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EFFECTIVENESS OF INCLUSION OF STEEL BRACING IN EXISTING RC FRAMED STRUCTURE

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ABSTRACT

Steel braced frame is one of the structural systems used to resist earthquake loads in structures. Many existing reinforced concrete structures need retrofitting to overcome deficiencies and to resist seismic loads. The use of steel bracing systems for strengthening or retrofitting seismically in adequate reinforced concrete frames is a viable solution for enhancing earthquake resistance. Steel bracing is economical, easy to erect, occupies less space and has flexibility to design for meeting the required strength and stiffness**.** In the present study multi-storey building, of ten storey with varying length to breadth ratio have been modelled using SAP 2000. SAP 2000 is used to perform linear and nonlinear dynamic analysis. In this study R.C.C. building is modeled and analyzed in three Parts I) Model without bracing and shear wall II) Model with shear wall system III) Model with different bracing system. It was found that steel bracing significantly reduces the lateral drift.

KEYWORDS: Analysis, Earthquake Strengthening, Retrofit, Seismic Performance, Steel Braced RC Structures

INTRODUCTION

A reinforced concrete building should be designed to have a capacity to carry combined loads (dead, live and seismic loads) at certain safety level and at certain degree of reliability. Proper account of loads, material properties, structural system, and method of analysis are fundamental factors in the design of structure. When this design is finally executed in the construction process, the expected performance of the structural building should come into satisfaction. However, this ideal condition is not always realized. Performance of structural building could be below the expected criteria in term of safety level and service life due to a variety of causes. In addition to faulty design and improper construction, there are other situations that could impair the future performance of structural building such as alteration of building functions, changes of seismic load characteristics in the area, ingress of aggressive agents from the environment, etc. In term of seismic load characteristics, it is common to come across buildings which used to be meeting the seismic requirements and now their seismic performance are in question due to increase in the current seismic demand. It is also common to discover buildings with degrading performance after damaged by earthquake and therefore, their seismic performance also do not meet the current standard. Retrofitting of deficient existing building to improve its seismic performance will be a pathway to assure the safety of the structure in the event of future earthquake. There are several technologies that could be chosen for this purpose such as adding a diagonal structural elements (bracing), shear walls, or by changing the relationship between structural elements. The use of steel bracing for retrofitting reinforced concrete structures has some advantages such as it is relatively cost-effective, does not significantly add the structural weight, is easy in application and can be customized with the necessary strength and rigidity.

STEEL BRACINGS

On a global basis of resisting earthquake loads, shear walls are commonly used in RC framed buildings, whereas, steel bracing is most often used in steel structures. In the last two decades, a number of reports have also indicated the effective use of steel bracing in RC frames. The bracing methods adopted fall into two main categories, namely:

- External bracing
- Internal bracing

In the external bracing system, existing buildings are retrofitted by attaching a local or global steel bracing system to the exterior frames. Architectural concerns and difficulties in providing appropriate connections between the steel bracing and RC frames are two of the shortcomings of this method. In the internal bracing method, the buildings are retrofitted by incorporating a bracing system inside the individual units or panels of the RC frames. The bracing may be attached to the RC frame either indirectly or directly.

There are two types of bracing systems

- Concentric Bracing System
- Eccentric Bracing System

The concentric bracings increase the lateral stiffness of the frame, thus increasing the natural frequency and also usually decreasing the lateral drift. However, increase in the stiffness may attract a larger inertia force due to earthquake.

Eccentric Bracings reduce the lateral stiffness of the system and improve the energy dissipation capacity. Due to eccentric connection of the braces to beams, the lateral stiffness of the system depends upon the flexural stiffness of the beams and columns, thus reducing the lateral stiffness of the frame.

Structural Modelling and Analysis

The finite element analysis software SAP2000 Nonlinear is utilized to create 3D model and run all analysis. The software is able to predict the geometric nonlinear behaviour of the space frames under static or dynamic loadings, taking into account both geometric nonlinearity and material inelasticity. The software accepts static loads (either forces or displacement) as well as dynamic (accelerations) action and has ability to perform eigen values, nonlinear static pushover and nonlinear dynamic analyses.

The buildings are modeled as a series of load resisting elements. The lateral loads to be applied on the buildings are based on the Indian standards. The study is performed for seismic zone IV as per IS 1893:2002. The buildings adopted consist of reinforced concrete and brick masonry elements. The frames are assumed to be firmly fixed at the bottom and the soil–structure interaction is neglected.

- G+9 storied building analysed for seismic forces.

- G+9 storied building with shear wall analysed for seismic forces.
- G+9 storied building with different types of bracing systems analysed for seismic forces.

Table 1: Model Data of Building

Structure	OMRF
No. of stories	G+9
Storey height	3.00 m
Type of building use	Public building
Type of soil	Medium soil
Foundation type	Isolated footing
Seismic zone	IV
Material Property	
Grade of concrete	M_{25}
Grade of steel	Fe 415
Young's modulus of M_{25} concrete, E	25×10^6 kN/m^2
Density of reinforced concrete	25 kN /m ^{3}
Density of brick masonry	20 kN/m^3
Member Properties	
Thickness of slab	125 mm
Beam size	300 mm × 450 mm
Column size	400 mm × 600 mm
Thickness of wall	230 mm (exterior) 150 mm (interior)

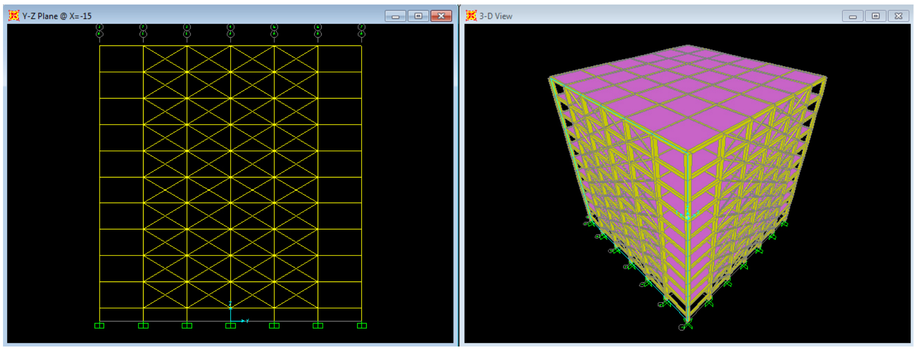

Figure 1: Concentric Bracing Model (XBF-1) of G+9 Storey Created in SAP 2000

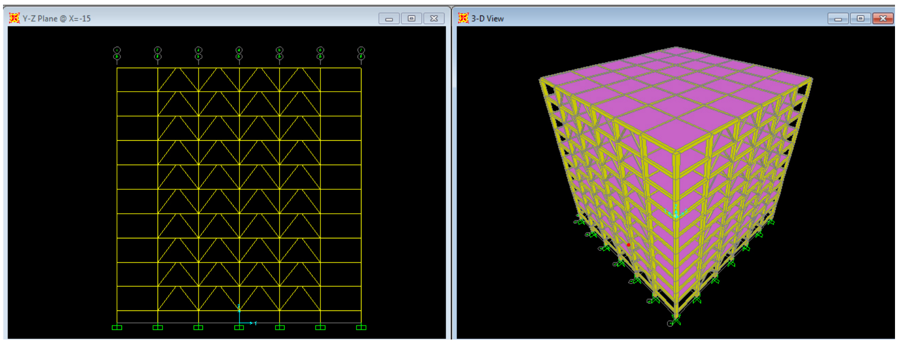

Figure 2: Eccentric Bracing Model (EBF) of G+9 Storey Created in SAP 2000

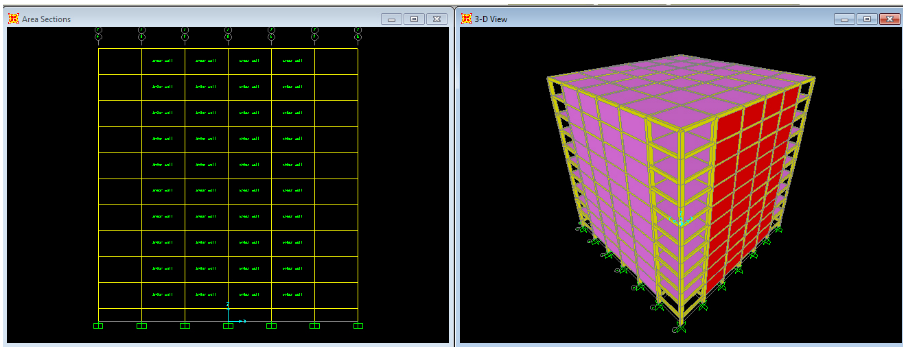

Figure 3: Shear Wall Model (SWF) of G+9 Storey Created in SAP 2000

RESULTS AND DISCUSSIONS

Analysis were conducted to evaluate the performance of concrete structures under seismic loading with and without lateral load resisting elements. Results of time history analysis have been used to observe and compare floor response of all the models.

Comparison of Different Lateral Load Resisting Models

Storey Drift

From the result it is clear that X bracing model significantly reduces the lateral drift than eccentric bracing. The difference in the lateral drift between shear wall model and concentric bracing model is negligible in top storey and vice versa in bottom storey.

Table 2: Comparison of Storey Drift for Different Lateral Load Resisting Models

Storey Height (m)	Time History Analysis			
	BF (mm)	XBF-1 (mm)	EBF (mm)	SWF (mm)
31.5	355.5	125.1	216.7	124.6
28.5	341.1	120.5	209.5	113.2
25.5	317.9	113.6	197.3	100.3
22.5	287.3	104.6	181.1	86.9
19.5	253.2	93.7	163.2	73
16.5	220.5	80.8	143.7	58.7
13.5	181.6	66.4	120.9	44.6
10.5	145.3	51.2	94.9	31.6
7.5	103.8	36.8	66.5	18.3
4.5	52.8	21.1	36.5	9.18

Inter Storey Drift Percentage

Inter-storey drifts δ define the relative lateral displacements between two consecutive floors. Generally expressed as ratios δ / h of displacement δ to storey height h. Inter-storey drift can be considered as a damage parameter.

Table 3: Damage Parameter

Performance Level	Inter- Storey Drift Percentage
Fully operational	< 0.2
Operational	< 0.5
Life safe	<1.5
Near collapse	< 2.5
Collapse	> 2.5

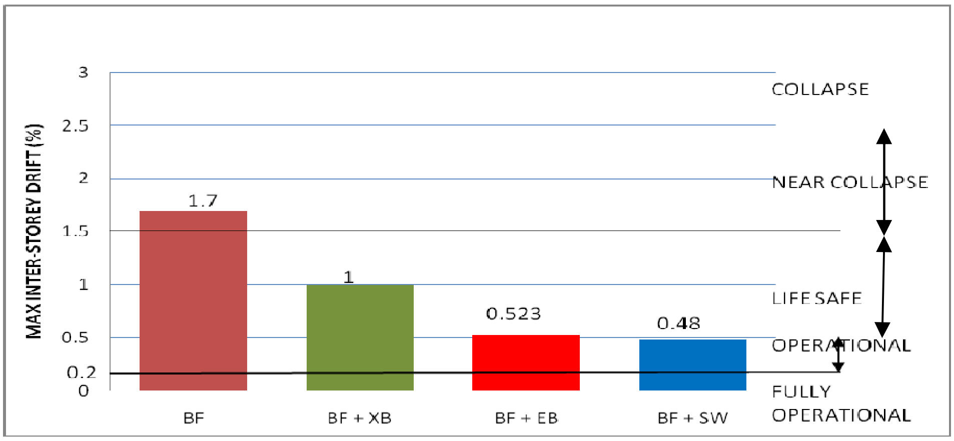

Figure 4: Maximum Inter-Storey Drift Ratio Capacity for Different Lateral Load Resisting Model

Comparison of Concentric and Eccentric Bracings

Comparison of Stiffness

The stiffness of frames was computed as the ratio of overall lateral force to the overall displacement. From the study it is clear that concentric bracings increase the lateral stiffness of the frame, thus increasing the natural frequency and also usually decreasing the lateral drift.

Table 4: Comparison of Stiffness

Type of Bracing	Base Shear (kN)	Maximum Displacement (mm)	Stiffness (kN/m)
BF	22552.089	243.9	9.246×10^4
XBF-1	23509.045	86.34	2.723×10^5
EBF	29467.051	149.1	1.976×10^5

Comparison of Maximum Axial, Shear Forces and Bending Moments in Columns at Base

It is seen that the maximum axial forces are increased for buildings with bracings compared to that of the building without bracings. Further, while bracings decrease the bending moments and shear forces in columns they increase the axial compression in the columns to which they are connected. Since reinforced concrete columns are strong in compression, it may not pose a problem to retrofit in reinforced concrete frame using concentric steel bracings. It seen that the bending moment values are smaller for the buildings with X types of bracing systems.

Table 5: Comparison of Maximum Axial, Shear Forces and Bending Moments in Columns at Base

Type of Building	Axial Force (kN)	Shear Force (kN)	Bending Moment (kNm)
BF	5567.092	765.507	1187.895
XBF-1	8337.219	325.626	486.0712
EBF	6173.879	530.834	811.8792

Comparison of Shear Forces and Bending Moments in Beam at Base

In eccentric bracing the vertical component of the bracing forces due to earthquake cause lateral concentrated load on the beams at the point of connection. This causes increase in shear force and bending moments in the beam to which it is connected.

Table 6: Comparison of Shear Forces and Bending Moments in Beam at Base

Type of Building	Shear Force (kN)	Bending Moment (kNm)
XBF-1	81.435	184.621
EBF	188.717	312.2173

The Effect of Length to Width Ratio of Building

In order to study the effect of length to width ratio in the performance of RC structure under seismic loading. Building with L/B ratio 1.5, 2 and 2.5 are prepared with X bracing in four panels in all four direction (configuration similar to XBF-1) and time history analysis is performed. The analysis results show that the percentage variation in top storey displacement, shear force and bending moment in the column at the base with respect to bare frame structure goes on increasing as L/B ratio increases.

Table 7: Comparison of Top Storey Drift for Varying L/B Ratio

L × B	L/B	Top Storey Displacement in mm (BF)	Top Storey Displacement in mm (XBF)	Percentage Variation w.r.t BF
45 × 30	1.5	320.9	219.2	31.692
60 × 30	2.0	344.1	216	37.227
75 × 30	2.1	383.5	227.7	40.625

Table 8: Comparison of Top Storey Drift for Varying L/B Ratio

L × B	L/B	Percentage Variation of SF w.r.t BF	Percentage Variation of BM w.r.t BF
45 × 30	1.5	97.184	84.103
60 × 30	2.0	97.369	85.506
75 × 30	2.1	97.55	85.82

CONCLUSIONS

The comparison of different lateral load resisting elements, which includes concentric bracing model, eccentric bracing model and shear wall model. Models are created and time history analysis is performed. Inter–storey drift capacity ratio is minimum for shear wall model. With the introduction of bracings the structure become life safe. The difference in the lateral drift between shear wall model and concentric bracing model is negligible in top storey and vice versa in bottom storey.

Comparison of concentric and eccentric bracings comparing the lateral stiffness, concentric bracings increase the lateral stiffness of the frame, thus increasing the natural frequency and also usually decreasing the lateral drift. However, increase in the stiffness may attract a larger inertia force due to earthquake. Eccentric Bracings reduce the lateral stiffness of the system and improve the energy dissipation capacity. Due to eccentric connection of the braces to beams, the lateral stiffness of the system depends upon the flexural stiffness of the beams and columns, thus reducing the lateral stiffness of the frame. Comparing axial force, shear force and bending moment in the column at base, concentric bracings decrease the bending moments and shear forces in columns, they increase the axial compression in the columns to which they are connected. Since reinforced concrete columns are strong in compression, it may not pose a problem to retrofit in RC frame using concentric steel bracings. Comparing bending moment and shear force in the beam to which bracing is connected, the vertical component of the bracing forces due to earthquake cause lateral concentrated load on the beams at the point of connection of the eccentric bracings. This causes increase in bending moment and shear force in eccentric bracings model.

Comparison of building with different L/B ratio indicates that the percentage variation in top storey displacement, shear force and bending moment in the column at the base with respect to bare frame structure goes on increasing as L/B ratio increases.

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