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TO STUDY PERFORMANCE OF HIGH-RISE BUILDING UNDER SEISMIC LOAD WITH RIGID FRAME, CORE AND OUTRIGGER SYSTEMS

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Abstract - *In this study considered, Performance of G+5, G+10 and G+15 building under lateral load with different structural systems, such as Rigid frame, Core, Outrigger structural system under seismic loading with seismic zone II, III, IV and V, based on soil type III (soft soil) and reduction factor 3 for ordinary RC moment-resisting frame, 5 for special RC moment-resisting frame. It is evaluated by Equivalent static analysis and Response Spectrum analysis for different load combinations as per IS: 1893:2002. Analysis of above mentioned structural systems are carried-out using E-TABS 2015 software. To check the performance of the building by considering following parameters such as, roof displacement, bending moment of inner and edge columns and core at base for core structural system and outrigger structural systems. The object of the study is to determine the degree of effectiveness of different structural system to increase the performance and sustainability. As the height of the building increases then a necessity of new structural system arise other than rigid frame system.*

Key Words: **Rigid frame system, Core system, Outrigger structural system, Response Spectrum analysis, Equivalent static analysis.**

1. INTRODUCTION

In seismically active zones, structures are subjected to lateral load such as earthquake forces and wind loads in addition to bearing primary gravity load. The performance of structure during an earthquake depends on the intensity of the earthquake and the properties of the structure. Properties such as material, sectional properties, and structural systems have a significant effect on lateral load resisting capacity of the structure. By using different types of structural systems such as rigid frame system, flat slabs system, braced-frame system, shear wall system, core system, mega column, outrigger frame system, tube system etc. the lateral load resisting capacity is increased to a maximum extent.

Many experimental and analytical studies have been conducted to obtain the position of outrigger to control the displacement of the building, but in controlling core moment and column reactions are secondary need of research[7]. So, an attempt is made in this paper to include column reaction and core moment which is discussed below.

1.1 CORE AND OUTRIGGER STRUCTURAL SYSTEM

The idea of outrigger in building structures into couple the perimeter and the internal structure as a whole to resist the lateral load. Both the internal core and the perimeter frame are uncoupled. Therefore, the core and the perimeter frame resist the lateral load by means of pure cantilever action only.

Outrigger increases the stiffness of buildings by means of converting the lateral force into push (compersion) and pull (tension) force in the perimeter structures. Hence, the outrigger is required to resist reverse and cyclic loading. The effective use of outriggers can be achieved in symmetric tall buildings in which core wall or shear wall is located at the center of the building for elevator purposes, this core wall and the exterior columns are the two major structural elements in resisting lateral loads. By connecting these outrigger beams rigidly from central shear wall to exterior columns the resistance to applied lateral loads can be achieved, Figure. 1. Depending on the type of connection between central core wall and exterior columns the outriggers are classified into two major types, conventional outrigger with and without belt truss and virtual outrigger.

Factors affecting outrigger structural system are type of outrigger, number of outriggers, position of outriggers, depth of outriggers, height of building, storey height, type of material used to core and outrigger beam, shape of building, shape of the shear wall at center, connection between core and outrigger and intensity of lateral loads.

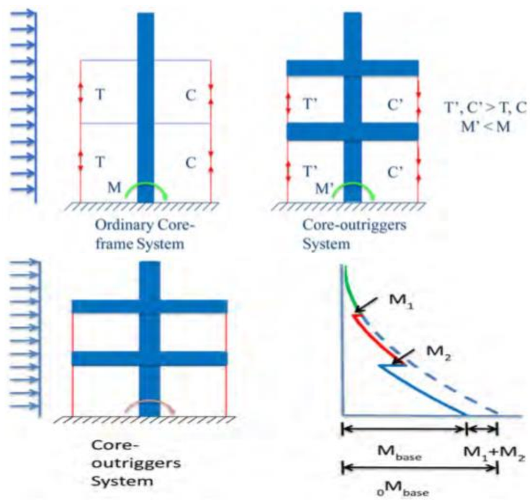


Fig - 1: Difference of moment diagraph between ordinary and outrigger structural system

Assuming outrigger are strong enough to restraining moment M1 and M2, the moment at base, oMbase will be reduced by M1+M2 i.e Mbase = oMbase + M1 +M2 .... (1)

Equation 1 can be rewitten as,

oMbase = Mbase – Mi .... (2)

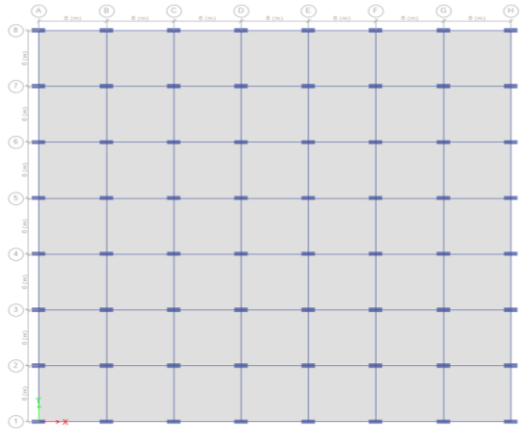
where Mi is restraining moment in i-number of outrigger. From equation 2, the base moment get smaller by either increasing the magnitude of Mi. however if the magnitude of Mi is limited or small, even though there are many outrigger, oMbase will still be close to Mbase. In other words, it is more efficient for an outrigger system, building with strong outrigger rather than incresing the number of outrigger with small stiffness.[2]

In the present study, the effect of material property, sectional property and structural system in high-rise buildings under seismic loading as per IS1893 (part-1):2002 are considered. The overall aim is to assess the structural performance of 5, 10 and 15 storeys with different seismic zones as per Indian standards. So an attempt is made to controlling top storey displacement, core moment and column reactions at edge and inner column. This investigation will serve as a reference for seismic resistant design of rigid frame, core and outrigger structural systems in high-rise RC buildings.

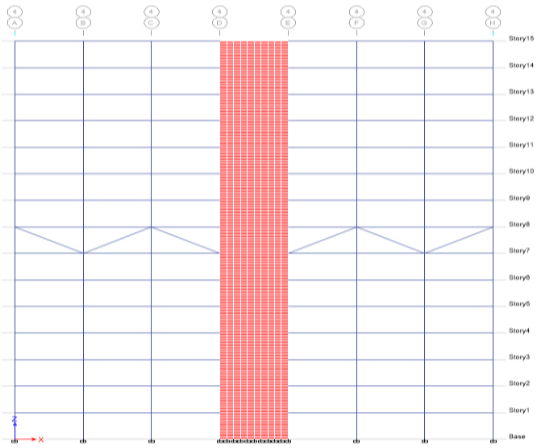
2. MODELING OF REINFORCED CONCRETE BUILDING

Modeling of RC buildings describes the structural configuration of different structural system are as shown in Figure 2. Frame selected for analysis is symmetrical in plan of 42x42m with Centre to Centre column spacing is 6m. Different structural system is introduced in order to minimize the top storey displacement, core moment and column reactions at edge and inner columns for 5, 10 and 15 storey buildings. The structural configuration of different storey buildings like material property (concrete and rebar grade) varied for every 5 storeys (material property will be same for all structural elements at that floor) and sectional property of column varied between 450x1200 to 450x600 and beam varied from 300x650 to 300x500 for 5, 10 and 15 storey in order to obtain optimum design forces and storey height is 3m. Slab, masonry walls and shear wall thickness is assumed to be 150mm, 200mm and 250mm respectively. Diagonal bracing type is adopted as outrigger beam and initial outrigger beam size 300x600mm and 400x600mm for 10 and 15 storey respectively.

Each building is subjected to gravity and lateral load. Wall load of 10kN/m on floor throughout beam length, floor finish of 1.5kN/m^2 and live load of 2kN/m^2 expect roof, at roof wall load of 4kN/m as parapet wall, floor finish of 3kN/m^2 and live load of 1.5kN/m^2. Seismic loading as per IS1893 (part1) – 2002, seismic zone II, III, IV and V at soil type III (soft soil).Natural time period of vibration by empirical expression as per IS1893 (part-1) – 2002 for 5, 10 and 15 storey building is 0.208, 0.416 and 0.625 sec respectively.



(a)



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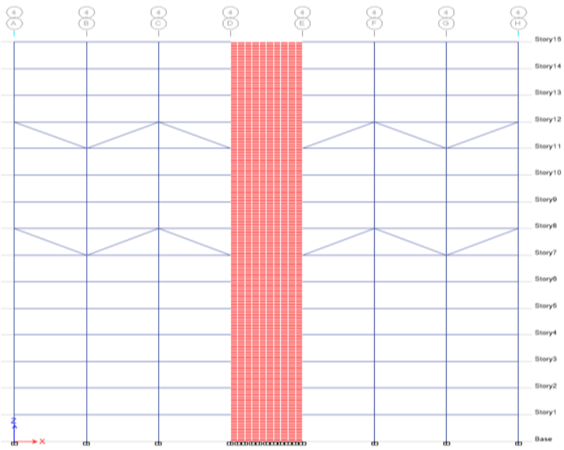

(c)

Fig-2: (a) Plan Rigid frame system (b) Section of core wall with outrigger at 0.5H (c) section of core wall with outrigger at 0.5H and 0.75H

2.1. Method of analysis

Generally following four types of analysis are used for seismic design and performance of buildings, viz linear equivalent static analysis, linear response spectrum analysis, nonlinear static pushover analysis and nonlinear time history analysis. In present study, Equivalent static analysis and response spectrum analysis are used. Dynamic analysis are performed as per clause no 7.8.1 (a), IS1893 – 2002. Response of building from earthquake considered by load combination as per IS456: 2000, Table 18. Modeling and analysis are carried out by ETABS-2015 software.

3. RESULTS AND DISCUSSION

In the present study roof displacement, parameters considered are base bending moment of inner and corner column and base moment of core in core structural system and outrigger structural system under seismic load as per IS1893 (part – 1): 2002 for different seismic zone II, III, IV and V and soil type III. The permissible limit for roof displacement is H/500, where H - height of the building from base.[5]

At initial stage of deciding the material property many trails are modeled for different grade of concrete from M40 to M25 and rebar from Fe415 to Fe500. 26.32% and 26.58 increases in roof displacement along X and Y direction is observed. So, differential grade of concrete is adopted for every 5 storeys through-out the research.

By replacing Fe415 to Fe500, there is no effect on roof displacement and base shear but, 14.52% reductions in rebar percentage in C27 inner column.[14]

From Table 1, it is observed that 40% and 39.86% of roof displacement is reduced for SMRF structure when compared to OMRF structure along X and Y direction respectively [6]. If OMRF rigid frame modeled for seismic zone II, III, IV and V the roof displacement exceeds the permissible limit so, OMRF rigid frame system in seismic zone III, IV and V is unsuitable for any storey buildings [13].

By adopting SMRF system for OMRF system, about 40% and 43.7% reduction in bending moment at inner and edge column are observed.

It is observed that 77.58% and 72.89% reduction in bending moment in inner column and edge column, 75.64% and 78.64% of reduction of roof displacement along X and Y direction when core structural system is introduced to rigid frame system for 5storey building under seismic zone IV and V.

From Table 2, for 10 storey building under seismic zones III, IV and V the rigid frame system is uneconomical, so there arise the necessity of structural system. For seismic zone III and IV by adopting core system 41.60% and 49.92% of roof displacement is reduced along X and Y direction respectively and 53.86% and 54.31% reduction in bending moment at inner and edge column and seismic zone V, by adopting core system roof displacement exceeds permissible limit so, outrigger system is introduced. 1st outrigger at 0.5H has best performance parameter like roof displacement, column moments and core moments when compared to other location like 0.25H, 0.75H and H. [1][4]

But at present study 10 storey building at 1st outrigger 0.5H the roof displacement is just 1.2mm above permissible limit for assumed section of outrigger. From literature [2] by increasing the depth of outrigger the permissible limit is achieved.

Base core moment is reduced by 19.80%, 17.41%, 11.05% and 7.25% when 1st outriggers are introduced at 0.25H, 0.5H, 0.75H and H with comparison to core system.

From table 3, For 15 storey building at seismic zone II roof displacement is under permissible limit, but for seismic III, IV and V the necessity for new structural system. For zone III, 31.04% and 37.84% reduction if roof displacement along X and Y direction and 52.82% and 53.61% reduction of bending moment at inner and edge column.

For seismic zone IV, by introducing core system the roof displacement exceed the permissible limit so, from table 2 the 1st outrigger at 0.5H have best performance so 1st outrigger arise so, 1st outrigger placed at 0.5H for 15 storey building 17.35% and 17.31% reduction in roof displacement and 7.32% reduction in base core moment when compared to core system.

For seismic zone V, by introducing 1st outrigger at 0.5H the roof displacement exceed the permissible limit so, 2rd outrigger is introduced at 0.25H[4], and 24.55% and 24.65% reduction of roof displacement is observed along X and Y direction, but below permissible limit is not achieved so from literature [2] sectional property of outrigger is increased, 27.22% and 27.08% reduction of roof displacement is observed along X and Y direction, 26.03% base core moment is reduced when compared to core system.

Table -1: Summary of results from Equivalent static analysis for 5 Storey building

LINEAR EQUIVALENT STATIC ANALYSIS (ESA)									
	Seismic Zone	Soil type	Structural system	Reduction factor	Roof displacement (mm)		Base BM of column (kN-m)		Base Core moment (kN-m)
					X	Y	C27	C1	
5 STOREY BUILDING	II	Soil type III (soft soil)	Rigid frame system	OMRF	24.2	28.6	250.95	211.85	-
				Special moment resisting frame system (SMRF)	14.5	17.2	150.57	119.28	-
	III		Rigid frame system		23.3	27.5	240.91	202.59	-
	IV		Rigid frame system		34.9	41.2	361.37	202.59	-
			Core system		8.5	8.8	80.99	54.91	81805.63
	V		Rigid frame system		52.3	61.9	542.06	480.31	-
			Core system		12.8	13.2	121.14	92.15	122708.5

Table -2: Summary of results from Equivalent static analysis for 10 Storey building.

	LINEAR EQUIVALENT STATIC ANALYSIS (ESA)								
	Seismic zone	Soil type	Structural system	Reduction factor	Roof displacement (mm)		Base BM of column (kN-m)		Base Core moment (kN-m)
					X	Y	C27	C1	
10 STOREY BUILDING	II	Soil type III (soft soil)	Rigid frame system	Special moment resisting frame system (SMRF)	32.7	44.4	476.2	439.55	-
	III		Rigid frame system		52.4	71.1	761.92	714.45	-
			Core system		30.6	35.6	351.52	319.28	144472.23
	IV		Rigid frame system		78.6	106.6	1142.89	1080.96	-
			Core system		46	53.3	526.89	488.21	216708.35
	V		Rigid frame system		117.8	159.9	1714.34	1630.73	-
			Core system		68.9	80	789.95	741.62	325062.53
			Outrigger at 0.25H		60	69.5	731.23	685.01	260692.3
			Outrigger at 0.5H		53.3	61.2	750.56	704.37	275215.9
			Outrigger at 0.75H		53.2	60.9	763.39	716.39	289127.9
			Outrigger at H		57.4	65.2	774.15	726.75	301487.7
			*Outrigger at 0.5H		50.9	58.7	744.87	698.97	268448.5

*Outrigger section revised from initial assumed for best location of outrigger [2]. Revised section mentioned in Table-4

Table -3: Summary of results from Modal Response Spectrum analysis for 10 Storey building.

MODAL RESPONSE SPECTRUM ANALYSIS (RSA)									
	Seismic Zone	Soil type	Structural system	Reduction factor	Roof displacement (mm)		Base BM of column (kN-m)		Base Core moment (kN-m)
					X	Y	C27	C1	
15 STOREY BUILDING	II	Soil type III (soft soil)	Rigid frame system	Special moment resisting frame system (SMRF)	58.4	71.5	749.7	704.56	-
	III		Rigid frame system		93.4	114.4	1199.52	1138.63	-
			Core system		64.5	71.1	565.88	528.17	205590.9
	IV		Rigid frame system		140.1	171.6	1799.36	1712.35	-
			Core system		85.3	97	847.51	792.38	294445.3
			Outrigger at 0.5H		70.5	80.2	831.47	776.74	272874.9

	V		Rigid frame system		145	167.6	2542.85	2408.79	-
			Core system		112.4	123.3	1421.40	1335.33	393459.9
			Outrigger at 0.5H		94.6	103.9	1397.83	1313.63	368427.7
			Outrigger at 0.5H and 0.75H		82.8	90.7	1397.92	1314.01	365633.1
			Outrigger at 0.5H and H		87.4	95.5	1400.29	1316.13	367787.7
			Outrigger at 0.5H and 0.25H		84.8	92.9	1320.83	1241.99	300402.8
			*Outrigger at 0.5H and 0.25H		81.8	89.9	1310.53	1232.43	291031.5

*Outrigger section revised from initial assumed for best location of outrigger [2]. Revised section mentioned in Table-4

Table -4: Suggested structural systems, material and sectional property for different storey under different seismic zones under soil type III. (C – Column, B – Beam)

	Seismic zone	Soil type	Structural system	Grade of Concrete and rebar	Sectional property (mm)
5 Storey	II	Soil type III (Soft soil)	Rigid frame system (OMRF)	1 to 5-M25 1to5-Fe500	C – 450x600 B – 300x500
	III		Rigid frame system(SMRF)		
	IV		Core system		C – 450x600 B – 300x500
	V		Core system		
10 Storey	II		Rigid frame system(SMRF)	1 to 5 – M30 6 to 10 – M25 1 to 10-Fe500	C – 450x1000 B – 300x600
	III		Core system		C – 450x1000 B – 300x600
	IV		Core system		
	V		Outrigger system (outrigger at 0.5H)		C – 450x1000 B – 300x600 *O – 400x600
15 Storey	II		Rigid frame system(SMRF)	1 to 5 – M40 6 to 10 – M30 11 to 15 – M25 1 to 15 – Fe500	C – 500x1000 B – 300x600
	III		Core system		C – 500x1000 B – 300x600
	IV		Outrigger system (outrigger at 0.5H)		C – 600x1000 B – 400x600 O – 400X600
	V		Outrigger system (outrigger at 0.5H, 0.25H)		C – 600X1000 B – 400X600 *O – 400x750

4. CONCLUSION

In this study, an effort is made to assess the seismic response parameter of different structural systems to bring roof displacement under permissible limit with minimum base bending moment in column and core. It is observed that material and sectional property have significant effect on displacement and base moments of the structure and by introducing outrigger structural system base core moment is reduced when compared to core system. As the height of the building increase then a necessity of new structural system arise other than rigid frame system. From above analysis results Table 1, 2 and 3, it is suggested Table 4, different structural systems with respect to that material and sectional property for different storey under different seismic zones.

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