Equivalent Static Analysis of High-Rise Building with Different Lateral Load Resisting Systems

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Abstract: ***This paper describes equivalent static analysis of high-rise building using program in STAAD.Pro with various conditions of lateral stiffness system. Some models are prepared that is pure frame structure, brace frame, shear wall frame. The results are good agreement with IS:1893 (Part 1)- 2002.***

Keywords: High-rise building, Equivalent Static Analysis, Story deflection

I. INTRODUCTION:

High-rise building is defined as a building 35 meters or greater in height, which is divided at regular intervals into occupiable levels. In tall building the lateral loads due to earthquake are a matter of concern. These lateral forces can produce critical stresses in the structure, induce undesirable stresses in the structure, induce undesirable vibrations or cause excessive lateral sway of the structure. Sway or drift is the magnitude of the lateral displacement at the top of the building relative to its base. Hence it is necessary to take in to account the seismic load for the design of high-rise structure. The different lateral load resisting systems used in high-rise building are: 1. Bare frame 2.Brace frame 3.Shear wall frame. In present study the effect of bracing, shear wall is studied under the earthquake loading. The results are studied for equivalent static method. The main parameters considered in this study to compare the seismic performance of different models are storey drift, base shear, story deflection, time period, bending moment, shear force, and axial force.

II. PARAMETRIC INVESTIGATION:

Seismic Analysis of high-rise building having following data is analyzed for different models of lateral load resisting systems. Typical plan is shown in figure 1. Analysis is done by taking into account the data form STAADpro. Space frame model is prepared. Member Properties are column size 0.23 X 0.45m, beam size 0.23 X 0.30m, shear wall 0.2m, concrete bracing 0.23 X 0.23m, thickness of slab 0.12m. Loads considered are floor load, wall load, live load and earthquake load. The grade of concrete is M_{20} & steel used is Fe_{415}.

The parametric study for following mentioned models is carried.

i) Bare frame

ii) Brace frame

Case 1 Bracing at location A in plan- Bracing is centrally located at exterior frame of Z direction through out height.

Case 2 Bracing at location B in plan- Bracing is centrally located at exterior frame of X direction through out height.

Case 3 Bracing at location A and B in plan- Bracing is centrally located at exterior frame of both X and Z direction through out height.

Case 4 Bracing at location C in plan- Bracing is located at exterior frame end corners of both X and Z direction through out height.

iii) Shear wall frame

Case 1 Shear wall at location A in plan- Shear wall is centrally located at exterior frame of Z direction through out height.

Case 2 Shear wall at location B in plan- Shear wall is centrally located at exterior frame of X direction through out height.

Case 3 Shear wall at location A and B in plan- Shear wall is centrally located at exterior frame of both X and Z direction through out height.

Case 4 Shear wall at location C in plan- Shear wall is located at exterior frame end corners of both X and Z direction through out height.

For present work equivalent static analysis as per IS:1893-2002 is carried out for reinforced concrete moment resisting frame having (G+14) storey situated in zone IV. The floor to floor height of the building is 3m. The total height of building is 45m.

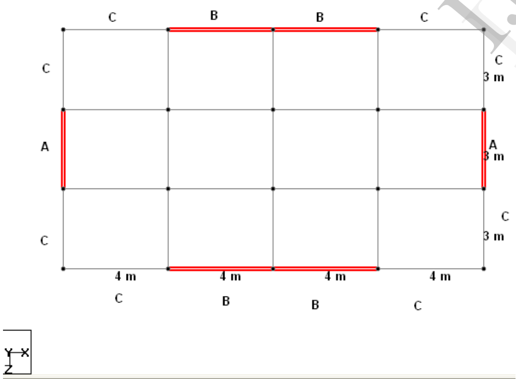


Figure 1: Plan of building showing location of braced frame & shear wall frame

III DESIGN PARAMETERS:

Type of zone Z = 0.24 (Table 2 clause 6.4.2 of IS: 1893-2002)
Soil Strata SS = 2.0 (Medium soil)
Reduction factor RF =5.0 (OMRF Structure Table 7 of IS: 1893-2002)
Importance factor = 1.5 (Table 6 Clause 6.4.2 of IS: 1893-2002)
Depth of foundation DT = 1.5m (Assumed depth of foundation)
Fundamental Natural Periods in seconds (Ta):
Ta = $0.075h^{0.75}$ (clause 7.6.1 of IS: 1983 (part 1)-2002)

Equivalent Static Analysis:

The total design lateral force or design base shear along any principal direction is given in terms of design horizontal Seismic coefficient and seismic weight of the structure. Design horizontal seismic coefficient depends on the zone factor of the site, importance of the structure, response reduction factor of the lateral load resisting elements and the fundamental period of the structure.
Following procedure is generally used for the equivalent static analysis:
i) Calculation of lumped weight.
ii) Calculation of fundamental natural period.
The fundamental natural period of vibration (T_a) in seconds of a moment resisting frame building,
$T_a = 0.075\ h^{0.75}$ (without brick infill panels)

$T_a = 0.09\ h/\sqrt{d}$ (with brick infill panels)
Where
h = Height of the building
d = Base dimension of the building at the plinth level in m, along the considered direction of the lateral force.
iii) Determination of base shear (V_B) of the building.

$$V_B = A_h \text{ x } W$$

Where,

$$A_h = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g}$$

Is the design horizontal seismic coefficient, which depends on the seismic zone factor (Z), importance factor (I), response reduction factor (R) and the average response acceleration coefficient (S_a/g). S_a/g in turn depends on the nature of foundation soil (rock, medium or soft soil sites), natural period and the damping of the structure.

iv)Lateral distribution of design base shear;

The design base shear V_B thus obtained is then distributed along the height of the building using a parabolic distribution expression:

$$Q = V_B \frac{W_1 h_1}{\sum_{j=1}^{n} W_j h_k^{\ 2}}$$

Where Q_1 is the design lateral force, W_1 is the seismic weight, h_1 is the height of the i^{th} floor measured from base and n is the number of stories in the building.

STAAD utilizes the following procedure to generate the lateral seismic loads.

1. User provides seismic zone co-efficient and desired "1893(Part 1)-2002 specs" through the DEFINE 1893 LOAD command.

2. Program calculates the structure period (T).

3. Program calculâtes Sa/g utilizing T.

4. Program calculates V from the above equation. W is obtained from self weight, joint weight(s) and member weight(s) provided by the user through the define 1893 load command.

5. The total lateral seismic load (base shear) is then distributed by the program among different levels of the structure per the IS: 1893 procedures.

General format:

- Define 1893 Load
- Zone IV 1893-Spec
- Self weight
- Joint Weight
- Joint-List Weight
- Member Weight

Load combinations considered in this analysis are

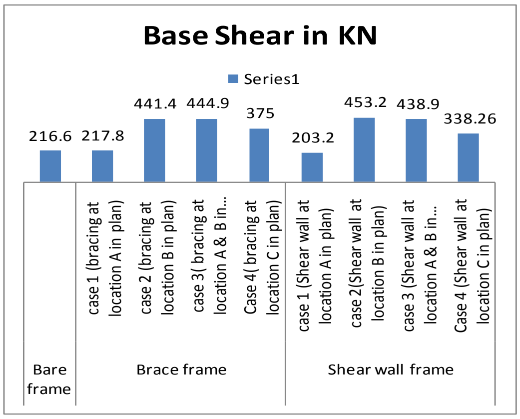
1) 1.5(DL+LL)
2) 1.2(DL+LL+EQX)
3) 1.2(DL+LL-EQX)
4) 1.2(DL+LL+EQZ)
5) 1.2(DL+LL-EQZ)
6) DL+1.5EQX
7) DL-1.5EQX
8) DL+1.5EQZ
9) DL-1.5EQZ

IV. RESULT AND DISCUSSION

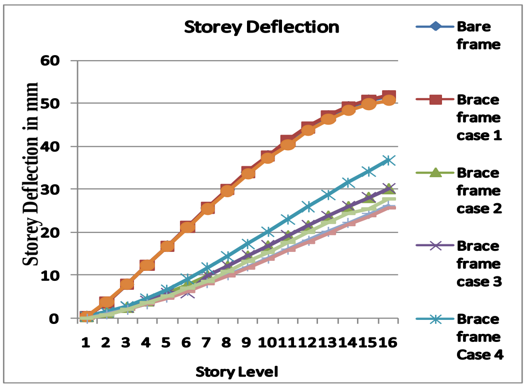
The variation of storey drift, base shear, story deflection, time period, bending moment, shear force, and axial force is evaluated for all these models and compared with equivalent static method.

Variation of base shear, story deflection, storey drift & time period

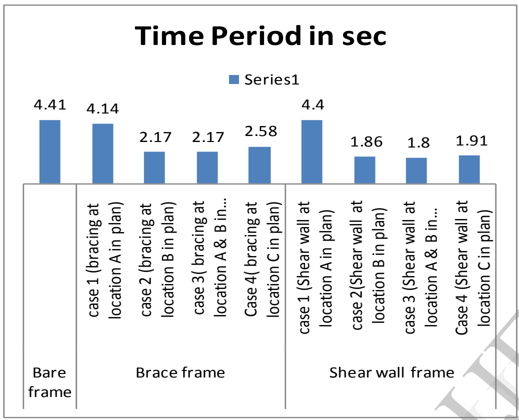
The parametric study to know base shear, story deflection, storey drift & time period in case of all models is performed here. The results are shown in table 1 to 4 & in graph 1 to 4 which are listed below. From Table 1 and graph 1, it is observed that base shear maximum for case 2 and 3 in both brace frame and shear wall frame. From Table 2 and graph 2, time period is also less for case 2 and 3 in both brace frame and shear wall frame. As base shear increases time period of models decreses and vise versa. Building with short time period tends to suffer higher accelerations but smaller displacement. Therefore, from table 3 & 4, graph 3 & 4 story deflection is also minimum for case 2 and 3 in both brace frame and shear wall frame. Story drift i.e. top story displacement is also reduced for case 2 and 3 in both brace frame and shear wall frame.



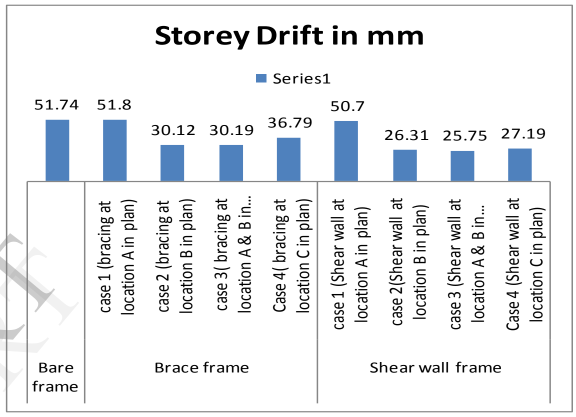
Graph 1 Design Base Shear in KN



Graph 3 Storey deflection in mm



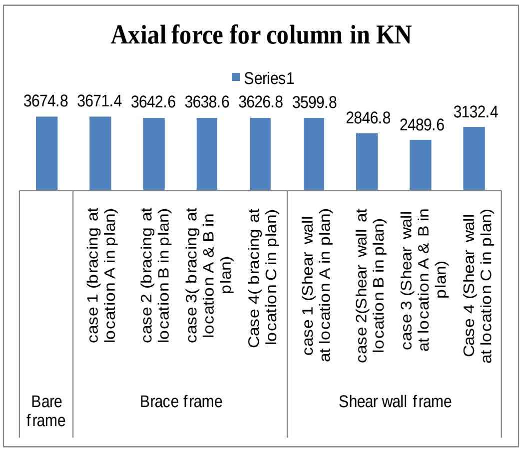
Graph 2 Time period in sec



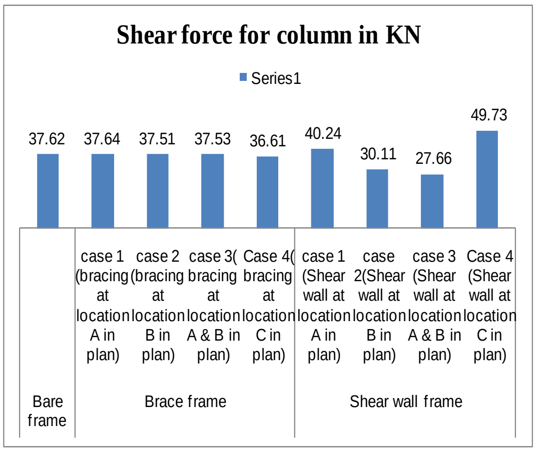
Graph 4 Storey drift in mm

Variation of axial force, shear force and bending moment:

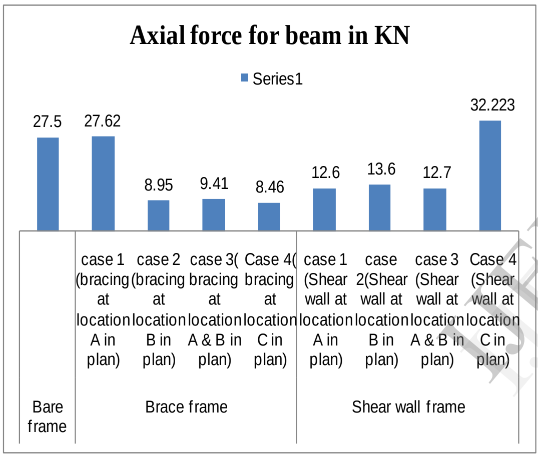
The parametric study to know axial force, shear force and bending moment in case of all models is performed here. The results are shown in table 5 to 10 & in graph 5 to 10 which are listed below. From Table 5 and graph 5, it is observed that overall the axial force for column are decreased from bare frame to shear wall frame. Shear wall frame models attracts minimum axial forces, Reduction of axial forces is due to provision of lateral resisting system. From table 6 & graph 6, axial forces in beam are less in for case 2 and 3 in both brace frame and shear wall frame. From table 7 & graph 7, shear force in column is minimum for case 2 and 3 in only shear wall frame. But only some Top Floors of all models gives maxium shear force values. From table 8 & graph 8, Shear force in beam is more but in shear wall models it is decreaed as compaire to others. From 9 & graph 9, bending moment in column values are more in shear wall models. From table 10& graph 10, it is observed that bending moments in beams of top floors gives maximum values. So there is need of special confinement reinforcement in top floors.



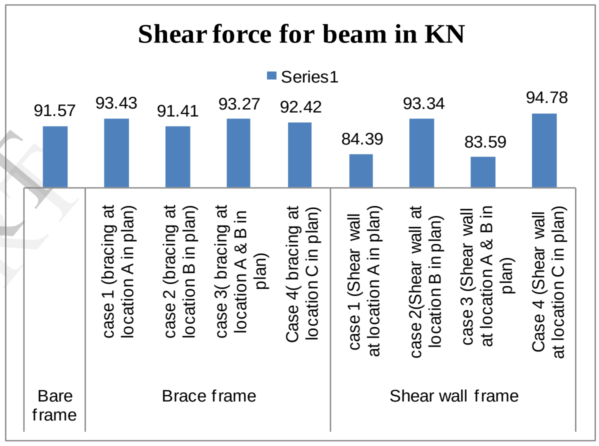
Graph 5 Axial forces for Column



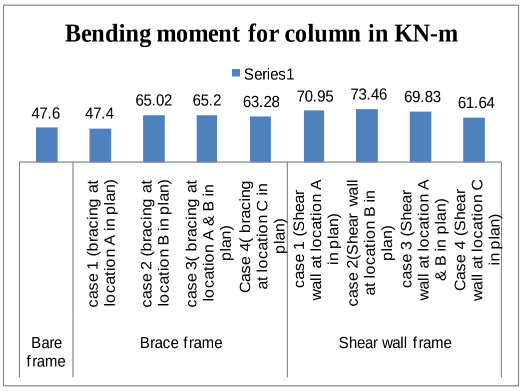
Graph 7 Shear forces for column



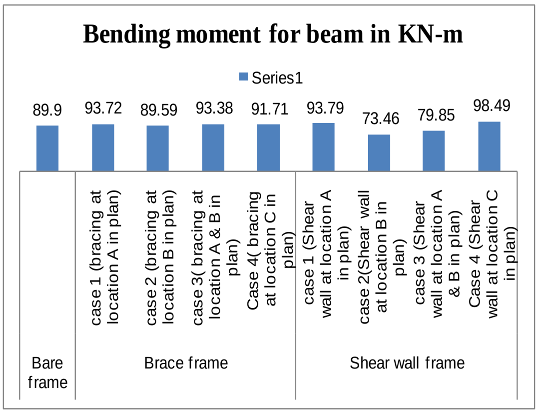
Graph 6 Axial forces for beam



Graph 8 Shear forces for beam



Graph 9 Bending moment for column



Graph10 Bending moment for Beam in KN-m

V. CONCLUSIONS

High-rise building (G+14 storey) with different lateral load resisting system is analyzed by using equivalent static method. Detailed parametric study has been performed for various models. Some prominent conclusions are summarized here.

- A significant amount of decrease in story drift has been observed in case 2 and 3 i.e. lateral stiffness system is centrally located at exterior frame of X direction through out height and lateral stiffness system is centrally located at exterior frame of X & Z direction through out height in both brace frame and shear wall frame compared to other models. Also shear wall models in case 2 and 3 gives less storey deflection and storey drift than bare frame and brace frame.

- A significant amount of decrease in time period of model in case 2 and 3 i.e. lateral stiffness system is centrally located at exterior frame of X direction through out height and lateral stiffness system is centrally located at exterior frame of X & Z direction through out height in both brace frame and shear wall frame compared to other models, therefore displacements in the structure are minimized.

- Base shear is also more in case 2 and 3. As base shear increases time period of models decreases and vise versa. Building with short time period tends to suffer higher accelerations but smaller displacement.

- Overall the axial force are decreased from bare frame models to shear wall models. Shear wall models attracts minimum axial forces. Reduction of axial forces is due to provision of lateral resisting system.

- Comparing the top storey drift in the longitudinal direction, it can be seen that it decreases by 41.79% & 41.65% in case 2 and 3 of brace frame as compared to bare frame and it decreases by 49.15% & 50% in case 2 and 3 of shear wall frame as compared to bare frame. The models with shear wall located at exterior frame of X & Z direction through out height is found most effective in resisting lateral loads because it shows least deflection as compare with other model.

- A significant amount of increase in the lateral stiffness has been observed in all models of brace frame and shear wall frame as compared to bare frame.

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Method		Brace frame				Shear wall frame			
ESM	Bare frame	case 1 (bracing at location A in plan)	case 2 (bracing at location B in plan)	case 3(bracing at location A & B in plan)	Case 4(bracing at location C in plan)	case 1 (Shear wall at location A in plan)	case 2(Shear wall at location B in plan)	case 3 (Shear wall at location A & B in plan)	Case 4 (Shear wall at location C in plan)
	216.6	217.8	441.4	444.9	375	203.2	453.2	438.9	338.3

Table 1 Design Base Shear in KN

Metho d		Brace frame				Shear wall frame			
ESM	Bare frame	case 1 (bracin g at location A in plan)	case 2 (bracin g at location B in plan)	case 3(bracing at locatio n A & B in plan)	Case 4(bracing at locatio n C in plan)	case 1 (Shear wall at locatio n A in plan)	case 2(Shear wall at locatio n B in plan)	case 3 (Shear wall at locatio n A & B in plan)	Case 4 (Shear wall at locatio n C in plan)
	4.41	4.14	2.17	2.17	2.58	4.4	1.86	1.8	1.91

Table 2 Time Period in sec

Metho d		**Brace frame**				**Shear wall frame**			
ESM	**Bare fram e**	case 1 (bracin g at location A in plan)	case 2 (bracin g at location B in plan)	case 3(bracing at locatio n A & B in plan)	Case 4(bracing at locatio n C in plan)	case 1 (Shear wall at locatio n A in plan)	case 2(Shear wall at locatio n B in plan)	case 3 (Shear wall at locatio n A & B in plan)	Case 4 (Shear wall at locatio n C in plan)
	51.74	51.8	30.12	30.19	36.79	50.7	26.31	25.75	27.19

Table 4 Storey drift (Top storey displacement) in mm

Story Level	**Bare frame**	**Brace frame**				**Shear wall frame**			
		case 1	**case 2**	**case 3**	**Case 4**	**case 1**	**case 2**	**case 3**	**Case 4**
1	0.55	0.55	0.63	0.63	0.6	0.56	0.13	0.13	0.17
2	3.78	3.78	1.6	1.6	1.53	3.82	1.04	1.02	1.07
3	7.95	7.97	2.74	2.75	2.89	8	2.16	2.11	2.29
4	12.38	12.42	4.22	4.23	4.69	12.39	3.48	3.4	3.71
5	16.87	16.91	5.96	5.98	6.81	16.82	4.97	4.86	5.33
6	21.33	21.38	7.92	5.95	9.2	21.2	6.6	6.46	7.12
7	25.7	25.76	10.03	10.07	11.8	25.49	8.36	8.18	8.66
8	29.9	30.01	12.26	12.3	14.54	29.65	10.21	9.99	11.11
9	34	34.07	14.56	14.6	17.38	33.61	12.14	11.88	13.26
10	37.81	37.81	16.89	16.95	20.27	37.33	14.12	13.82	15.48
11	41.3	41.37	19.23	19.29	23.17	40.43	16.15	15.8	17.75
12	44.41	44.48	21.53	21.6	26.04	43.76	18.19	17.8	20.03
13	47.06	47.13	23.79	23.85	28.85	46.32	20.24	19.81	22.29
14	49.18	49.25	25.98	26.05	31.58	48.35	22.28	21.81	24.45
15	50.73	50.8	28.1	28.18	34.24	49.8	24.32	23.8	25.54
16	51.7	51.8	**30.12**	**30.19**	36.79	50.7	**26.31**	**25.75**	27.79

Table 3 Storey deflection in mm

Method		Brace frame				Shear wall frame			
ESM	Bare frame	case 1 (bracing at location A in plan)	case 2 (bracing at location B in plan)	case 3(bracing at location A & B in plan)	Case 4(bracing at location C in plan)	case 1 (Shear wall at location A in plan)	case 2(Shear wall at location B in plan)	case 3 (Shear wall at location A & B in plan)	Case 4 (Shear wall at location C in plan)
	3674.8	3671.4	3643	3638.6	3626.8	3599.8	2846.8	2489.6	3132.4

Table 5 Axial forces for Column in KN

Method		**Brace frame**				**Shear wall frame**			
ESM	**Bare frame**	case 1 (bracing at location A in plan)	case 2 (bracing at location B in plan)	case 3(bracing at location A & B in plan)	Case 4(bracing at location C in plan)	case 1 (Shear wall at location A in plan)	case 2(Shear wall at location B in plan)	case 3 (Shear wall at location A & B in plan)	Case 4 (Shear wall at location C in plan)
	27.5	27.62	8.95	9.41	8.46	12.6	13.6	12.7	32.223

Table 6 Axial forces for beam in KN

Method		**Brace frame**				**Shear wall frame**			
ESM	**Bare frame**	case 1 (bracing at location A in plan)	case 2 (bracing at location B in plan)	case 3(bracing at location A & B in plan)	Case 4(bracing at location C in plan)	case 1 (Shear wall at location A in plan)	case 2(Shear wall at location B in plan)	case 3 (Shear wall at location A & B plan)	Case 4 (Shear wall at location C in plan)
	37.62	37.64	37.51	37.53	36.61	40.24	30.11	27.66	49.73

Table 7 Shear forces for column in KN

Method		**Brace frame**				**Shear wall frame**			
ESM	**Bare frame**	case 1 (bracing at location A in plan)	case 2 (bracing at location B in plan)	case 3(bracing at location A & B in plan)	Case 4(bracing at location C in plan)	case 1 (Shear wall at location A in plan)	case 2(Shear wall at location B in plan)	case 3 (Shear wall at location A & B in plan)	Case 4 (Shear wall at location C in plan)
	91.57	93.43	91.41	93.27	92.42	84.39	93.34	83.59	94.78

Table 8 Shear forces for beam in KN

Method		**Brace frame**				**Shear wall frame**			
ESM	**Bare frame**	case 1 (bracing at location A in plan)	case 2 (bracing at location B in plan)	case 3(bracing at location A & B in plan)	Case 4(bracing at location C in plan)	case 1 (Shear wall at location A in plan)	case 2(Shear wall at location B in plan)	case 3 (Shear wall at location A & B in plan)	Case 4 (Shear wall at location C in plan)
	47.6	47.4	65.02	65.2	63.28	70.95	73.46	69.83	61.64

Table 9 Bending moment for Column in KN-m

Method		**Brace frame**				**Shear wall frame**			
ESM	**Bare frame**	case 1 (bracing at location A in plan)	case 2 (bracing at location B in plan)	case 3(bracing at location A & B in plan)	Case 4(bracing at location C in plan)	case 1 (Shear wall at location A in plan)	case 2(Shear wall at location B in plan)	case 3 (Shear wall at location A & B in plan)	Case 4 (Shear wall at location C in plan)
	89.9	93.72	89.59	93.38	91.71	93.79	73.46	79.85	98.49

Table 10 Bending moment for Beam in KN-m