IMPACT OF REDUCTION IN STIFFNESS OF SLAB ON THE BEHAVIOUR OF RCC STRUCTURE

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Abstract – *The various codes have suggested different values of stiffness modifiers for different structural elements in respect of serviceability and ultimate limit of the structure. The present work is carried out in order to incorporate the effect of crack section in structural analysis of the high-rise building (RCC) to attain the maximum resistance to earthquake loads and to protect building to some extent from earthquakes. A response spectrum analysis is carried out by using ETABS 18 software on four 3D models of same 32-story RCC building by considering the reduction in values of out of plane stiffness modifiers of all the slabs in each model, for the ultimate condition of the building. The results obtained are compared by considering parameters such as top storey displacement, story drift, major moment and required reinforcement percentage of shear walls at the base. According to analysis and design of model 4, it may be concluded that shear walls will be strengthened and well-designed during seismic events and this will improve the seismic performance of the building.*

Key Words: slab stiffness, stiffness modifier, crack section effect.

1. INTRODUCTION

As height of the building increases, having adequate strength and stiffness is very important for resisting lateral loads and stability of the high-rise building. Contribution of stiffness of structural members has impact on the overall behaviour of the building subjected to earthquake. For this study, the stiffness of slab (out of plane stiffness) is reduced further while the stiffness values of remaining structural elements are kept as mentioned in IS 16700: 2017.

In the present study a response spectrum analysis by ETABS 18 software is performed on four 3D models of 32-story RCC building in order to incorporate the effect of crack approximately, by further reduction in stiffness of slab element in each model for the ultimate condition of the building.

The Stiffness modifiers are the factors used to reduce stiffness of concrete sections for taking into consideration the cracking of RCC sections in analysis of the structure. Stiffness modifiers are introduced to reduced moment of inertia of different members due to cracking. The Table-1 shows the stiffness modifiers given by the various codes under factored loads.

Table -1: Stiffness modifiers given by different codes

Codes	Stiffness Modifiers			
	Slab	Beam	Column	Wall
IS 16700:2017	0.25	0.35	0.7	0.7
IS 1893:2016	-	0.35	0.7	-
ACI 318:2014	0.25	0.35	0.7	0.7
IS 15988:2013	-	0.5	0.7	0.8

Area element or shell element has two types of stiffnesses in plane stiffness and out-of-plane stiffness. In plane stiffness referred to as f11, f22, f12 and out-of-plane stiffness referred to as m11, m22, m12. In this study, for slab element the in-plane stiffness modifiers are taken as 0.25 as per Table 6-cracked RC section properties in IS 16700: 2017, Clause no. 7.2, and the out of plane stiffness modifiers are reduced. Out-of-plane stiffness modifiers for slab are considered as 0.25 Ig (25% of moment of inertia) in model 1, 0.2 Ig in model 2, 0.1 Ig in model 3 and 0.01 Ig in model 4. For the remaining structural elements stiffness modifier values are taken as mentioned in IS 16700:2017.

2. LITERATURE REVIEW

The research work which has been carried out previously on stiffness reduction of reinforced concrete elements is reviewed. An investigation of effect of concrete cracking on the lateral response of building structures is carried out by Ahmed et.al. (2008) (5). They examined the effect of concrete cracking on its stiffness. They carried out the present work to study the quantitative effect of cracking and deflections amplification on the response of RCC building. The building with different aspect ratio and different relative height are analyzed. They carried out analysis of structures using STAAD PRO software.

Sang-Whan Han *et.al.* (2009) (6) developed equations for calculating slab stiffness reduction factor in the Effective beam width model (EBWM) with respect to applied moment (Ma) normalized by cracking moment (Mcr) by conducting nonlinear regression analysis using stiffness reduction factors estimated from collected test results of 20 interior and 10 exterior slab-column connection specimens.

D. P. N. Kontoni *et.al.* (2018) (11) performed a time history analysis by using SAP2000 software on thirteen models of 12-story RC buildings in order to illustrate the contribution of column stiffness and column cross sections (square or rectangular), beam stiffness and slab stiffness, building floor plans (square or rectangular) on building resistance to an earthquake. In order to investigate what percentage each type of element contributes to the overall performance of an high-rise building under seismic load, the stiffness of each type of element is reduced by 10% to 90%. From the literature survey it has been observed that:

1. Slab stiffness has impact on overall behavior of building subjected to earthquake. In absence of stiffness modifiers, the structure would be stiffer and thus attract higher lateral forces due to earthquake.

2. As the slab moment due to lateral loads increases, more cracks will propagate in the slabs and the slab stiffness will decrease due to crack formation. Thus, the reduction in slab stiffness due to the effect of cracks should be reflected in the analysis of reinforced concrete building.

3. Ductile reinforced concrete structures experience large plastic deformations during an earthquake.

4. Cracking due to seismic shock are different for different configuration of structure and their age.

5. We can incorporate approximately the effect of crack in structural analysis of R.C.C. Buildings to find responsible response of the structure to ground movement by considering values of stiffness modifier.

3. MODELLING OF STRUCTURE

For the analysis high rise RC building, located in zone III having irregular configuration in the plan of the building has been considered. The building comprising of Ground + 32 floors + Terrace. Total height of the building is 109.25 m from foundation to terrace, with typical floor to floor height 3.05m. Total plan dimension is 36.7m x 33m. Raft foundation resting on rock/hard soil has been considered in the analysis. Structural system is a shear wall structure. A response spectrum analysis by ETABS 18 software was performed on four 3D models of same 32-story RCC building, for the ultimate condition of the building i.e. under factored loads. In the analysis of all four models only out-of-plane stiffness modifiers for slabs are changing and values of stiffness modifiers for other structural elements are same as per IS 16700:2017.

Model 1: Model considering in plane stiffness modifiers (f11, f22, f12) & out-of-plane stiffness modifiers (m11, m22, m12) for slab as 0.25 (as mentioned in IS 16700:2017)

Model 2: Model considering in plane stiffness modifiers (f11, f22, f12) for slab as 0.25 & out-of-plane stiffness modifiers (m11, m22, m12) for slab as 0.20

Model 3: Model considering in plane stiffness modifiers (f11, f22, f12) for slab as 0.25 & out-of-plane stiffness modifiers (m11, m22, m12) for slab as 0.10

Model 4: Model considering in plane stiffness modifiers (f11, f22, f12) for slab as 0.25 & out-of-plane stiffness modifiers (m11, m22, m12) for slab as 0.01

Figure 1 and 2 shows the mathematical model and the typical floor plan of ETABS Model.

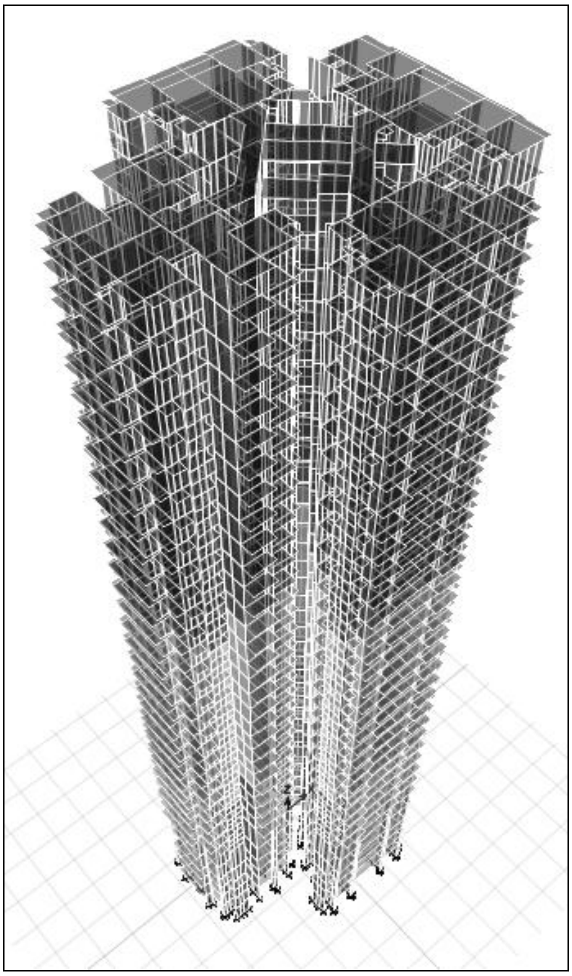

Fig-1: Mathematical Model

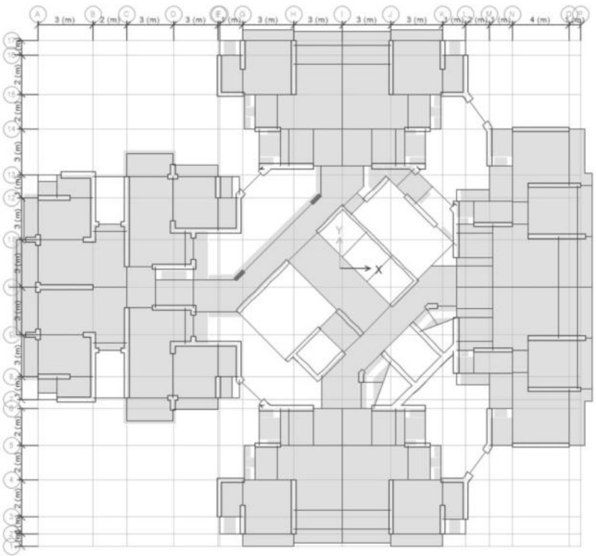

Fig -2: Typical Floor Plan of ETABS Model

The details of the grade of the concrete used at various floors are given in Table-2.

Table -2: Grade of Concrete

Structural Element	Cube Compressive Strength (fck)
Columns/ Shear Walls	Foundation to 9th floor – 60 N/mm²(M60) 9th floor to 20TH floor- 50 N/mm²(M50) 20th floor to Terrace floor- 40 N/mm²(M40)
Beams and Slabs	Ground to 9th floor - 45 N/mm²(M45) 10th floor to 20TH floor- 40 N/mm²(M40) 21st floor to Terrace floor- 30 N/mm²(M30)

In the analysis, the floor slabs are assigned as shell (shell thin) element and are considered as semi rigid diaphragms.

Steel Reinforcement are Thermo-Mechanically Treated bars.

Specified characteristic field strength (fy) is 500 N/mm². Modulus of elasticity (Es) is 2.0 x 10^5 Mpa.

Basic Design Wind Speed is 44 m/sec.

DL=1.5 to 5.5 KN/m^2 (on various areas according to usage)

LL=2 to 5 KN/m^2 (on various areas according to usage)

Seismic loads are determined from IS 1893:2016 (Part 1),

Clause no. 7.6.2 (a) based on the following parameters:

Seismic Zone: III

Seismic Zone Factor (Z) = 0.16

Importance Factor (I) = 1.2

Response Reduction Factor (R) = 4

4. RESULTS AND DISCUSSION

The results obtained are compared by considering parameters such as top storey displacement, story drift, major moment and required reinforcement percentage of shear wall at base.

Top Story Displacement:

The deflection due to the designed lateral force should not exceed H/250, as earthquake is the governing factor. Therefore, the maximum permissible earthquake limit in this case is 109.25*1000/250 = 437 mm

The top storey displacement in X direction for all four models is shown in Table-3. Also, the effect of top storey displacement in X direction is presented in figure 3.

Table -3: Top Story Displacement in X Direction

MODEL NO.	Top Storey Displacement In X Direction (mm)
MODEL 1	79.084
MODEL 2	82.858
MODEL 3	93.927
MODEL 4	119.008

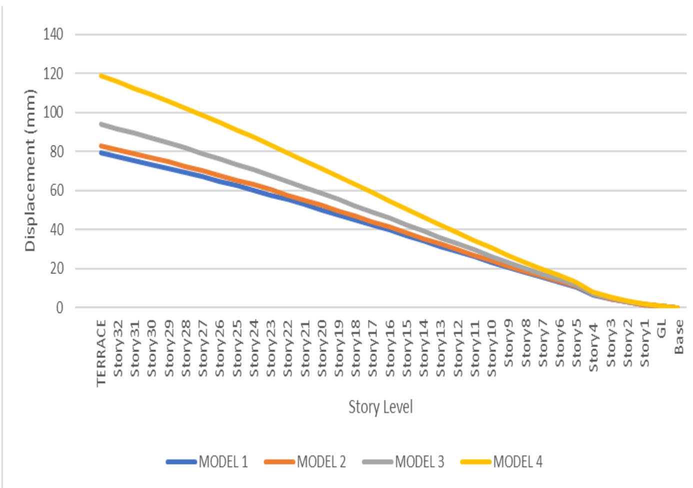

Fig-3: Top Story Displacement in X Direction

The top storey displacement in Y direction for all four models is shown in Table-4.

Also, the effect of top storey displacement in X direction is presented in figure 4.

Table -4: Top Story Displacement in Y Direction

MODEL NO.	Top Storey Displacement in Y Direction (mm)
MODEL 1	138.641
MODEL 2	145.664
MODEL 3	164.766
MODEL 4	194.697

Fig-4: Top Story Displacement in Y Direction

Table 3 and 4 shows values of lateral displacement at top of building due to earthquake in positive X and Y direction. From the graphs in Fig 3 and 4, it is observed that as the out-of-plane stiffness modifier of slab decreases the lateral displacement due to earthquake forces in X and Y direction increases.

Story Drift:

Story drift is the lateral displacement of a story relative to the story below. The story drift in any story due to the designed lateral force should not exceed 0.004 times story height (IS 1893-2002, clause 7.11.1). Story drift ratio is story drift divided by the story height. The values reported in ETABS are divided by story height. Therefore, the maximum permissible earthquake limit in this case is 0.004.

Table -5 gives the values of the story drift in X direction for all four models at different story level. Also the effect is illustrated in figure 5.

Table -5: Story Drifts in X Direction

Story Level	Story Drifts in X Direction			
	Model 1	Model 2	Model 3	Model 4
TERRACE	0.000707	0.000735	0.00082	0.001103
Story32	0.000736	0.000763	0.000845	0.001127
Story31	0.000761	0.000787	0.000868	0.001153
Story30	0.00078	0.000806	0.000888	0.001181
Story29	0.000796	0.000823	0.000909	0.001207
Story28	0.000811	0.000838	0.000932	0.001233
Story27	0.000824	0.000852	0.000955	0.001257
Story26	0.000836	0.000865	0.000978	0.001281
Story25	0.000848	0.000878	0.001	0.001304
Story24	0.000859	0.000896	0.001022	0.001325
Story23	0.000873	0.000915	0.001043	0.001344
Story22	0.000888	0.000931	0.00106	0.00136
Story21	0.000897	0.000941	0.00107	0.001369
Story20	0.000902	0.000946	0.001076	0.001374
Story19	0.00091	0.000954	0.001084	0.001379
Story18	0.000915	0.00096	0.00109	0.001381
Story17	0.00092	0.000965	0.001094	0.00138
Story16	0.000923	0.000968	0.001096	0.001375
Story15	0.000925	0.000969	0.001096	0.001365
Story14	0.000924	0.000968	0.001092	0.001352
Story13	0.00092	0.000963	0.001083	0.001333
Story12	0.000913	0.000954	0.00107	0.00131
Story11	0.000901	0.000941	0.001052	0.00128
Story10	0.000886	0.000925	0.00103	0.001244
Story9	0.00087	0.000907	0.001006	0.001204
Story8	0.000854	0.000887	0.000979	0.00116
Story7	0.000821	0.000852	0.000935	0.001096
Story6	0.000783	0.00081	0.000882	0.00102
Story5	0.000667	0.000689	0.000748	0.000861
Story4	0.000536	0.000552	0.000594	0.000675
Story3	0.000576	0.000589	0.000627	0.000702
Story2	0.000426	0.000434	0.000451	0.000495
Story1	0.000295	0.000301	0.000316	0.000347
GL	0.000178	0.000179	0.000182	0.000188
Base	0	0	0	0

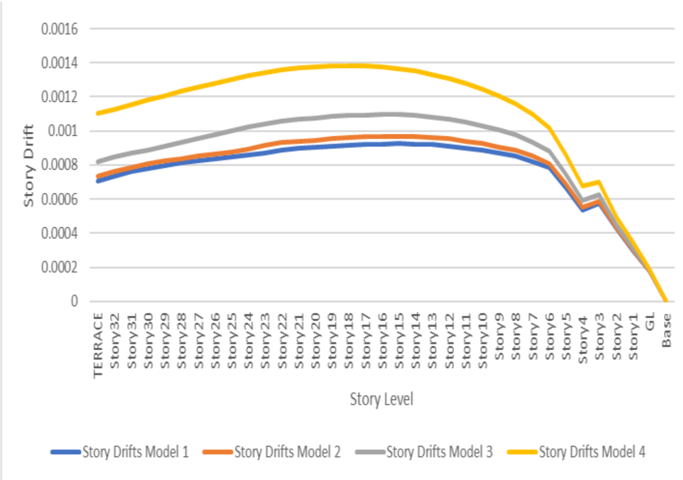

Fig-5: Story Drifts in X Direction

Table -6 gives the values of the story drift in Y direction for all four models at different story level. Also the effect is illustrated in figure 6.

Table -6: Story Drifts in Y Direction

Story Level	Story Drifts in Y Direction			
	Model 1	Model 2	Model 3	Model 4
TERRACE	0.001435	0.001524	0.001774	0.002189
Story32	0.001512	0.001598	0.001836	0.002227
Story31	0.001534	0.00162	0.00186	0.02255
Story30	0.001564	0.00165	0.00189	0.002283
Story29	0.00159	0.001676	0.001916	0.002308
Story28	0.001613	0.001699	0.001938	0.002328
Story27	0.001632	0.001718	0.001957	0.002345
Story26	0.001648	0.001734	0.001973	0.002359
Story25	0.001662	0.001748	0.001986	0.00237
Story24	0.001673	0.001759	0.001996	0.002377
Story23	0.001679	0.001765	0.002001	0.002378
Story22	0.001682	0.001768	0.002001	0.002372
Story21	0.001676	0.001761	0.001992	0.002357
Story20	0.001659	0.001744	0.001973	0.002334
Story19	0.001652	0.001734	0.001959	0.002311
Story18	0.001637	0.001718	0.001939	0.002283
Story17	0.00162	0.0017	0.001915	0.00225
Story16	0.001598	0.001676	0.001886	0.00221
Story15	0.001572	0.001647	0.001851	0.002162
Story14	0.00154	0.001613	0.001808	0.002107
Story13	0.001501	0.001571	0.001758	0.002042
Story12	0.001455	0.001521	0.001699	0.001967
Story11	0.0014	0.001463	0.00163	0.00188
Story10	0.001336	0.001395	0.00155	0.001781
Story9	0.001263	0.001317	0.001461	0.001674
Story8	0.001192	0.001241	0.001372	0.001569
Story7	0.001115	0.001161	0.001281	0.001457
Story6	0.001029	0.00107	0.001176	0.001331
Story5	0.000871	0.000902	0.000985	0.001106
Story4	0.000649	0.000671	0.000727	0.000809
Story3	0.000681	0.000704	0.000763	0.000838
Story2	0.000456	0.000469	0.000504	0.000546
Story1	0.000336	0.000344	0.000364	0.000392
GL	0.000196	0.000199	0.000204	0.000221
Base	0	0	0	0

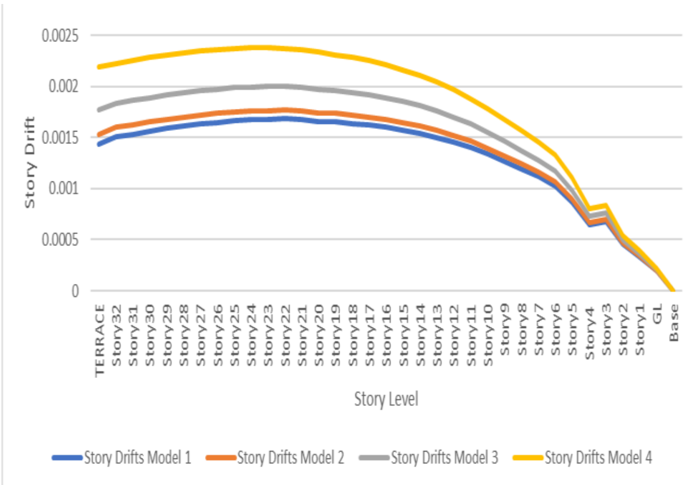

Fig-6: Story Drifts in Y Direction

From the Table 5 and 6 it has been observed that as the out-of-plane stiffness of slab decreases the story drifts increases. The values of story drifts are within limit. A comparative graph for Maximum story drift due to earthquake in X and Y direction is shown in figure 5 and 6.

Shear wall moment at base:

As stiffness of slab decreases, major moment (M33) at base of some shear walls increases. Increasing moments in some shear walls are shown here. Table 7, 8 and 9 gives moments at base of shear walls W11(P13, P13A), W30(P63), W41(P51, P51A) respectively in all four models.

From Tables 7, 8, 9 it is observed that as the out-of-plane stiffness modifier of slab decreases, major moment (M3) at base of some shear walls increases. The effect is represented graphically in figures 7, 8 and 9.

Table -7: Moment at Base in Shear Wall W11(P13, P13A)

Pier Label	M3 (KN-m) at Ground Floor			
	MODEL 1	MODEL 2	MODEL 3	MODEL 4
P13	1938.8763	1972.6537	2072.2538	2300.6891
P13A	144.6	145.9	148.2	148.8

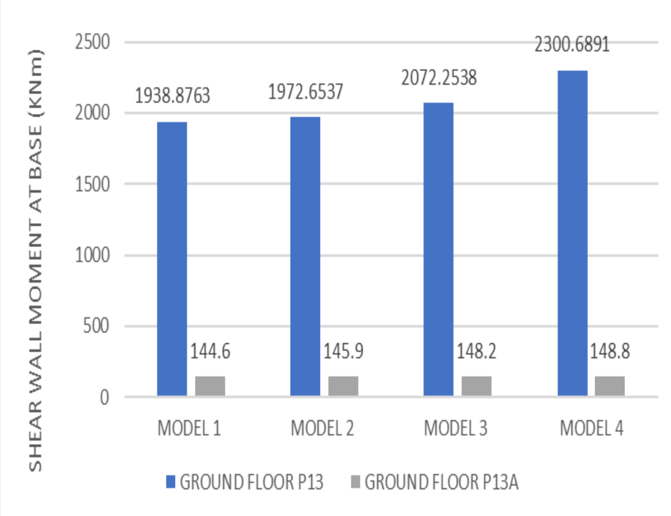

Fig-7: Moment at Base in Shear Wall W11(P13, P13A)

Table -8: Moment at Base in Shear Wall W30(P63)

Pier Label	M3 (KNm) at Ground Floor			
	MODEL 1	MODEL 2	MODEL 3	MODEL 4
P63	919.4005	933.471	970.8891	1032.1874

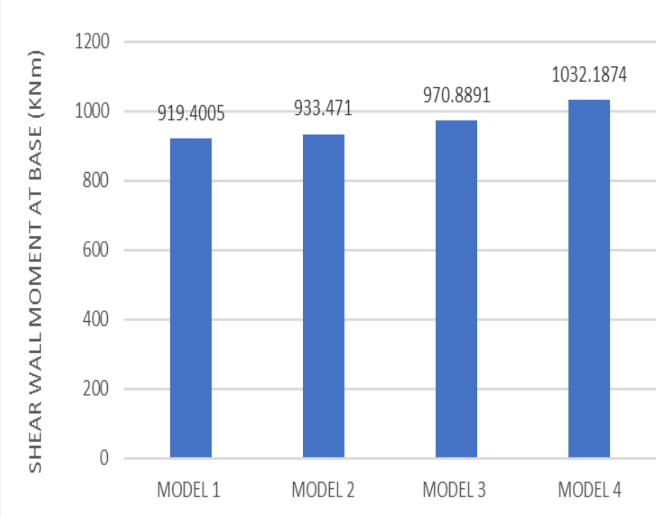

Fig-8: Moment at Base in Shear Wall W30(P63)

Table -9: Moment at Base in Shear Wall W41(P51, P51A)

Pier Label	M3 (KNm) at Ground Floor			
	MODEL 1	MODEL 2	MODEL 3	MODEL 4
P51	5897.4122	6042.0525	6359.4027	6734.5908
P51A	248.8	251.3	254.6	258.8

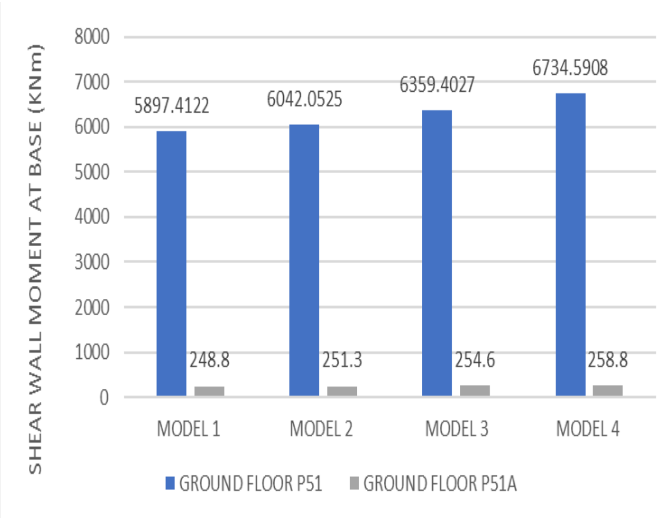

Fig-9: Moment at Base in Shear Wall W41(P51, P51A)

Required reinforcement percentage in shear wall at base:

Maximum required reinforcement % in shear wall depends on wind and earthquake loads anticipated at the location. Minimum required reinforcement % in shear wall is 0.25%. Graph shows required reinforcement % in a particular shear wall at base in all four models.

Table -10: Required Reinforcement % in shear wall W11(P13, P13A) at base

Pier Label	Required Reinforcement % in shear wall at base			
	MODEL 1	MODEL 2	MODEL 3	MODEL 4
P13	0.37	0.44	0.66	1.16
P13A	0.25	0.25	0.25	0.46

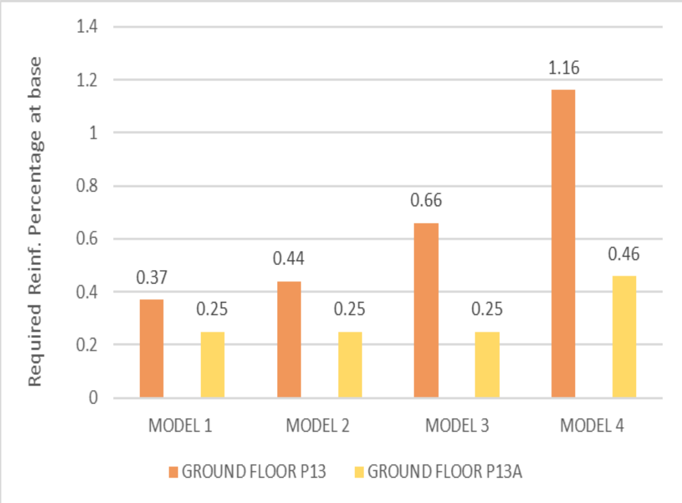

Fig-10: Required Reinforcement % in shear wall W11(P13, P13A) at base

Table -11: Required Reinforcement % in shear wall W41(P51, P51A) at base

Pier Label	Required Reinforcement % in shear wall at base			
	MODEL 1	MODEL 2	MODEL 3	MODEL 4
P51	0.25	0.25	0.25	0.52
P51A	1.72	1.77	1.85	2.31

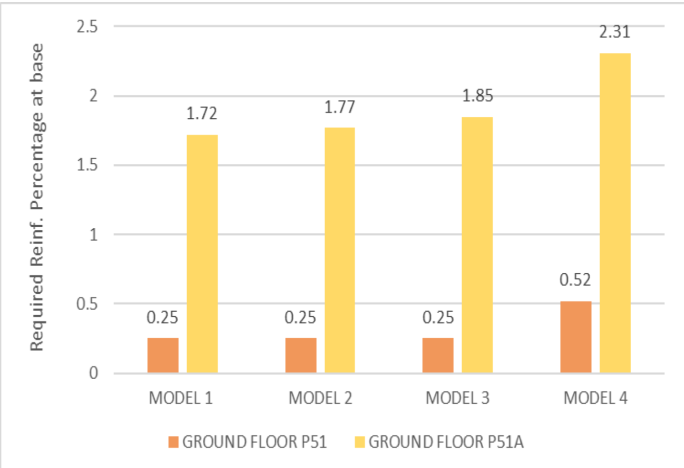

Fig-11: Required Reinforcement % in shear wall W41(P51, P51A) at base

From Tables 10 and 11 it is observed that as the stiffness modifier of slab decreases the required reinforcement % at base of some shear walls increases. Hence some shear walls should be strengthened by addition of steel reinforcement to take higher moments, so that they are not under designed in earthquake. Figure 10 and 11 shows graphical representation of required reinforcement % in shear walls at base.

5. CONCLUSIONS

From the present study following broad conclusions are drawn:

1. In the structural analysis of R.C.C. building model considered; effect of crack is incorporated approximately by further reduction in stiffness of slab element to attain the maximum resistance against earthquakes.

2. Stiffness modifiers are used to reduce out of plane stiffness of the slab element by decreasing moment of inertia upto 20%, 10% and 1%.

3. Reducing out of plane stiffness of slab to less than 10% the slab will only transmit in-plane forces and will not be able to contribute to resist any bending moments.

4. Slab will not take part in load bearing and whole load will directly transfer through the slab to supporting structural elements. Hence, beams located under the slab will generate higher moments.

Therefore, supporting structural elements (beams, shear walls) should be strengthened by addition of steel reinforcement to take higher moments, so that they are not under designed in earthquake.

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