CHAPTER 3

MODELING OF THE STRUCTURE

3.1 GENERAL

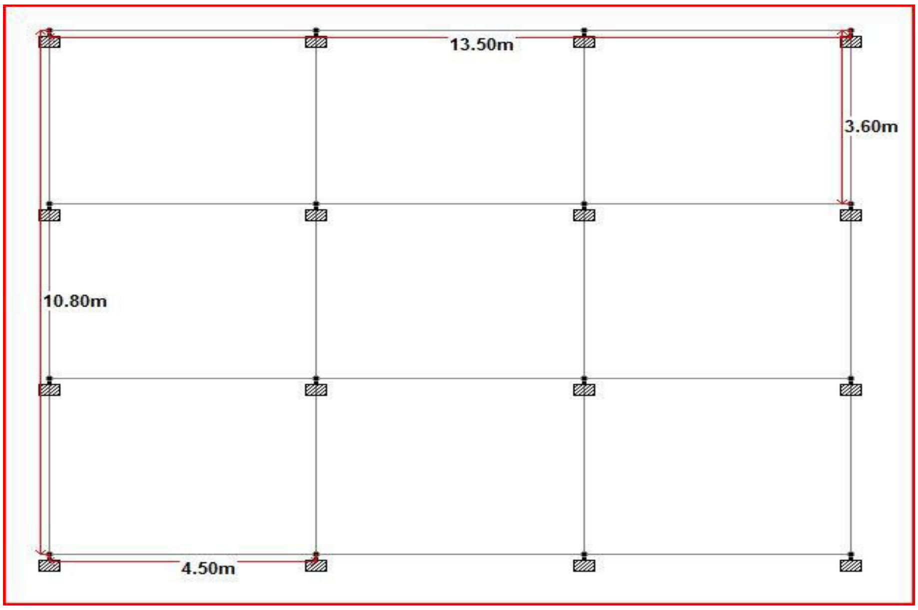
Many structures are in need of some kind of rehabilitation as a result of the deterioration they undergo with time. Poor quality construction materials, substandard design codes, exposure to corrosive and saline environments, overloading of structures, and damage due to natural disasters such as earthquakes and hurricanes can cause serious deterioration of infrastructure. It is also important for structural members to have adequate strength and deformation capacity to ensure seismic performance of buildings. The present study aims at arriving an effective method of retrofitting for a column with respect to the load carrying capacity, ductility and energy dissipation capacity. The analysis and design of column used in the experimental investigation is discussed in the following sessions.

3.2 STRUCTURAL CONFIGURATION

A six storey RC building located at Chennai, India (in seismic zone III as per IS 1893 (Part 1): 2002) on medium soil was analysed. The interior ground floor column of the building is used for the analysis. The height of the column was 3 m and the cross section was 300 mm x 300 mm. The longitudinal and transverse beams were 300 mm x 600 mm. M20 grade concrete and Fe 415 grade steel was used for design. The specifications of the materials used to cast the column specimen are discussed as follows. The cement used was ordinary Portland cement of 43 grades conforming to

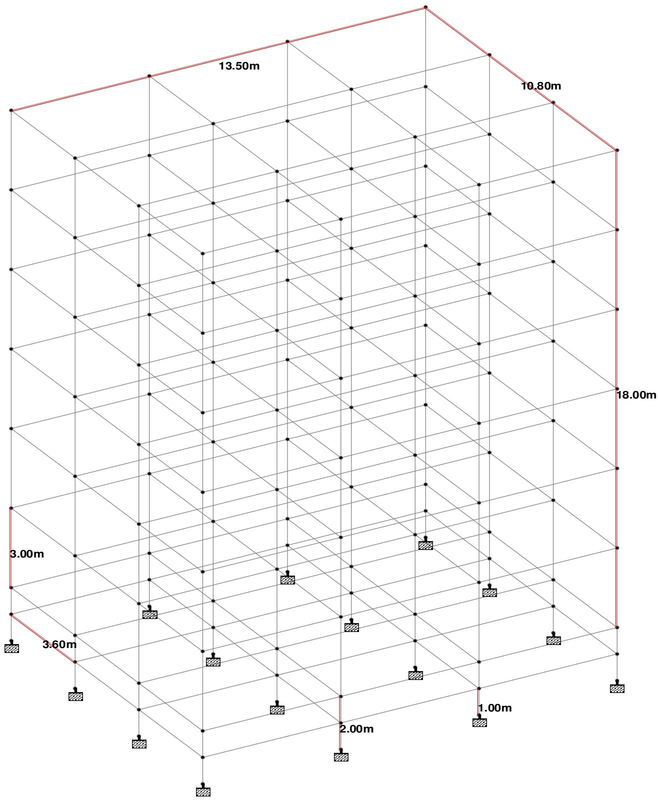
IS8112: 1989. River sand passing through 4.75 mm IS sieve and having a fineness modulus of 3.16 was used as fine aggregate. Crushed granite stones of maximum size not exceeding 8 mm were used as coarse aggregate. The mix proportion adopted was 1: 1.42: 2.48 and the water cement ratio were kept as 0.5. The 28 day average compressive strength from 150 mm cube test was 23.32 N/mm^2. Thermo mechanically treated steel rods of yield stress 452 N/mm^2 were used as reinforcement. The specimens were cast in horizontal position inside a steel mould. Specimens were de- moulded after 24 hours and then cured under wet gunny bags for 28 days.

To arrive at the forces for design, the building is analysed using the software STAAD Pro. The base of structure is fully fixed by constraining all the degrees of freedom and seismic analysis is performed using equivalent static method given in IS 1893:2002. The STAAD Pro model for the building generated is shown in Figure 3.1 (a) to (d).

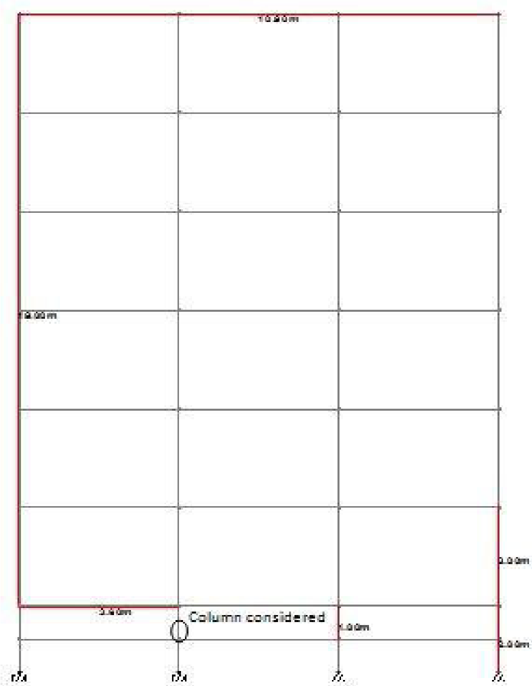


(a)

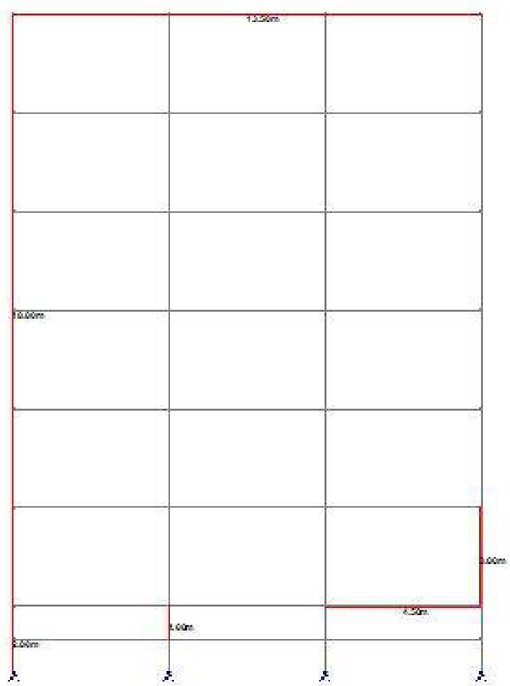
Figure 3.1 (a) Plan of the building, (b) Isometric view of the building, (c) Elevation of longitudinal frame and (d) Elevation of transverse frame



(b)



(c)



(d)

Figure 3.1 (Continued)

3.3 LOADING

Load combinations are considered as per IS 1893: 2002 and are shown in Table 3.1. EQX implies earthquake loading in X direction and EQY stands for earthquake loading in Y direction. DL and LL stands for Dead Load and Live Load respectively.

Table 3.1 Load combinations for earthquake loading

S.No	Load Combination	DL	LL	EQ
1	1.5DL+1.5LL	1.5	1.5	
2	1.2(DL+LL*+EQX)	1.2	0.25*	1.2
3	1.2(DL+LL*-EQX)	1.2	0.25*	-1.2
4	1.2(DL+LL*+EQY)	1.2	0.25*	1.2
5	1.2(DL+LL*-EQY)	1.2	0.25*	-1.2
6	1.5(DL+EQX)	1.5	-	1.5
7	1.5(DL-EQX)	1.5	-	-1.5
8	1.5(DL+EQY)	1.5	-	1.5
9	1.5(DL-EQY)	1.5	-	-1.5
10	0.9DL+1.5 EQX	0.9	-	1.5
11	0.9DL-1.5 EQX	0.9	-	-1.5
12	0.9DL+1.5 EQY	0.9	-	1.5
13	0.9DL-1.5 EQY	0.9	-	-1.5

3.4 FORCES IN THE STRUCTURAL ELEMENTS

The shear forces, bending moments and axial forces around the interior beam-column joints due to the induced earthquake loading were estimated. Seismic analysis was performed using equivalent lateral force method given in IS 1893: 2002

3.4.1 Design of Beam

Plane frames were analysed and the force resultants for various load cases such as dead load, live load and earthquake load in beam of short frame were estimated and are shown in Table 3.2.The force resultants for different load combinations considering earthquake load in Y direction which is predominant, is shown in Table 3.3. The beam region of the joint was checked for axial stress, member size, minimum and maximum reinforcement to design as a flexural member. The design moment and shear force from the critical load combinations for the beam were 160.05 kNm and 112.8 kN respectively. Spacing of ties on the beam near joint was calculated as per IS 456: 2000: Two legged ties of 8 mm diameter were provided at a spacing of 100 mm centre to centre. The beam bars were provided with adequate development length to take care of the pull out force under cyclic loading. All the test specimens were cast as one-third scale models. The reinforcement details of the prototype beam and column is shown in Table 3.4 and Figure 3.2 shows the reinforcement details of the model beam and column.

Table 3.2 Force resultants in beam of short frame for various load cases

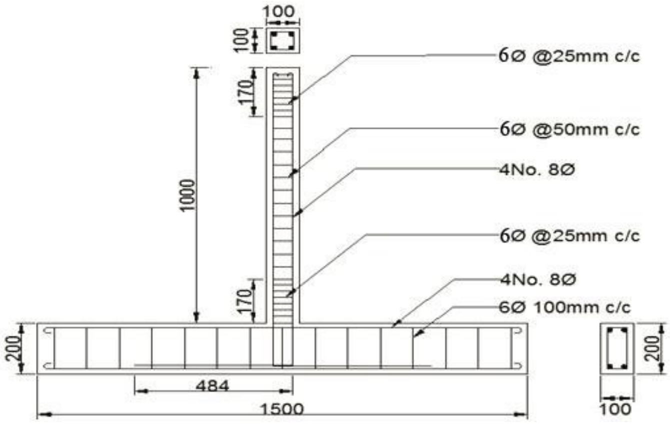
Load Case	**Left end(A)**		**Centre**		**Right end (B)**	
	Shear (kN)	**Moment (kNm)**	**Shear (kN)**	**Moment (kNm)**	**Shear (kN)**	**Moment (kNm)**
Dead Load	24.90	-12.70	-3.38	9.69	31.60	24.70
Live Load	8.10	-4.70	-1.62	4.04	11.30	10.50
Earthquake Load EQY	-50.30	94.00	-50.30	3.46	50.30	87.00

Table 3.3 Force resultants in transverse beam for different load combinations

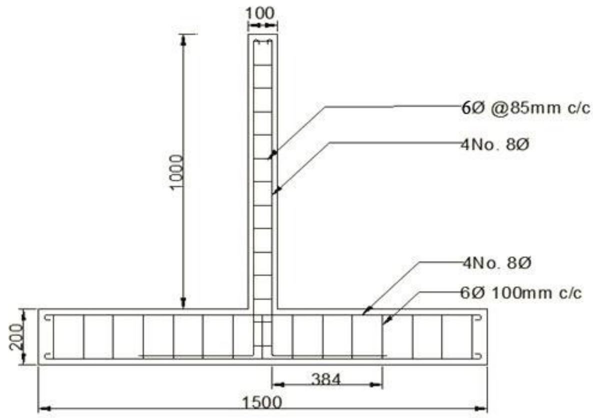
Sl. No.	Load Combinations	Left end		Centre		Right end	
		Shear (kN)	Moment (kNm)	Shear (kN)	Moment (kNm)	Shear (kN)	Moment (kNm)
1	1.5DL+1.5LL	49.50	-26.10	-7.51	20.62	64.35	52.80
2	1.2(DL+0.25* LL+EQY)	-28.05	96.15	-64.91	17.00	101.67	137.19
3	1.2(DL+0.25* LL-EQY)	92.67	-129.45	55.81	8.70	-19.05	-71.61
4	1.5(DL+EQY)	-38.1	121.95	-80.53	19.74	122.85	167.55
5	1.5(DL-EQY)	112.8	-160.05	70.37	9.36	-28.05	-93.45
6	.9DL+1.5EQY	-53.04	129.57	-78.50	13.92	103.89	152.73
7	.9DL-1.5EQY	97.86	-152.43	72.40	3.54	-47.01	-108.27

Table 3.4 Details of reinforcement in beams and columns

Beam		Column	
Top Main reinforcement	Bottom Main Reinforcement	Longitudinal reinforcement	Lateral Ties
2- 22 Φ bars	2- 22 Φ bars	6-20 Φ bars	8 Φ@300mmc/c



(a) Detailed as per IS 13920:1993



(b) Designed as per IS 456:2000

Figure 3.2 Reinforcement details of the model column specimens

3.4.2 Design of Column

The column was designed for earthquake loading in both X-direction and Y-direction Hence, all 13 load combinations as shown in Table 3.5 were considered and critical combination is selected (Park and Paulay).. Since the joints are subjected to large shear force during earthquakes; joint shear strength should be checked. Hence adequacies of depth and width for the column are checked as per the proposed provisions for beam-column joints. The column is checked for flexural member considering the lower axial force.

Table 3.5 Forces in Column for different Load Combinations

Column end	**Force/Moment (kN/kNm)**	**1.5(DL+LL)**	**1.2(DL+LL+EQX)**	**1.2(DL+LL-EQX)**	**1.2(DL+LL+EQY)**	**1.2(DL+LL-EQY)**	**1.5(DL+EQX)**	**1.5(DL-EQX)**	**1.5(DL+EQY)**	**1.5(DL-EQY)**	**(0.9DL+1.5EQX)**	**(0.9DL+1.5EQX)**	**(0.9DL+1.5EQY)**	**(0.9DL+1.5EQY)**
A_B	**Axial Load**	-839	-748	-594	-458	-885	**-782**	-590	-419	**-858**	-508	-315	-145	-678
A_T		647.9	572.4	464.2	369.1	667.4	596.4	461.1	342.3	715.2	384.9	249.6	**130.8**	503.7
B_B		-648	-572	-464	-369	-667	-596	-461	-342	-715	-385	-250	-131	-504
B_T		456.6	398.3	332.3	276.5	454.1	412.8	330.3	260.6	482.6	264.2	181.7	111.9	333.9
A_B	**Moment M_x**	-14.6	46.68	-70	-11.6	-11.6	61.5	-84.3	-11.4	-11.4	66.06	-79.7	-6.84	-6.84
A_T		-12.9	44.76	-65.4	-10.3	-10.3	58.95	-78.8	-9.9	-9.9	62.91	-74.8	-5.94	-5.94
B_B		-14	45.96	-68.3	-11.2	-11.2	60.45	-82.4	-11	-11	64.83	-78	-6.57	-6.57
B_T		-14.1	36	-58.6	-11.3	-11.3	48	-70.2	-11.1	-11.1	52.44	-65.8	-6.66	-6.66
A_B	**Moment M_y**	-13.5	-10.8	-10.8	50.28	-71.9	-9.9	-9.9	66.45	**-86.3**	-5.94	-5.94	70.41	-82.3
A_T		-12.9	-10.3	-10.3	48.72	-69.4	-9.45	-9.45	64.35	-83.3	-5.67	-5.67	68.13	-79.5
B_B		-12.9	-10.3	-10.3	51.72	-72.4	-9.45	-9.45	68.1	-87	-5.67	-5.67	71.88	-83.2
B_T		-13.1	-10.4	-10.4	40.32	-61.2	-9.6	-9.6	53.85	-73.1	-5.76	-5.76	57.69	-69.2
A_B	**Shear Force F_y**	9.3	7.44	7.44	-34.3	49.2	6.75	6.75	-45.5	**58.95**	4.05	4.05	-48.2	56.25
A_T		-8.7	7.44	-6.96	33.36	-47.3	-6.3	-6.3	44.1	-56.7	-3.78	-3.78	46.62	-54.2
B_B		8.7	6.96	6.96	-33.4	47.28	6.3	6.3	-44.1	56.7	3.78	3.78	-46.6	54.18
B_T		-8.7	-6.96	-6.96	29.88	-43.8	-6.3	-6.3	39.75	-52.4	-3.78	-3.78	42.27	-49.8
A_B	**Shear Force F_x**	9.9	-31.6	47.4	7.92	7.92	-41.6	**57.15**	7.8	7.8	-44.7	54.03	4.68	4.68
A_T		-9.3	30	-44.9	-7.44	-7.44	39.45	-54.2	-7.35	-7.35	42.39	-51.2	-4.41	-4.41
B_B		9.3	-30	44.88	7.44	7.44	-39.5	54.15	7.35	7.35	-42.4	51.21	4.41	4.41
B_T		-9.3	25.44	-40.3	-7.44	-7.44	33.75	-48.5	-7.35	-7.35	36.69	-45.5	-4.41	-4.41

The exterior column was designed for an axial load of 858 kN and a moment of 86.3 kNm, which were the critical values obtained from the thirteen different load combinations. Six numbers of 20 Φ bars were provided with bars distributed equally on all faces of column. The joint was designed for strong column-weak beam conditions for earthquake in Y direction and earthquake in X direction as per the draft revision of IS 13920 (Jain and Murty 2005b). Special confining reinforcement were provided in the joint region for detailing as per IS13920: 1993.

3.4.3 Design of Interior Joint

The joint shear strength and strong column weak beam conditions for earthquake in Y direction and earthquake in X directions were checked as per draft revision of IS 13920 and found satisfied. The shear in joint while earthquake in Y direction and in X direction are shown in Figure 3.3.

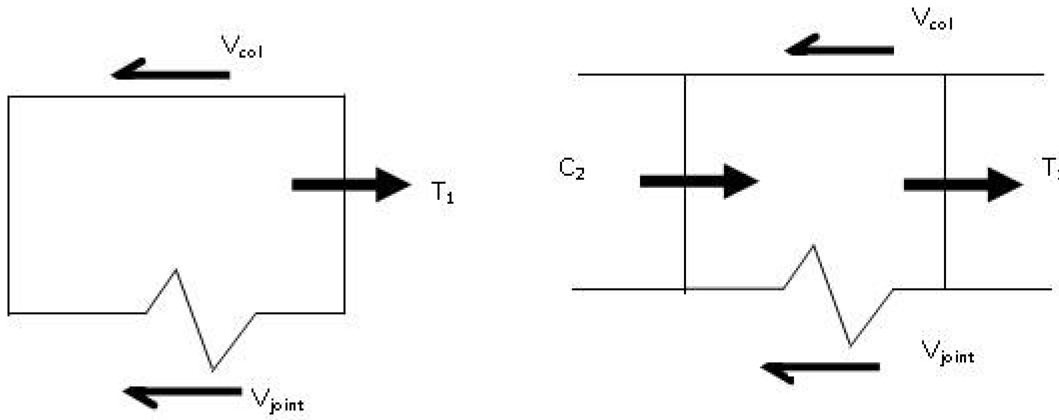
Since equal reinforcement were provided at the top and bottom of transverse beam, the column shear for sway to right or to left during earthquake loading in Y direction, V_{col} was obtained as 74.50kN. The force developed in the top reinforcement of beam T_1 was 651.55kN. Thus the joint shear force, is obtained from Equation (3.1) as 577.04 kN.

$$V_{joint} = T_1 - V_{col} \tag{3.1}$$

For the earthquake loading in X direction, the column shear for sway to right or to left, V_{col} was obtained as 98.50 kN. The force developed in the top reinforcement of right longitudinal beam T_1 was 488.66 kN. The force developed in the bottom reinforcement of left longitudinal beam T_2 was 325.78 kN. Thus the joint shear force V_{joint} is obtained from Equation (3.2) as 715.94 kN.

$$V_{joint} = T_1 + C_2 - V_{col} \tag{3.2}$$

where C_2 is the compressive force in the left beam which is equal to the tensile force T_2 developed in the left beam.



(a) Earthquake in Y direction **(b) Earthquake in X direction**

Figure 3.3 Joint shear in beam- column joint

The effective width of joint (b_j) as per draft revision of IS 13920, is lesser of (i) $b_j = b_b + 0.5h_c$ and (ii) $b_j = b_c$ where, b_b is the width of beam; h_c is the depth of column in the considered direction of shear; b_c is the width of column. Effective shear area of joint $A_{ej} = b_j h_j$: where h_j is the depth of joint which can be taken as depth of column.

Shear strength of the joint ($1.0A_{ej}\sqrt{f_{ck}}$) was obtained as 739.43 kN; which is higher than the joint shear force for the earthquake loading in Y direction and in X direction. Hence, the joint has adequate shear strength in both directions as per proposed revision. The flexural strength ratio of column to beam for earthquake in Y direction and earthquake in X direction were obtained as 1.84 and 1.39 respectively. Hence, the requirement of strong column-weak beam condition was satisfied for the earthquake loading in both Y and X directions. Thus the joint sub assemblage considered for the experimental study was checked for shear strength, and strong column-weak beam theory.

The original structure has been reduced three times following the laws of similitude. Thus the dimensions of beam- column joint are reduced to those as shown in Table 3.6 following the laws of similitude.

Table 3.6 Dimensions of test specimens

Sl. No	Scale Factor	Member	Prototype (mm)	Model (mm)
1.	1/3	Height of Column	3000	1000
2.		Breadth of column	300	100
3.		Width of column	300	100
4.		Length of Beam	4500	1500
5.		Width of Beam	300	100
6.		Depth of Beam	600	200

3.5 SUMMARY

A six storey RC building was analysed using STAAD Pro and the beam - column joint of an interior joint was designed and checked for the joint shear strength. The dimensions of the prototype and model were arrived at and the reinforcement details are presented.