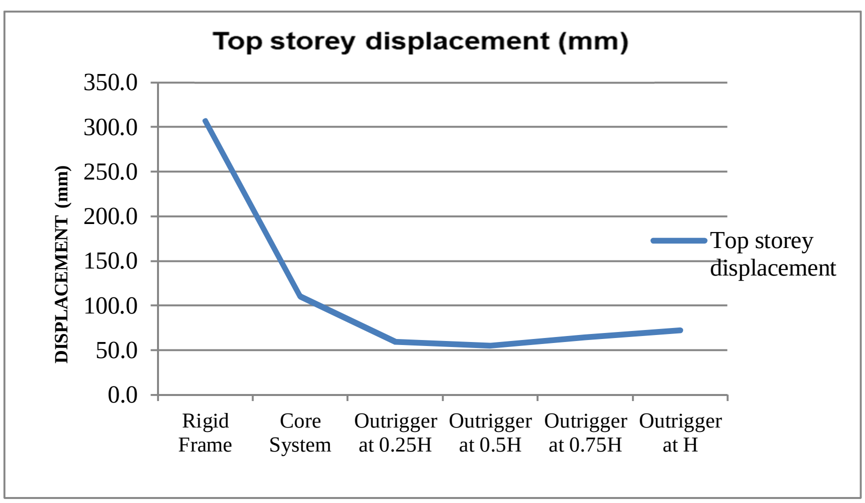

Fig v:Roof displacement for rigid frame, core system and outrigger system

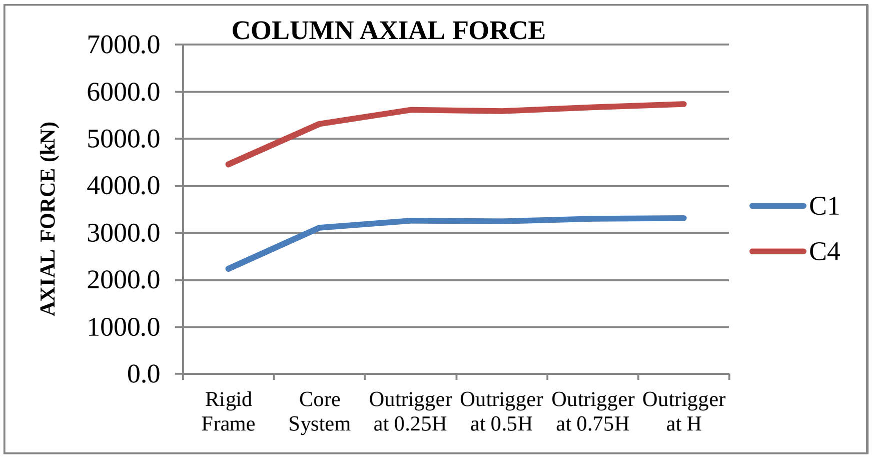

Fig vi:Column axial force for column C1 and C4

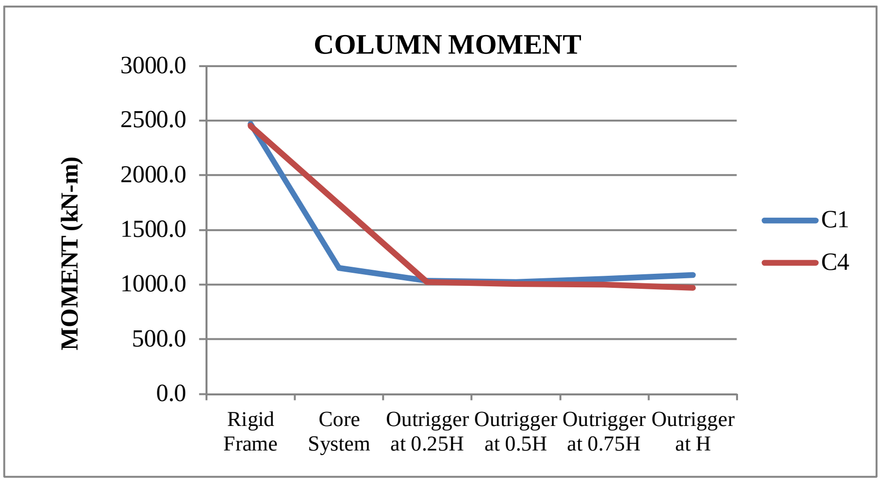

Fig vii:Column moment for column C1 and C4

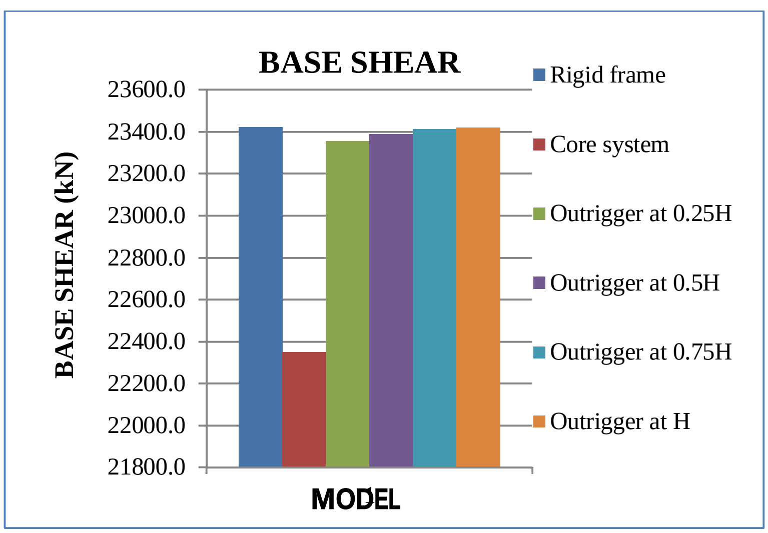

Fig. viii:Base shear for rigid frame, core system and outrigger system.

From Table 3, Rigid frame and core system fails for 10 story model at IV and soil type III and also 1 number outrigger placed at 0.5H is effective in reducing roof displacement compared to outrigger placed at 0.5H, 0.75H and H. Top story displacement reduces by 55.6% when core system is replaced by 1 number outrigger system placed at 0.5H.

B. 15 Story

Grade of concrete is M40 from story 1 to 5, M30 from story 6 to 10 and M25 from story 11 to 15 and of rebar is Fe500 throughout. The sizes of beam , column and outrigger are 300mmx600mm, 500mmx1000mm and 400mmx600mm respectively at seismic zone II and III. Whereas the sizes are 400mmx600mm, 600mmx1000mm, and 400mmx600mm at seismic zone IV and V.

Table iii: Summary of results

Parameters / Model	Top story displacement (mm)	Column forces at base				Base shear (kN)
		C1		C4		
		Axial force (KN)	BM (kN-m)	Axial force (KN)	BM (kN-m)	
Rigid Frame	208.5	2193.7	1663	4739	1660	16699
Core System	131.1	3049.5	592.6	5062	614.6	16543
Outrigger at 0.5H	117.7	3315.0	570.7	5098	598.4	16692
Outrigger at (0.5H and 0.25H)	99.2	3383.0	575.9	5131	588.0	17936
Outrigger at (0.5H and 0.75H)	102.6	3387.6	562.7	5139	594.3	17944
Outrigger at (0.5H and H)	108.3	3394.4	561.3	5167	571.6	17984
Outrigger at (0.5H, 0.25H and 0.75H)	48.9	3488.2	516.5	5288	530.8	19186
Outrigger at (0.5H, 0.25H and H)	50.1	3540.7	511.8	5364	498.8	18616

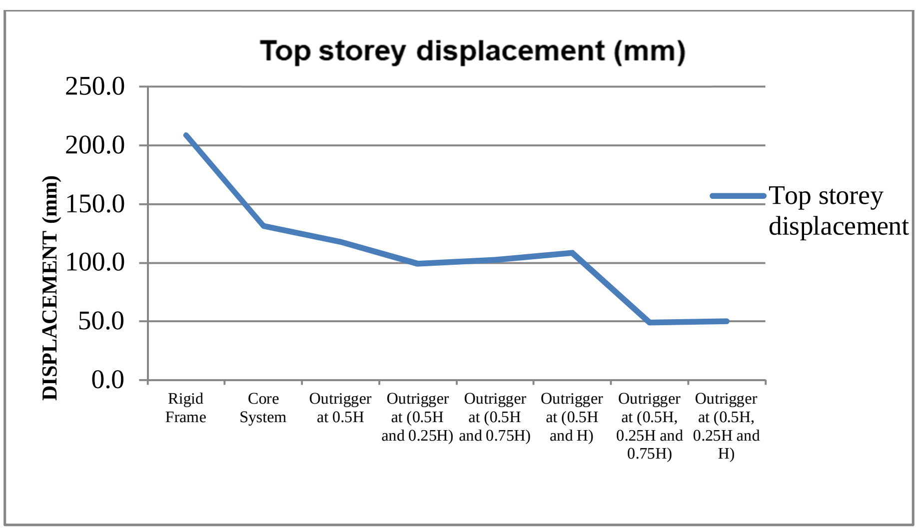

Fig ix:Roof displacement for rigid frame, core system and outrigger system

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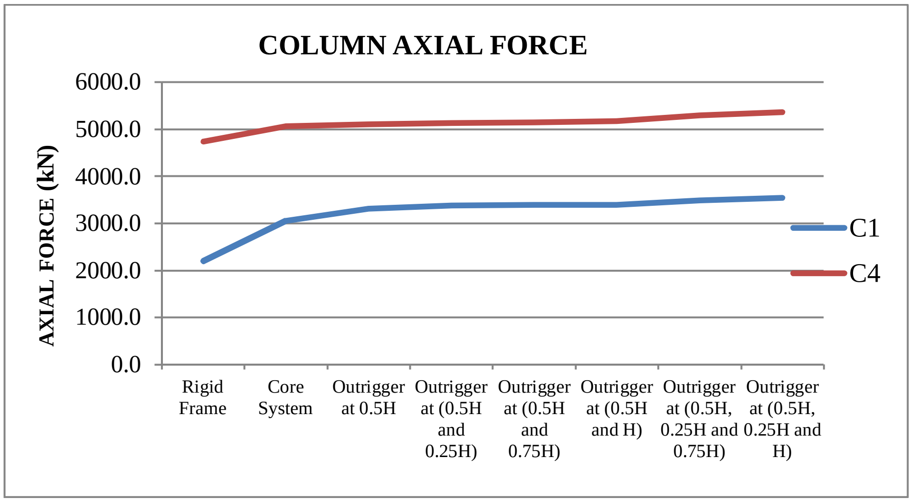

Fig x:Column axial force for column C1 and C4

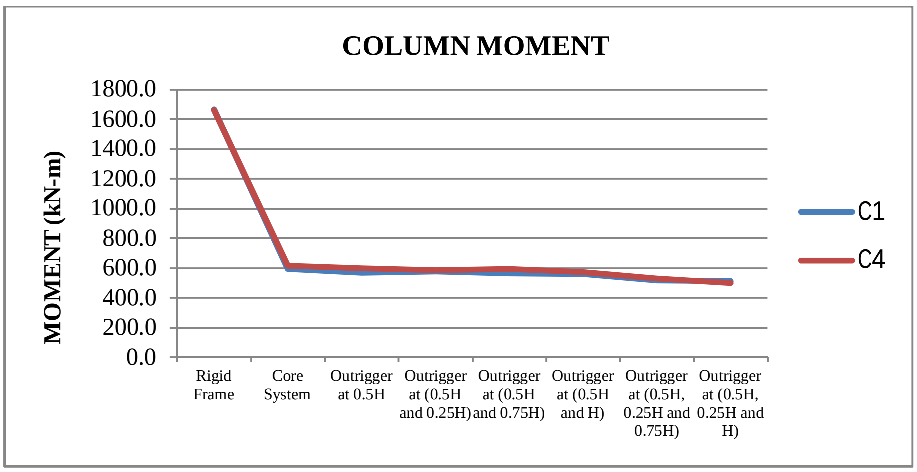

Fig. xi: Column moment for column C1 and C4

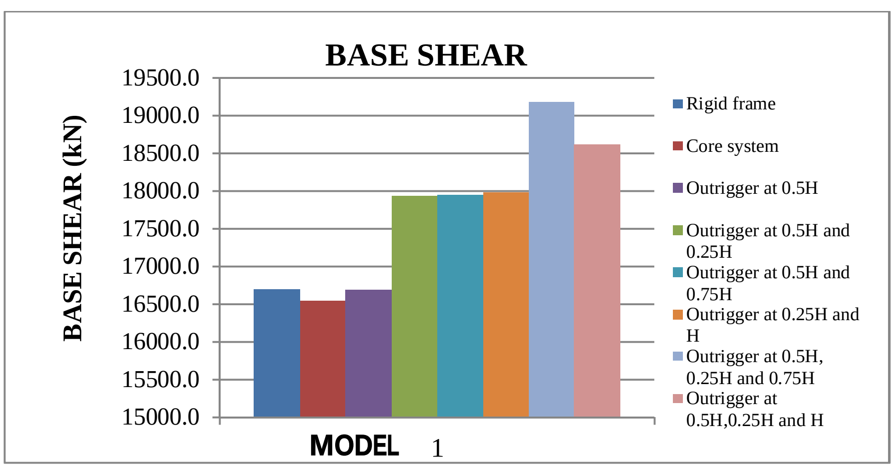

Fig. xii: Base shear for riigid frame, core and outrigger system.

From Table 4, the optimum positioning for placing the 1 number outrigger is at 0.5H .So by keeping position of 1 number outrigger at 0.5H as constant, 2 number outrigger positions are varied and checked and is found that 2 number outrigger placed at 0.5H+0.25H is effective. Similarly, 3 number outrigger are tried and 0.5H+0.25H+0.75H is found effective. From the tabulated results, roof displacement reduces by 62.8% when core is replaced by outrigger.

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C. 20 Story

Grade of concrete is M40 from story 1 to 5, M30 from story 6 to 10 and M25 from story 11 to 20 and of rebar is Fe500 throughout. The sizes of beam , column and outrigger are 300mmx600mm, 500mmx1000mm and 400mmx600mm respectively at seismic zone II and III. Whereas the sizes are 400mmx600mm, 600mmx1000mm, and 400mmx600mm at seismic zone IV and 400mmx600mm, 700mmx1000mm, and 400mmx1000mm at seismic zone V.

Table. iv: Summary of results

Parameter	Top story displacement (mm)	Column forces at base				Base shear (kN)
		C1		C4		
Model		Axial force (KN)	BM (kN-m)	Axial force (KN)	BM (kN-m)	
Rigid Frame	376.5	2736	1986.3	6237	1978	17693
Core System	194.3	4111	726.8	7268	718	17483
Outrigger at 0.5H	156.9	4453	716.6	6604	708	17520
Outrigger at (0.5H and 0.25H)	145.6	4705	663.3	6071	655	17558
Outrigger at (0.5H, 0.25H and 0.75H)	120.7	4839	699.2	5613	690	18426
Outrigger at (0.5H, 0.25H, 0.75H and H)	98.9	4953	668.1	5712	659	17632

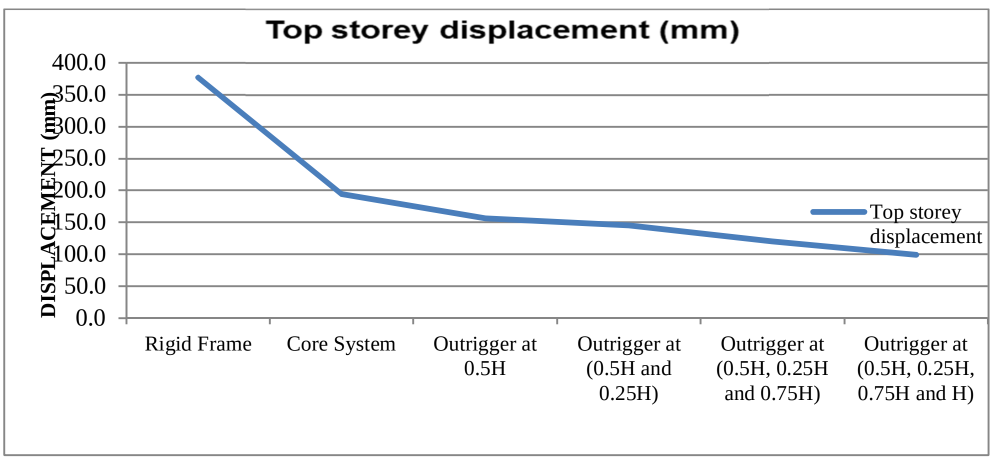

Fig. xiv: Roof displacement for rigid frame, core system and outrigger system

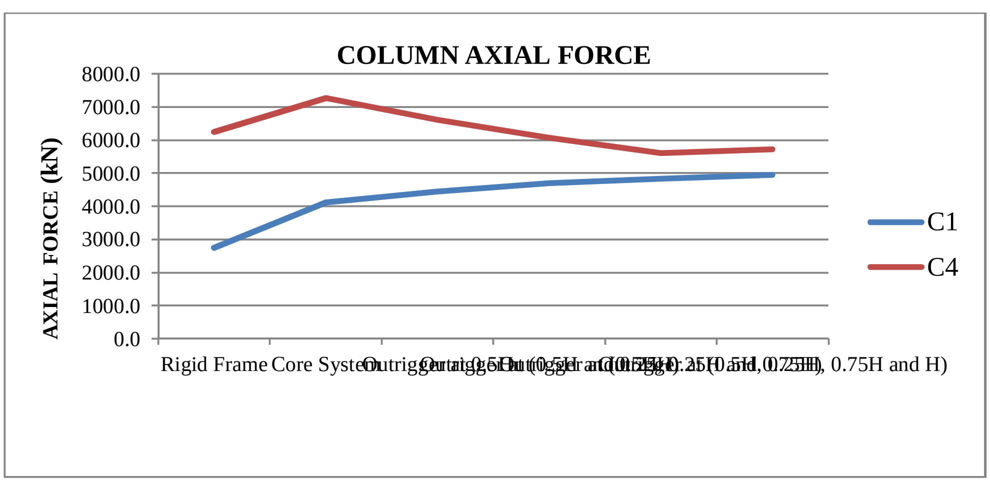

Fig. xv:Column axial force for column C1 and C4

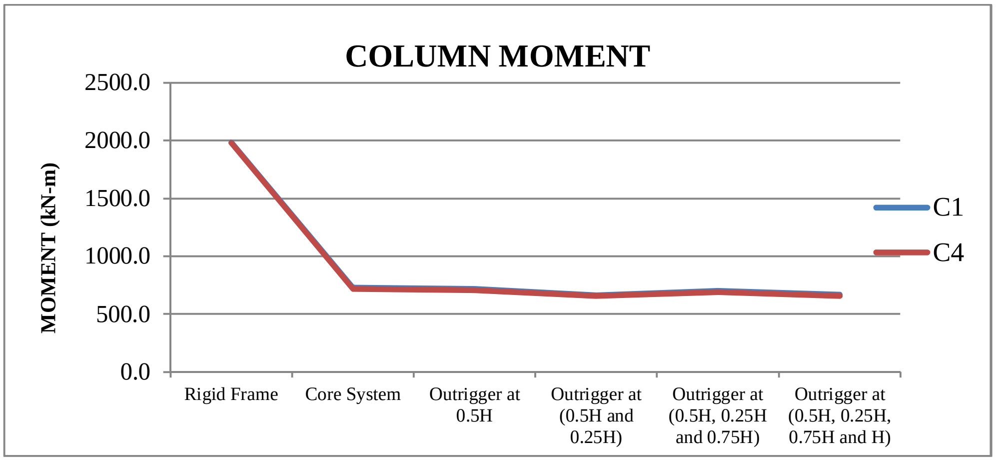

Fig. xvi:Column moment for column C1 and C4

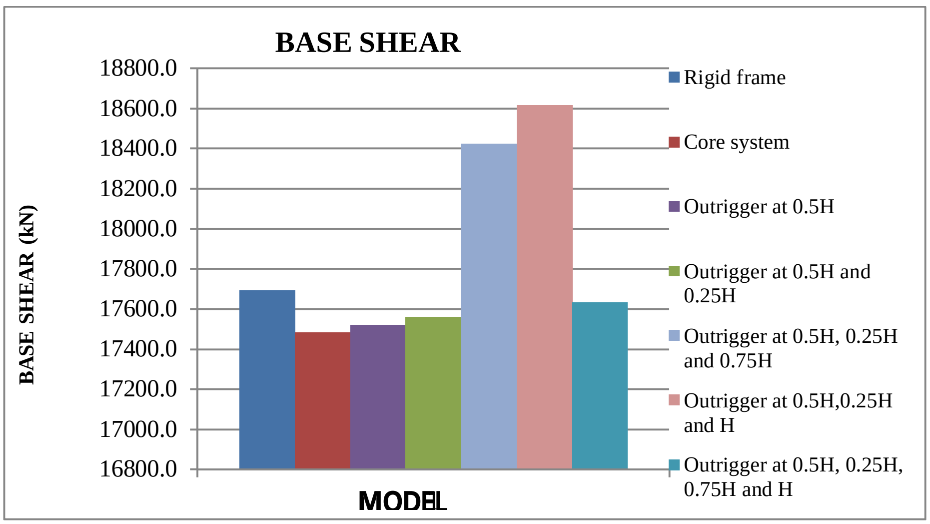

Fig. xvii: Base shear for riigid frame, core and outrigger system.

From Table 5,the combination of outrigger placed at 0.5H+0.25H+0.75H+H is tried and roof displacement is within the limit. From the tabulated results, a reduction in roof displacement of 49.14% is observed when core system is replaced by the combination of outrigger .Bending moment of critical columns C1 and C4 decreased by 8.07% and 8.16% and respectively.

IV. CONCLUSIONS

Rigid frame did not perform effectively in any of the seismic zones for the considered heights of structures in soft soil when analysed as per IS 1893-2016.As the height of building increases then necessity of new structural system arises. Outrigger structural system depends on number and its position throughout the height of the building. For minimum top story displacement, the order of best position for 1 number outrigger is 0.5H, 0.25H and 0.75H respectively. Outrigger performs well compared to rigid frame and core system. Maximum roof displacement is observed in case of rigid frame compared to core and outrigger structural system.

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