OPTIMIZATION OF SPECIAL MOMENT RESISTING FRAME INSTALLED WITH BUCKLING RESTRAINED BRACES

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KEYWORDS

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ETABS
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ABSTRACT

In recent years, the seismic design of structures has experienced significant changes because of the increased demand for optimization of the structural capacities of buildings in order to minimize the level of damage, economic loss, and structure repair costs after an earthquake. The purpose of this project is to evaluate the performance of Special Moment Resisting Frame (SMRF) building installed with Buckling Restrained Braces (BRB) designed according to the current Indian Standards, minimum design loads for buildings and other structures. The project also investigates the differing results from the time history analyses completed using ETABS, commonly used structural analysis software. For the Nonlinear Dynamic Procedure (NDP), a time-history analysis is performed in which a model that incorporates the nonlinear load-deformation capacities of individual members in the structure is subjected to earthquake ground motions to obtain forces and displacements. And then, the optimization of the sections will be taken into consideration from the results of analyses of the SMRF building and the SMRF building installed with Buckling Restrained Braces.

1. INTRODUCTION

1.1. GENERAL

In general, as the height of a building increases, its overall response to lateral load (such as wind and earthquake) increases. When such response becomes sufficiently great such that the effect of lateral load must be explicitly taken into consideration in design, a multistory building is said to be tall. Tall buildings are prone to excessive displacements, necessitating the introduction of special measures to contain these displacements. The lateral load effects on buildings can be resisted by Frame action, Shear Walls, or Dual System. Peak inter-storey drift and lateral displacement (or side sway) are two essential parameters used for assessing the lateral stability and stiffness of lateral force resisting systems of tall buildings. Selection of such a strong and stiff enough deformation resisting systems that will curtail the drift within acceptable code limits should be the main motive of structural designers. To economize the structure structural optimization techniques should be used. For large projects it is necessary to go for structural optimization because it directly affects cost of construction.

Many Metropolitan cities are facing vast growth of infrastructure whether it may be in terms of horizontal development or vertical development. Metropolitan cities like Delhi and Mumbai have high population and in forth coming years land availability problems will increase tremendously which will in turn affect the overall growth of the city, so most of the builders in construction industries prefers vertical development of structures. As we increases number of stories or height of structure, huge lateral forces come into picture which will tend to increase the construction cost of the project in terms of consumption of steel, concrete and such other materials. Hence usually optimization techniques are adopted to economize the structure.

New and different approaches to design have become possible through the increased speed of computers and software tools of optimization theory. The optimization exercise commences right from the architectural concept stage. Suggested grid dimensions by architecture usually do not result into most economical structural member sizes and reinforcement consumption. In general optimization includes discretization of a whole structure into a series of sub frames with slab, beams, columns and footings. The main parameters involved in the investigation of this project are fundamental time period, base shear, and area of reinforcement and volume of concrete per square feet in (mm2). These parameters are indirectly indicates the cost effectiveness of the individual technique and there by the structure.

There are many RCC and Steel structures that do not satisfy the lateral strength necessities of current seismic codes and are susceptible to major damage in the event of earthquake. So, several techniques are used to make buildings more resistant to earthquakes. Buckling-Restrained Braced Frame (BRBF) systems have shown predictable performance and robust energy dissipation capacity when subjected to seismic loading.

However, the low post-yield stiffness of Buckling-Restrained Braces (BRB) may cause BRBFs to exhibit large maximum and residual drifts. To reduce residual story drifts, it is suggested that one option is to design the BRBFs as a Dual system; the addition of Special Moment Resisting Frames, which exhibit large deformability in the elastic range, can serve as a restoring force mechanism to partially re-center the building after a significant seismic event. Buckling Restrained Braced Frames (BRBFs) can provide significant elastic stiffness and cause small elastic drifts, while Special Moment Resisting Frames (SMRFs) have small lateral stiffness to the extent that limiting lateral drifts in SMRF is the governing design criteria. By combining these two systems, a dual system with advantages of the two systems can be provided and the disadvantages of the two systems can be prevented as well. The flexible SMRF remains elastic after the BRBF have yielded and provide additional stiffness and prevent large drifts leading in less residual drifts for the whole structure(Silwal, Ozbulut, & Michael, 2016).

Steel moment-resisting frame (SMRF) with open first storey (soft storey) is known to perform well as compared to the reinforced cement concrete (RCC) frames during strong earthquake shaking. RCC framed structures are more durable and have less maintenance, but they have a disadvantage of being less ductile in lateral direction. It is found that RCC columns and beams fail in bending and torsion which causes exposure of steel during earthquake. Developing effective seismic protective systems for new or existing structures requires striking a balance between stiffness, strength, and damping. The balance can be achieved by energy dissipation, base isolation, and provision of structural control devices to dissipate energy and reduce deformations.

The purpose of this study was to optimize the seismic performance of a representative twelve storied steel frame by evaluating the performance in terms of drift limits, lateral load carrying capacity and then strengthening using Buckling Restrained Brace (BRB). The strengthening of the frame was required to be done to reduce excessive deformation and to improve lateral load and energy dissipation capacity of the frame. And to optimize the building as much as possible with BRB installed in an SMRF building.
In this research paper, mild steel pipe section filled with concrete is used as Buckling Restrained Brace (BRB). The thickness of mild steel pipe and that of concrete infilled was decided on the basis of the axial force acting on BRB. It is supported by single diagonal bracings in between the bays. And SMRF was designed as per Indian Standard codal provisions.

Evaluation of bare SMRF structure and the same SMRF structure installed with BRB was performed on structural analysis software ETABS. Nonlinear Time History Analysis was performed and the modified SMRF frame was then optimized even more. The beam and column sections got reduced by some percentage.

2. METHODOLOGY

2.1. GENERAL

A G+12 SMRF building was considered at first for the time history analysis using three earthquake excitations. Then the same building was again analyzed after installing of BRB in it using the same earthquake excitations. And at last, the sections of the two buildings were compared.

2.2. SMRF MODEL DESCRIPTION

A multistoried steel (G+12) moment resisting frame is analyzed as shown in fig.1 using the structural analysis software ETABS. The frame was planned in such a way that it will have twelve stories and five bays. The height of the storey was 3 m and the building has five bays at 4m in each direction. The building was framed and designed for Pune location, considering it in Zone III. The SMRF was designed as per Indian Standard codal provisions. And the sectional properties are shown in table1.

CONDITIONS ASSIGNED:

1) Structure = SMRF
2) No. of stories = G+12
3) Storey height = 3m
4) Bay width = 4m
5) Seismic zone = III (0.16)
6) Soil type = 2nd (medium)
7) Importance factor = 1.5
8) Response Reduction Factor = 5
9) Modal damping = 0.05

10) Height of the building = 36m
11) Width of the building = 20m

The load combinations were defined as per the Indian Standards codal provisions.

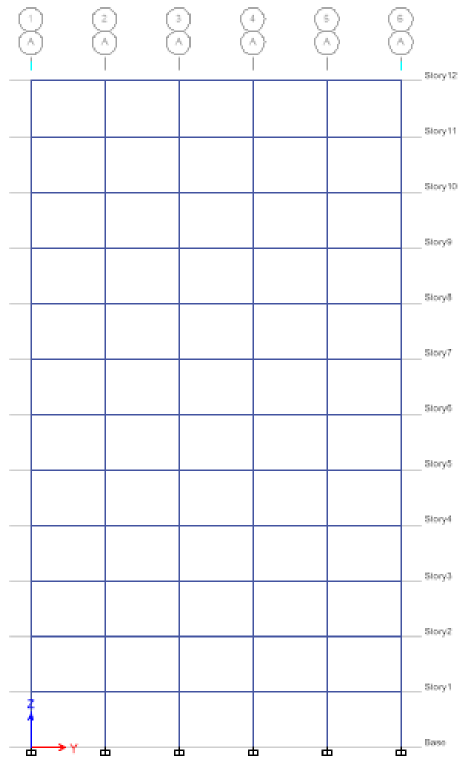

Figure1. SMRF Structural Model

Table1. SECTIONAL PROPERTIES OF BARE SMRF MEMBERS:

SECTIONS USED FOR BEAMS	SECTIONS USED FOR COLUMNS
W14×22	W33×130
W14×34	W40×249
	W40×324

2.3. NONLINEAR TIME HISTORY ANALYSIS

Nonlinear time-history analysis was conducted on ETABS to assess the performance of BRBF and BRBF–SMRF systems when subjected to ground motion records.

At first, the time history functions are defined wherein the time history database files of selected earthquakes are imported.

After defining the nonlinear model in load case, the Mass Source is assigned.

Mass Source factor for ***Dead Load is taken as 100% i.e. 1.*** And ***Live Load is taken as 25% of total live load*** **i.e. 0.25**.

The percentage of imposed load to be considered in calculation of seismic weight is taken from IS 1893 Part-1: 2016. For floor loads upto and including 3kN/m^2, percentage of imposed load is taken as 25%. And for distributed floor loads above 3kN/m^2, percentage of imposed load is taken as 50% as per IS 1893 Part-1:2016.

The mass multipliers assigned for load patterns are shown in the fig.2 below.

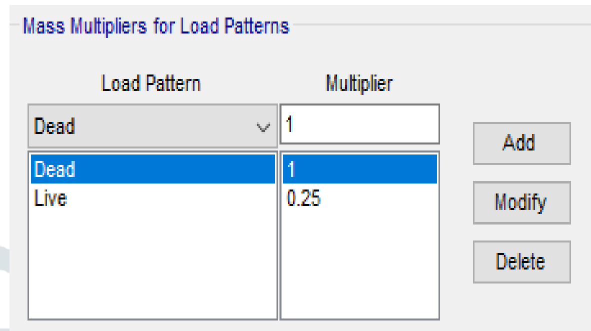

Figure2. Mass Multipliers for load patterns.

Then the Scale Factors for the three selected ground motion records were calculated.

The value of the scale factor should be:

$$SF = I \times g/(2R) \qquad (1)$$

Therefore, SF = 1.5×9.81/(2×5) = 1.47

In which, I is the Importance Factor. R is the Response Reduction Factor. And 'g' is acceleration due to gravitational force (=9.81).

After this, the ***constant damping is assigned as 5% of critical damping for the purpose of estimating A_h in the design lateral force V_B of a building*** as per clause 7.2.1 of IS 1893 Part-1:2016. Then the Time History Function is created and the analysis is run.

As some of the heavy sections failed under this analysis, therefore the need generates for designing the Buckling Restrained Brace

2.4. EARTHQUAKE EXCITATION

The three selected earthquake ground motion databases for nonlinear time history analysis were: Bhuj, Burma-India border and Imperial Valley. Then, these three time histories were then scaled according to IS: 1893 (Part I) (2002) for soil of type II in zone III and importance factor of 1.5. Response Reduction Factor considered for the analysis is 5 according to IS: 1893(Part I) 2002.

The details of the selected ground motion databases for time history analysis are shown in table2 below.

Table2. GROUND MOTION DATABASES:

EARTHQUAKE RECORDS	YEAR	EARTHQUAKE RECORD DESCRIPTION	RECORDING DIRECTION/COMPONENT	PGA (G)	SCALE
Bhuj, India	2001	Ahmedabad, India	N 78 E	0.106	0.9823
India–Burma Border	1988	Bokajan, India	S 56 E	0.2243	1.0002
Imperial Valley, CA	1979	USGS 952, El Centro Array 5	IMPVALL/H-E05140	0.4481	0.9664

2.5. DESIGN OF BUCKLING RESTRAINED BRACE

2.5.1. MANUAL DESIGN OF BRB

Factors such as seismic weight of each floor, zone factor, acceleration coefficient, modulus of elasticity, stiffness etc. are needed to be considered in the design of BRB.

According to IS 1893, a building located somewhere in India is considered. From the location of the building, values such as seismic zone factor (Z), importance factor (I), design acceleration coefficient

(S_a/g), response reduction factor (R) is then considered. From the values acquired, clause 6.4.2 of IS 1893 (Part 1): 2016 is used and design horizontal seismic coefficient (A_h) is obtained.

$$A_h = \frac{(Z/2)(S_a/g)}{(R/I)} \quad (2)$$

From the design horizontal seismic coefficient (A_h), design base shear (V_B) along any principle direction of the building is found. This is obtained by multiplying seismic weight of building (W) to the design horizontal seismic coefficient (A_h) as per clause 7.6.1 of IS 1893 (Part 1): 2016.

$$V_B = A_h W \quad (3)$$

After finding out the total design base shear, the lateral forces acting on each story is evaluated. The Lateral Load Distribution is the major factor affecting the design of Buckling Restrained Brace.

Lateral Load Distribution with height by the Static Method is done by following expression to which the base shear is multiplied to get the lateral load on each story.

Lateral forces on each story

$$= V_B \times (W_i h_i^2 / \sum W_i h_i^2) \quad (4)$$

For most practical purposes, an accurate estimate of the stability effects may be obtained by what is commonly referred to as P-delta analysis. Elaborating the name, P means the force acting on the body and delta means the horizontal displacement. This is basically a destabilizing effect. Seismic and wind loads also induce horizontal deflection in the members. If a uniformly distributed lateral load of 'f' per unit height H is applied to a flexural cantilever, the lateral displacement Δ at the top for a constant EI is:

$$\Delta = (0.125\, f\, H^4) / EI \quad (5)$$

Story drift is the difference of displacements between two consecutive stories divided by the height of that story and which should not be exceeded by 0.004 times the story height, under the action of design base shear V_B with partial safety factor for all loads taken as 1.0 as per IS 1893:2016 under clause 7.11.1.

Later design of buckling restrained braces is continued with basic stress formula i.e. stress is equal to force per unit cross sectional area, and on basis of area calculated the stiffness of bracing is calculated by following formula:

$$K_{brace} = (AE/L) \cos^2 \Theta \quad (6)$$

With the bracing stiffness calculated, column stiffness according to column end condition considered is added, to get total stiffness of structure. Stiffness of structure is governing parameter for the deflection of story. The deflection of story after placing of braces is then verified by following formula where, F is force acting, k is its stiffness, and x is deformation:

$$\mathbf{x = F / k_{total}} \qquad \mathbf{(7)}$$

Hence, it is known if the Buckling Restrained Brace provided is suitable or not. If the deformation of structure is cut down to large extent or even if optimization of sections is possible under this bracing then it means that the bracing provided are best suited to structure.

2.6. INSTALLING BRB TO THE EXISTING SMRF STRUCTURE

The SMRF was modified by installing Buckling Restrained Braces as shown in fig.3. In this research paper, mild steel hollow section filled with concrete is used as BRB.

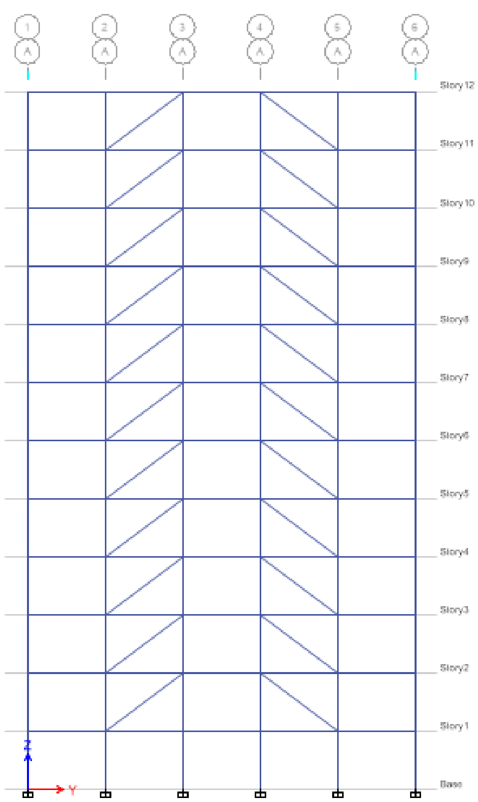

Figure3. SMRF Structural Model with BRB

The performance-based design of BRB is done using ETABS-2016. The grade of steel used for the core of BRB is Fe250 and the concrete that is filled in the hollow section is of M20 grade. The thickness of mild steel pipe and that of concrete infilled was decided according to the formulas given in Indian Standards. It is supported by single diagonal braces.

The sections become slender after installation of BRB in an SMRF structure. The sizes of beams and columns are reduced after installing BRB to SMRF building.

Table3. SECTIONAL PROPERTIES OF SMRF MEMBERS INSTALLED WITH BRB

SECTIONS USED FOR BEAM	SECTIONS USED FOR COLUMNS
W10×22	W27×129
W12×50	W27×336
	W36×247
	W36×247

As we know that, BRB is a structural brace in a building, designed to allow the building to withstand cyclical lateral loadings, typically earthquake-induced loading, this in turn lead to a reduction in member (column and beam) sizes given in table3. Also, BRBs are usually faster to erect than SCBFs, resulting in cost savings to the contractors. Also, an independent study concluded that the use of BRBF systems, in lieu of other earthquake systems, produced a cost per square foot savings of up to $5 per square foot.

3. RESULTS

On comparing the analysis that is carried out on SMRF structure with and without Buckling Restrained Brace on it as an energy dissipator, the following parameters for optimization of the structure are obtained.

3.1. STOREY DISPLACEMENT

Storey Displacement is the total displacement of i^{th} storey with respect to ground and its maximum permissible limit prescribed in IS codes for buildings. Here, the storey displacement along the height of the structure shows better performance in the case of modified SMRF with BRB. BRB being stronger Energy Dissipating Device, it has shown better performance at all floors.

It is observed that when compared for all the three earthquakes, the storey displacement of the modified SMRF with BRB building was comparatively lesser than that of the bare SMRF structure. Storey Displacement profile of the bare SMRF and modified SMRF with BRB of all earthquake time histories can be seen in figures 4, 5 and 6 below.

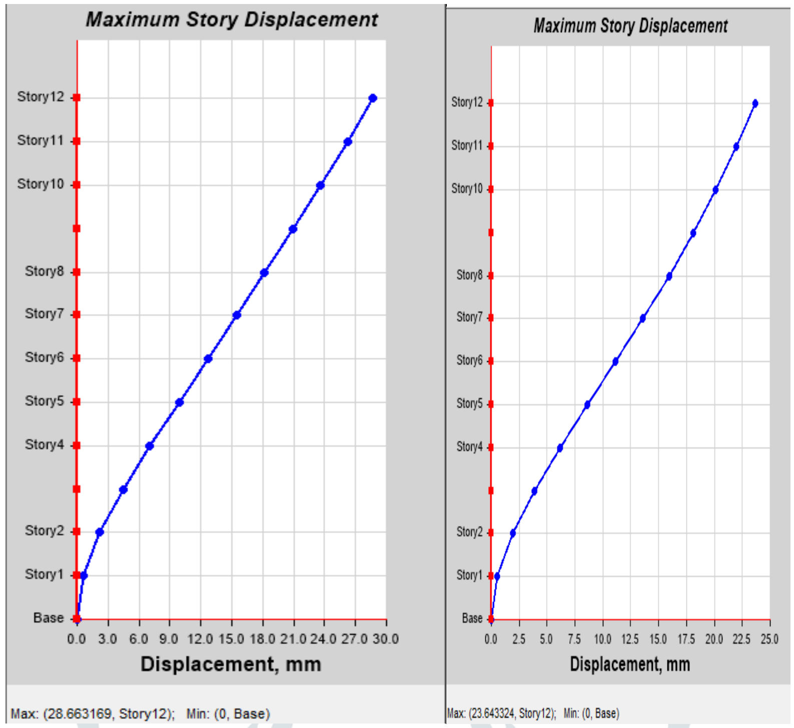

Figure4. Imperial Valley Earthquake Storey Displacement along the height of the structure of bare SMRF and SMRF with BRB.

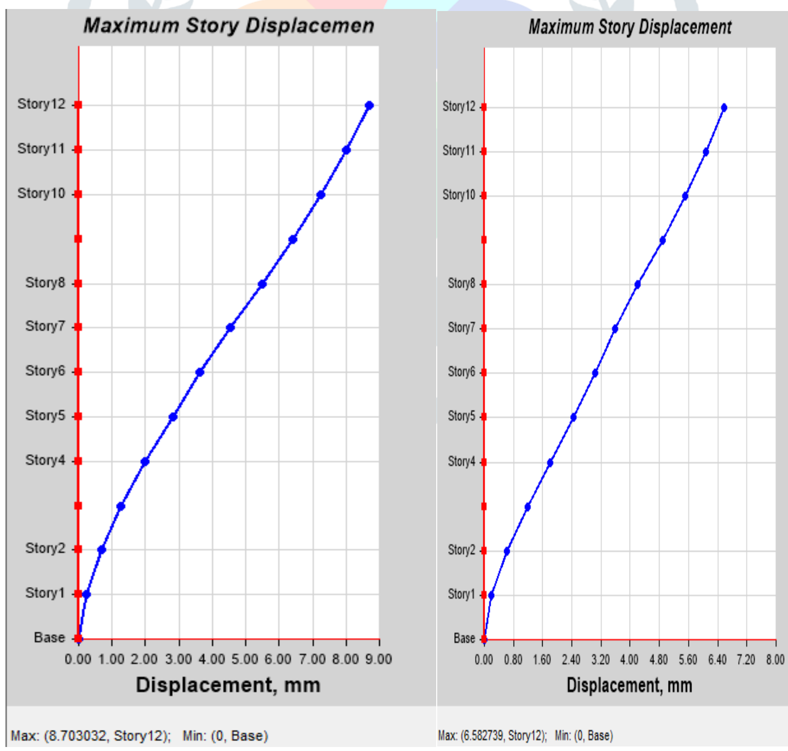

Figure5. India-Burma Border Earthquake Storey Displacement along the height of the structure of bare SMRF and SMRF with BRB.

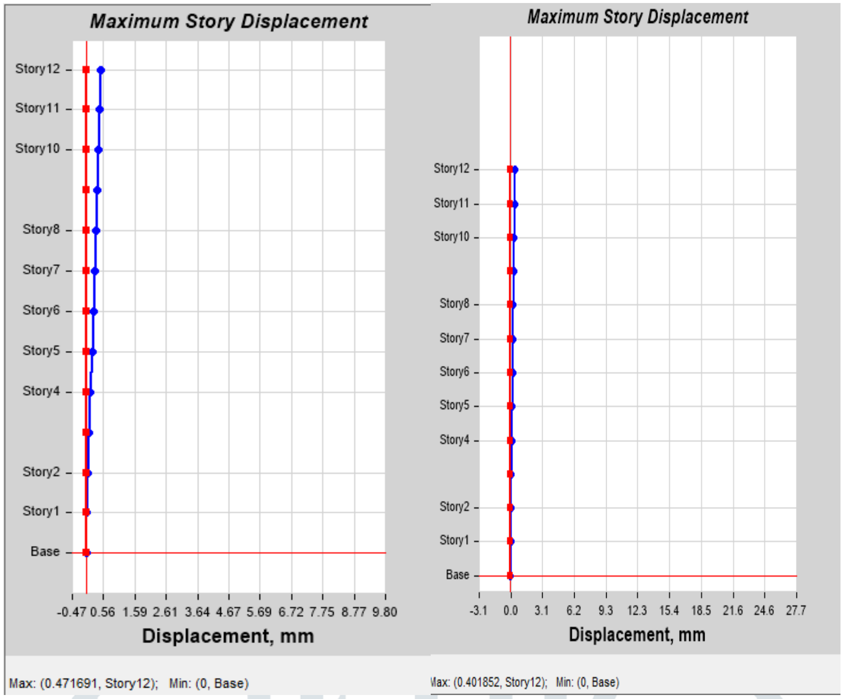

Figure6. Bhuj Earthquake Storey Displacement along the height of the structure of bare SMRF and SMRF with BRB.

3.2. ROOF DRIFT

The greater the drift, the greater is the damage. Peak interstory drift values larger than 0.06, indicates severe damage. It's seen that after installing BRB in the SMRF structure, there is a decrease in storey drifts as well as in the roof drift of the modified SMRF structure. There is a visible decrease in the roof drift of the structure. Modified SMRF with BRB has shown good performance in decreasing the roof drift by 22%.

3.3. BASE SHEAR

Base shear is the total horizontal seismic shear force at the base of structure. The results obtained from Nonlinear Time History Analysis regarding base shear along longitudinal direction for the model are presented in table4 for Imperial Valley Time history, Bhuj Time History and India-Burma Border Time History.

Table4. BASE SHEAR VALUES OF DIFFERENT EARTHQUAKE CASES

EARTHQUAKE CASE	BASE SHEAR OF BARE SMRF (KN)	BASE SHEAR OF SMRF WITH BRB (KN)
IMPERIAL VALLEY	105.06	189.27
BHUJ	17.21	9.81
INDIA-BURMA BORDER	480.83	302.75

3.4. OPTIMIZATION OF SECTIONS OF THE STRUCTURE

After placing BRB in the existing SMRF structure, the sections of the structure have become much slender as shown in table5. The sizes of beams and columns have reduced to some good extent, making the structure slender and also cost effective to the contractor.

Table5. SECTIONAL PROPERTIES OF FRAME MEMBERS

SMRF		SMRF with BRB	
Sections Used For Beams	Sections Used For Columns	Sections Used For Beams	Sections Used For Columns
W14×22	W33×130	W10×22	W27×129
W14×34	W40×249	W12×50	W27×336
	W40×324		W36×247

Table6. MODAL PROPERTIES FOR THE VARIOUS STRUCTURAL CONFIGURATIONS

STRUCTURAL SYSTEM	FIRST MODE PERIOD	FIRST MODE FREQUENCY
BARE SMRF	1.609	0.621
SMRF WITH BRB	1.652	0.605

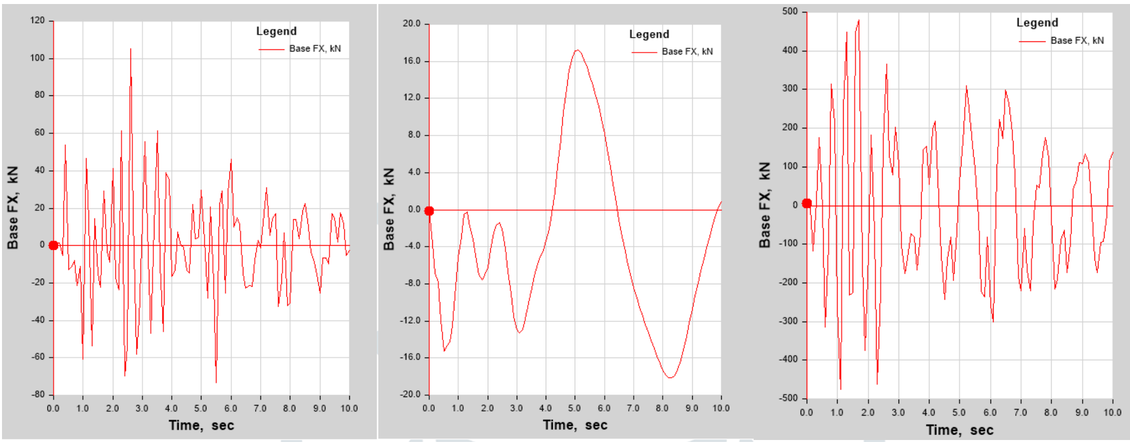

Figure7. Base Shear responses of Imperial Valley, Bhuj and India-Burma Border earthquakes respectively.

4. CONCLUSIONS

The structural optimization plays a vital role in today's highly competitive industry, where there is continuous increase in customer demand for superior quality, better safety and affordable Cost. The conventional ways of design development largely depend on excessive material Usage, very high design margins – hence, in turn ending up consuming more material into the Structures, buildings. Since last couple of decades, computational power is becoming more Efficient and affordable to everyone.

In current century, many construction projects all Over the world are going through financial crises because of high financial budgets. Time delay takes place, which in turn affects the growth of the construction of huge projects. In order to avoid time delay and thereby the growth, economic construction methodology should be adopted.

India is a developing country, huge construction projects are yet to come. For Large projects, it is necessary to go for structural optimization because it directly affects cost of Construction.

A procedure has been presented in this paper that combines performance-based seismic design methodology for optimizing member sizing of steel special moment resisting frames in accordance with design criteria and steel design criteria.

Buckling Restrained Bracings (BRB) are proven to be more effective in increasing the seismic performance of the structure than the conventional braced system.

This study has focused on the development of general multiobjective optimization procedures for performance-based seismic structural design. A simple structural model was used for seismic performance evaluation. With the change in sizes of columns and beams, the structure is economical. Also, the floor wise reduction of column sizes leads to more cost efficiency.

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