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Structural and Economic analysis of RC Frame building with and without bracing

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ABSTRACT

In modern era buildings must have ability to sustain earthquakes. Structures need to be suitably designed and detailed to ensure stability, strength and serviceability with acceptable levels of safety to resist seismic forces. In this study structural and economics analysis of moment resisting RC frame building with and without bracing for DBE and MCE conditions was studied. It was observed that buildings stiffened by bracing perform better during earthquake. The performance of building stiffened by properly designed bracing has been better with respect to both life safety and damage control.

Key words: Earthquake, bracing, Economic RC frame

INTRODUCTION

During an earthquake, the ground accelerations cause structures to vibrate and induce inertial forces in them. Earthquakes occurred in the past have shown the consequences of neglecting the seismic forces in design of structures. Hence, structures need to be suitably designed and detailed to ensure stability, strength and serviceability with acceptable limits of safety as per Indian codal provision to resist seismic forces. The resultant inertial force at any level depends on the mass at the floor level and also on the height above the foundation. The distribution of the inertial force along the building height is parabolic with maximum value at the top floor [1-3]. In regions of high seismic intensity, it is desirable to minimize the weights at the various floor levels, particularly at the roof and upper storey [4-6]. The concept of earthquake resistant design is that the structure should be designed to resist the forces, which may occur at least once during the life of a structure due to moderate earthquake that will cause minor damage. Such an earthquake is characterized as Design Basis Earthquake. The chances of occurrence of this earthquake are 10% in 50 years [7]. In case of severe earthquake that may occur once in lifetime of the structure, a controlled structural damage is accepted but total collapse is avoided. Such an earthquake is characterized as Maximum Considered Earthquake with a return period of 2500 years and 2 % as the probability of occurrence [8-9].

The objective of this study is to examine seismic and economics analysis of moment resisting RC frame building with and without bracings for Design Basis Earthquake and Maximum Considered Earthquake. Structural economics refers to comparison of structural cost, i.e., the cost of structural steel and concrete. The structural cost is the cost of structural steel and concrete required in structural members such as beams, columns and bracings of the superstructures. The slabs and foundations have been excluded. Further, labour cost, erection cost, etc; also have not been considered. In this study structural economics of moment resisting RC frame building with and without bracing for DBE and MCE conditions was analyzed during earthquakes. It was observed that buildings stiffened by bracing perform better during earthquake. The performance of building stiffened by properly designed bracing has been better with respect to both life safety and damage control.

BUILDING DESCRIPTION

Basic Structure

A G+10 storey building with square plan 16 m x 16 m is considered. Floor to floor height considered is 3.1 m. The height of building measured from the ground level is 35.3 m. The depth of the foundation below the ground level is 1.2

m. The building is located in the seismic Zone IV and is resting on hard rock. The following general points are worth noting regarding the building:

a) Slabs are not provided at ground floor and the floor will directly rest on the ground. Ground beams passing through column are provided.
b) All external walls are 230 mm thick and internal walls are 150 mm thick.
c) All floor diaphragms are considered to be rigid.
d) Centre to centre dimensions are followed for analysis and design and the effect of finite size joint width is not considered.
e) Seismic loads are considered to act in the horizontal direction (along either of the two principle directions) and not in the vertical direction.
f) Stiffness of infill walls is not considered in the seismic analysis of the building.
g) Deductions for opening is not done while calculating the seismic weight of building.
h) Wind load is not considered.
i) Building is considered to be fixed at the base level in all the cases.

Building Design

Four different types of RC buildings designated as Type I, Type II, Type III and Type IV are considered for computing the structural cost. The line plan showing positions of columns for all building is shown in Fig. 1.

Fig.2 (a) shows the elevation of Type I and Type III buildings. Fig 2(b) shows the elevation of Type II and Type IV building.

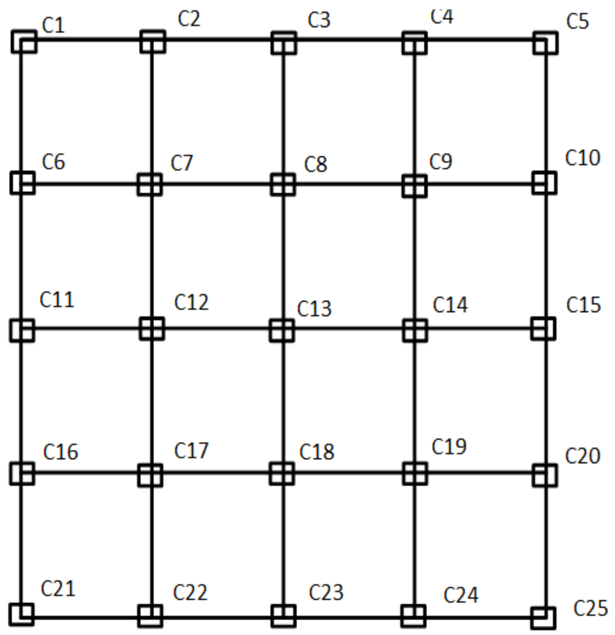

Fig. 1 Line plan of Type I, Type II, Type III and Type IV Buildings

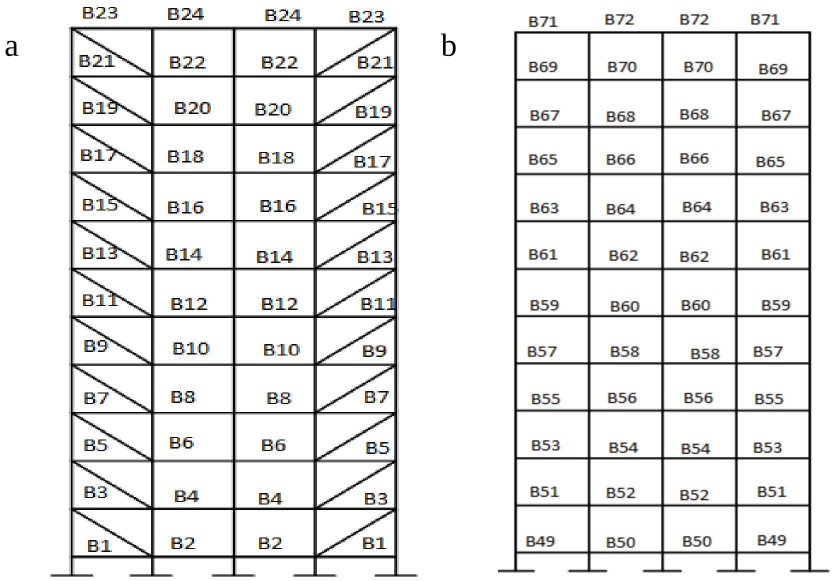

Fig. 2 Elevation of (a) Type I and Type III Buildings, (b) Type II and Type IV Building

Table-1 The preliminary data for RC frame building of eleven storey

Types of structure	Multi-storey rigid space frame
Seismic zone	Zone IV
Soil types	Type I (Rock Type)
Number of storey	Eleven (G+10)
Infill wall	External: 230 mm
	Internal: 115 mm
Slab thickness	120 mm
Beam size	300 mm x 450 mm for Type-1, Type-2 and Type-3 300 mm x 500 mm for Type-4
Column size	For Type-1, Type-2, and Type-3 buildings GF: 500 mm x500 mm 1st to 3rd floor: 450 mm x 450 mm 4th to 7th floor: 400 mm x 400 mm and 8th to 10th floor: 350 mm x 350 mm For Type-4. GF 550 mm x 550 mm 1st to 3rd floor: 550 mm x 550 mm 4th to 7th floor: 500 mm x 500 mm 8th to 10th floor: 450 mm x 450 mm
Floor height	3.1 m
Earthquake load	As per IS 1893 (Part 1)-2002[10]
Live load on floors	3 kN/m^2
Grade of concrete	M 25
Grade of steel	Fe 415
Unit weight of masonry	20 kN /m^2
Size of bracing	300 mm x 300 mm

2.3. Modeling

Models provide the means of simulation of actual behavior of structures. RC moment resisting frames consist of columns, beams, slabs, bracings, member joints, brick masonry walls, foundations and the foundation strata (soil). Such a complex system involving numerous elements is often simplified by taking advantage of the behavior of the components and response behavior of the system to a particular loading. It is assumed that connections are stronger than the connected members. The design procedure is included with the rules to implement this assumption so that the deformations of the joints do not affect the displacements of the members.

Three dimensional analyses of all the four types of buildings have been carried out using SAP 2000 [11]. In SAP 2000, beams and columns are modeled using 3D frame element and concrete bracing is also modeled as 3D frame element. Building joints are model as rigid jointed bare frame with weight of infill walls as uniformly distributed loads on concerned beams. All the buildings have equal storey height of 3.1 m centre to centre. All the buildings have been considered fixed at the ground level and situated in zone IV on hard soil.

ANALYSIS OF BUILDINGS

Primary loads acting on the building are dead load, live load and earthquake load or seismic load. These loads are applied on the model and analysis is done using SAP 2000 [11]. Seismic analysis is carried out by using response spectrum analysis technique.

The base shear V_b, is obtained from the response spectrum analysis. The ratio $\overline{V_b}/V_b$ is calculated. This factor should be greater than 1. All response quantities are multiplied by this factor, i.e., $\overline{V_b}/V_b$ to get the final response. Fundamental time period of buildings are given in Table 2.

Table-2 Fundamental Time Period of Buildings

Type of Building	Time Period (Sec)	
	SAP[11]	Code As per clause 7.6.2.of [10]
I	1.2512	0.7943
II	1.8529	0.7943
III	1.2188	0.7943
IV	1.5141	0.7943

Base shear is calculated in each type of building after applying correction factor $\overline{V_b}/V_b$. V_b is base shear calculated by SAP 2000. These values for all types of buildings are given in Table 3.

Table-3 Base Shear and Correction Factor

Case	X direction		Y direction		Correction factor	
	$\overline{V_b}$ (kN)	V_b (kN)	$\overline{V_b}$ (kN)	V_b (kN)	X direction	Y direction
I	1340.01	754.49	1340.01	754.49	1.77	1.77
II	1309.47	471.25	1309.47	471.25	2.78	2.78
III	2697.92	1542.5	2697.92	1542.5	1.75	1.75
IV	2779.14	1229.86	2779.14	1229.86	2.26	2.26

The storey drift is the difference in lateral displacement between two consecutive floor levels. Damage to non-structural components of building depends on drift. The lateral floor displacement and storey drift for Type I, II, III and IV buildings are given in Fig 3. Maximum Storey drift of Type I, Type II, Type III and Type IV Building is 2 mm, 4.9 mm 3.8 mm, and 6.8 mm, respectively. Maximum storey drift of all building for the lateral load satisfy the clause 7.11 of IS 1893-Part 1:2002.

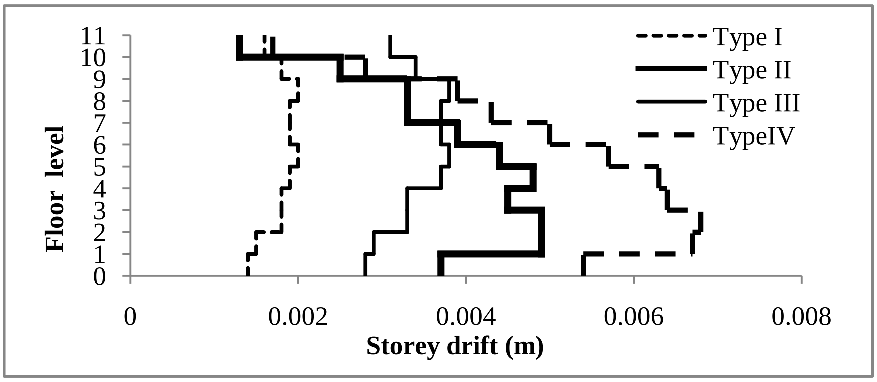

Fig. 3: Storey drifts for different type of buildings

STRUCTURAL COST OF BUILDINGS

Structural cost of the building is the sum of the total cost of reinforcement steel and total cost of concrete required for beams, columns and bracings in the building. The cost of the slabs and foundations are not included in the computation of structural cost. It also does not include the cost of labour and cost of erection, etc. In the present work, the structural cost of the building is considered as the cost of concrete and cost of steel reinforcement in beams, columns and bracings. The cost of steel reinforcement is taken as Rs 67/ kg (CPWD [12]) and cost of concrete is taken as Rs 5849 / m^3. Table 4 gives the quantity of steel required for beams, columns, and braces for each building. Table 5 gives the quantity of concrete required for each building.

Table 4: Quantity of Steel in kg

Type of Buildings	Beams	Columns	Bracings	Total steel in kg.
I	26651.56	32300.72	6224.28	65176.56
II	42393.62	37020.89	-	79414.51
III	39054.86	40210.59	13743.21	93008.66
IV	76290.52	55426.163	-	131716.68

Table 5: Quantity of Concrete in m^3

Type of Buildings	Beams	Columns	Bracings	Total concrete in m^3
I	259.20	169.75	40.08	469.03
II	259.20	180.45	-	439.66
III	259.20	181.31	40.08	480.58
IV	288.00	336.20	-	624.20

The cost of structural steel and the cost of concrete for each type of building along with the total structural cost are given in Table 6.

Table 6: Structural Cost of Buildings

Case	Cost of steel @ Rs 67 / kg	Quantity of concrete in m^3	Cost of concrete @ Rs 5849 / m^3	Total cost in (Rs)
I	2998121.76	469.03	2298486	5296607.76
II	3653050	439.66	2154544	5807594.47
III	4278398	480.58	2355082	6633481.65
IV	6058967	624.20	3058868	9117835.88

The quantities of steel and concrete required for Type IV building are largest as compared to Type II, Type III and Type IV building. The quantity of steel required in Type I is the least.
The structural costs of Type I building and Type IV building are, respectively, the minimum and the maximum. The structural cost of Type II building is greater than the Type I building and the structural cost of Type IV building is greater than Type III building.

CONCLUSIONS

Based on the design of buildings for four different cases and determining the cost of steel and cost of concrete for these cases, the following conclusions can be drawn.

- The fundamental time period for Type I and Type II buildings obtained by using SAP are respectively 1.2512 sec and 1.8529 sec. The position of braces in Type I building makes the building stiff causing reduction in the fundamental time period
- The fundamental time period of Type III and Type IV building obtained by using SAP are respectively 1.2188 sec and 1.5141 sec. The position of braces in Type III building makes the building stiff causing reduction in the fundamental time period.
- The non structural damage will be less in case of Type I building as compared to Type II building up to the ninth storey.
- The non structural damage will be less in case of Type III building as compared to Type IV building up to the eight storey.
- The structural cost of Type I building is least in comparison to Type II, Type III, and Type IV buildings.

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