Retrofitting of Reinforced Concrete Frames using Steel Bracing

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Abstract— Steel braced frame is one of the structural systems used to resist earthquake loads in multi-storied buildings. Many existing reinforced concrete buildings need to retrofit to overcome the deficiencies to resist seismic loads. The use of steel bracing systems for strengthening or retrofitting seismically inadequate reinforced concrete frames is a viable solution for enhancing earthquake resistance. Bracing system reduces bending moments and shear forces in the columns. The lateral load is transferred to the foundation through axial action. Total weight of the existing structure will not change significantly after the application of the bracings. Steel bracing is economical, easy to erect, occupies less space and has flexibility to design for meeting the required strength and stiffness. The bracing system improves not only the lateral stiffness and strength capacity but also the displacement capacity of the structure. In the present study, the seismic performance of reinforced concrete (RC) buildings rehabilitated using concentric steel bracing is investigated. The bracing is provided for peripheral columns. A ten storey building is analyzed for seismic zone III as per IS 1893-2002 using ETABS 2015 Software. The models are retrofitted with various steel bracing systems on periphery columns storey-wise and analyzed for seismic forces. The building is analyzed for models with Diagonal bracing, 'V' type bracing, Inverted 'V' type bracing, Combined 'V' type bracing, 'X' type bracing, 'K' type bracing and compared with an un-braced frame. The effectiveness of various types of steel bracing in rehabilitating a ten storey building is examined. The effect of the distribution of the steel bracing along the height of the RC frame on the seismic performance of the rehabilitated building is studied. The main parameters in this study to compare the seismic analysis of buildings are lateral displacement, storey drift, axial forces in the columns, Base shear. The percentage reduction in lateral displacement is found out. It is found that the 'X' type of steel bracing significantly contributes to the structural stiffness and reduces the maximum storey drifts of the frames. The bracing systems improve not only the lateral stiffness but also the displacement capacity of the structure.

Key words: Earthquake Strengthening, Retrofitting, Steel Braced RC Structures, Seismic Performances, Analysis

I. OBJECTIVES OF THE STUDY

1) The present project work is aimed at evaluating the response of braced and un-braced structure subjected to seismic loads.
2) To compare the displacement and storey drift for different types of bracing systems.
3) To compare the variation in maximum lateral displacement for different types of bracing systems.
4) To compare the percentage reduction in lateral displacement for the braced frame to that of un-braced frame.
5) To identify the suitable bracing system for resisting the seismic load efficiently.
6) To study the behavior of building on influence of various types of bracing systems provided at the peripheral columns of the building.

II. LITERATURE REVIEW

Marc Badoux and James O. Jirsa, (1990) (1). " Steel Bracing of RC Frames for Seismic Retrofitting." J. Struct. Eng., 10.1061/(ASCE)0733-9445(1990)116:1(55), 55-74., The use of steel bracing systems for retrofitting seismically inadequate reinforced concrete frames is examined. Diagonal bracing provides an excellent approach for strengthening and stiffening existing buildings for lateral forces. A variety of retrofitting objectives, ranging from drift control to collapse prevention, can be achieved. The designer can determine the force path in the retrofitted structure and adjust the strength and stiffness as needed. An analytical study is performed to gain understanding into the behavior of a braced frame under cyclic lateral loading, particularly frames with weak short columns. Inelastic buckling of the braces influences detrimentally the inelastic cyclic behavior of a braced frame. Instability can be prevented by using braces that yield in compression or buckle elastically at low axial loads. The advantages of altering beams of a braced frame with weak short columns are described. The beam strength can be reduced to produce a more favorable (ductile) frame failure mechanism. Combining bracing with beam alterations can significantly improve inelastic behavior of the braced frame.

Nitin Bhojkar, Mahesh Bagade(2) "Seismic Evaluation of High-rise Structure by Using Steel Bracing System". In this paper, the seismic analysis of reinforced concrete (RC) buildings with different types of bracing is studied. A G+9 building is analyzed for seismic zone III as per IS 1893: 2002 using STAAD Pro software. The main parameters consider in this paper to compare the seismic analysis of buildings are lateral displacement, story drift, axial force, base shear. It is found that the X type of steel bracing significantly contributes to the structural stiffness and reduces the maximum inter-storey drift of the frames. The bracing system improves not only the lateral stiffness and strength capacity but also the displacement capacity of the structure.

Mahmoud Reza Maheri A. Sahebi(3) "Use of steel bracing in reinforced concrete frames". In this paper the use of steel bracing in concrete-framed structures is investigated. The investigation is carried out through a series of tests conducted on a number of model frames. The object of the tests was to determine the degree of effectiveness of different diagonal bracing arrangements to increase the the in-plane shear strength of the concrete frame and to observe the relative behavior of tension and compression braces. The important question of the proper connections between the steel braces and the concrete frame is also considered. The test results indicate a considerable increase in the in-plane strength of the frame due to steel bracing. As an overall conclusion it is noted that, with proper connection between the brace and the frame, the steel bracing could be a viable alternative or supplement to shear walls in concrete framed buildings in seismic areas.

Nauman Mohammed, Islam Nazrul(4) "Behavior of Multi-storey RCC Structure with Different Type of Bracing System (A Software Approach)" evaluated the response of braced and un-braced structure subjected to seismic loads and to identify the suitable bracing system for resisting the seismic load efficiently. After the analysis of the structure with different types of structural systems, it has been concluded that the displacement of the structure decreases after the application of bracing system. The maximum reduction in the lateral displacement occurs after the application of cross bracing system. Bracing system reduces bending moments and shear forces in the columns. The lateral load is transferred to the foundation through axial action. The performance of cross bracing system is better than the other specified bracing systems. Steel bracings can be used to retrofit the existing structure. Total weight of the existing structure will not change significantly after the application of the bracings

Viswanath K.G, Prakash K.B, Anant Desai(5) "Seismic Analysis of Steel Braced Reinforced Concrete Frames" The seismic performances of reinforces concrete (RC) buildings rehabilitated using steel bracing is investigated. The bracing is provided for peripheral columns. A four storey building is analyzed for seismic zone IV as per IS 1893-2002 using STAAD.Pro Software. The effectiveness of various types of steel bracing along the height of the RC frame on the seismic performances of the rehabilitated building is studied. The performances of the building are evaluated terms of global and story drifts. The study is extended to eight storied twelve storied and sixteen storied building. The percentage reduction in lateral displacement is found out. It is found that the X type of bracing significantly contributes to the structural stiffness and reduces the maximum inter-storey drift of the frames.

III. Introduction

A. Seismic Retrofitting

Seismic retrofitting is the modification of existing structures to make them more resistant to seismic activity, ground motion, or soil failure due to earthquakes. With better understanding of seismic demand on structures and with our recent experiences with large earthquakes near urban centers, the need of seismic retrofitting is well acknowledged. Prior to the introduction of modern seismic codes in the late 1960s for developed countries (US, Japan etc.) and late 1970s for many other parts of the world (Turkey, China etc.), many structures were designed without adequate detailing and reinforcement for seismic protection. In view of the imminent problem, various research works has been carried out. State-of-the-art technical guidelines for seismic assessment, retrofit and rehabilitation have been published around the world. The retrofit techniques outlined here are also applicable for other natural hazards such as tropical cyclones, tornadoes, and severe winds from thunderstorms. Whilst current practice of seismic retrofitting is predominantly concerned with structural improvements to reduce the seismic hazard of using the structures, it is similarly essential to reduce the hazards and losses from non-structural elements. It is also important to keep in mind that there is no such thing as an earthquake-proof structure, although seismic performance can be greatly enhanced through proper initial design or subsequent modifications.

B. The Retrofitting Process

1) Decision to Brace a Structure

The main steps in the process leading to retrofitting a structure with a steel bracing scheme are, the evaluation of the seismic adequacy of the structure (step 1) consists of comparing Performance requirements with expected behavior under seismic loads. If the structure is found inadequate (step 2), the owner must choose between retrofitting or replacement (step 3). The retrofitting scheme must be designed to correct deficiencies in the existing structure; that is, lack of strength, stiffness, or ductility (step 4). The retrofitting scheme should also be considered in terms of its impact on aesthetic qualities and on the usability of the building during and after construction. Bracing may be combined with other retrofitting techniques. For example, bracing of perimeter frames may be used with column strengthening or infill shear walls in interior frames.

2) Design of the Bracing System

The choice of the bracing system configuration (step 6) includes selecting frames and bays to be braced and selecting bracing patterns. Changes in the force distribution in the existing structure must be considered to avoid overloading certain members, or introducing torsional eccentricities in the plan of the structure, or within the braced frames. Once a configuration has been chosen, the bracing system can be designed and detailed (step 7). To maximize the drift range in which the braced frame responds elastically, brace slenderness should be low and drift levels at which the frame and the bracing system suffer significant damage should be kept as similar as possible. If columns function as vertical elements of the bracing system, they must be able to carry the additional loads. Connections of the bracing system must be detailed (welds, bolted joints) carefully to avoid local failures under inelastic cyclic deformations. The foundations of the braced frames may need strengthening because the retrofitted structure typically imposes greater forces on foundations. In the construction phase of a retrofitting scheme (step 8), allowance should be made for higher fitting tolerances and for in-situ modifications.

A steel bracing system can be inserted in a frame to provide lateral stiffness, strength, ductility, hysteretic energy dissipation, or any combination of these. The braces are effective for relatively more flexible frames, such as those without infill walls. The braces can be added at the exterior frames with least disruption of the building use. For an open ground storey, the braces can be placed in appropriate bays while maintaining the functional use. Passive energy dissipation devices may be incorporated in the braces to enhance the seismic absorption. The types of bracing, analysis and design of braces must be considered. The connection between the braces and the existing frames is an important consideration of this strategy.

IV. DESCRIPTION OF THE SAMPLE BUILDING

Type of frame	Reinforced Concrete Frame
RC building	10 Storey building
Storey height	3 mts
Beam size	0.23 m x 0.30 m.
Column size	0.23 m x 0.60 m
Thickness of slab	0.125 m
Thickness of brick wall over all floor	0.230 m
Steel bracing used	ISA 110X110X10 mm
Live load	3 KN/m^2
Floor finish load	1 KN/m^2
The unit weight of concrete	25 KN/m^3
Unit weight of brick masonry	20 KN/m^3
The compressive strength of concrete	25 N/mm^2
Yield strength of steel	415 N/mm^2
Seismic Zone	III
sub-soil type	2 (medium)
Importance factor	1
Response Reduction Factor	3
Method of Analysis	Linear Static Analysis

Table 1: Description of the Sample Building

- Seismic analysis is carried out on building models using the software ETABS 2015.
- The load cases considered in the seismic analysis are as per IS 1893 – 2002.

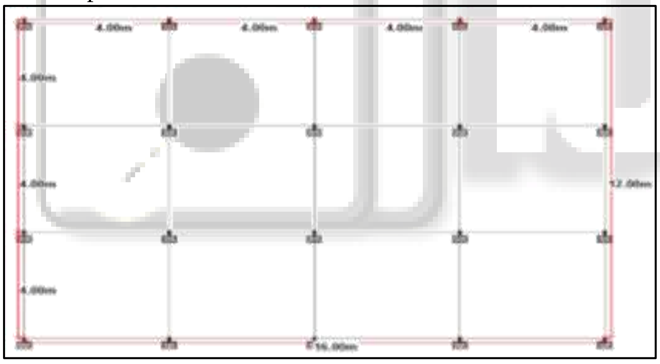

Fig. 1: Plan of the Building

- Model 1 10 Storey Building without bracing
- Model 2 10 Storey Building with ‘X’ bracing
- Model 3 10 Storey Building with Diagonal bracing
- Model 4 10 Storey Building with ‘V’ type bracing
- Model 5 10 Storey Building with Inverted ‘V’ type bracing
- Model 6 10 Storey Building with combined V bracing
- Model 7 10 Storey Building with ‘K’ type bracing

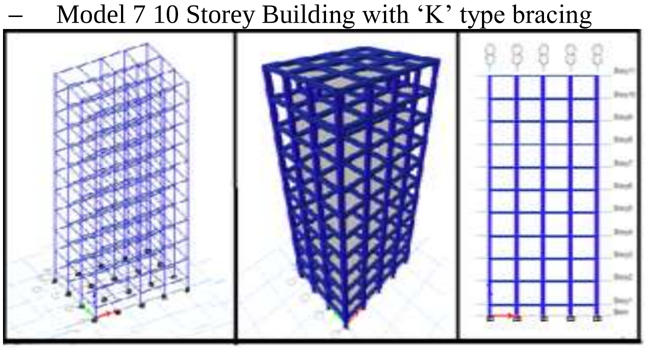

Fig. 2: Model 1 (Unbraced)

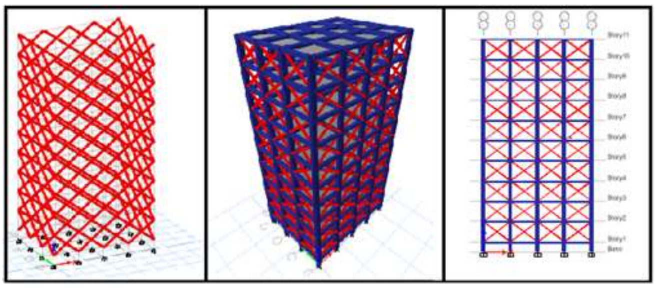

Fig. 3: Model 2 ('X' Bracing)

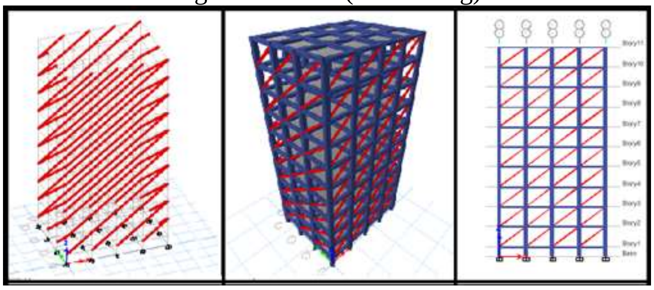

Fig. 4: Model 3 (Diagonal Bracing)

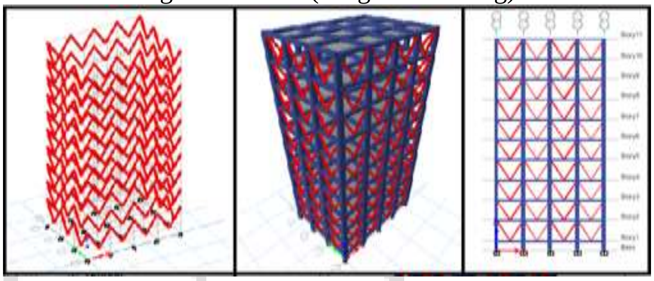

Fig. 5: Model 4 ('V' Bracing)

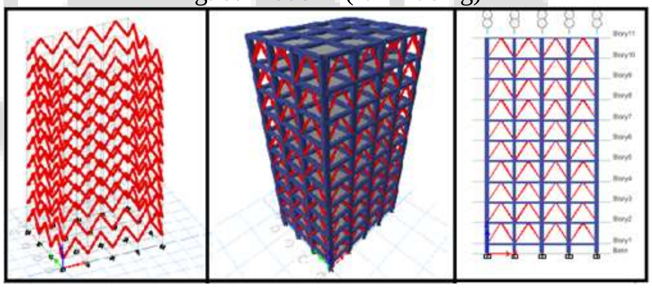

Fig. 6: Model 5 (Inverted V Bracing)

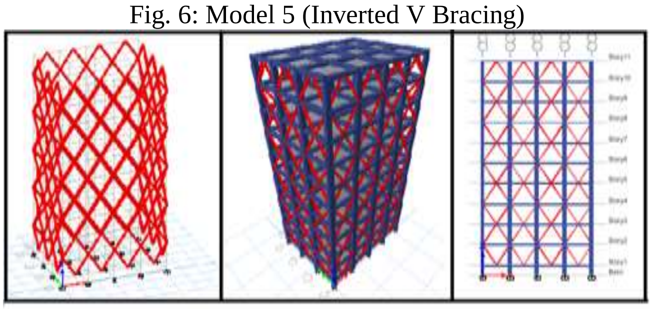

Fig. 7: Model 6 (Combined V Bracing)

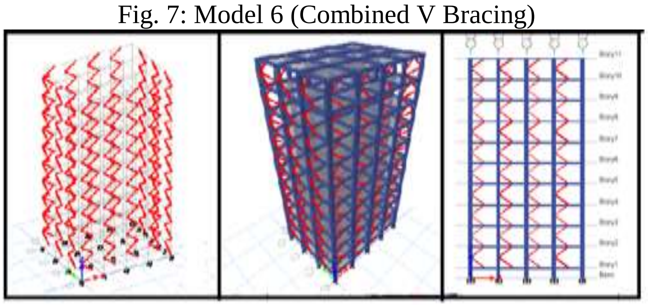

Fig. 8: Model 7 (‘K’ Bracing)

V. RESULTS & DISCUSSIONS

A. Lateral Displacement

It is observed that the lateral displacement is reduced to largest extent for X type of bracing systems, while the displacement is maximum for the un-braced system. The displacement is reduced sequentially for bracing type Inverted V, combined V, V type diagonal bracing and K bracing. These patterns are observed due to increased stiffness provided by the respective bracings. Top roof displacement for the system with X bracing is reduced by 66.66% in X direction as compared to that of un-braced system.

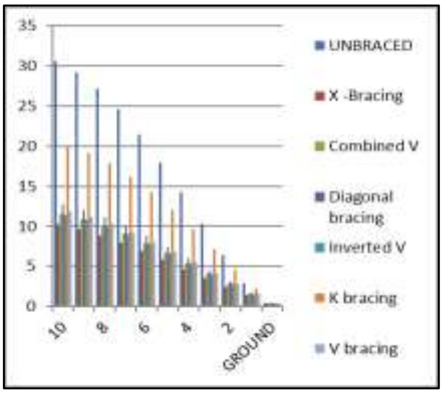

Fig. 9: Maximum Lateral Displacement (mm) in X Direction

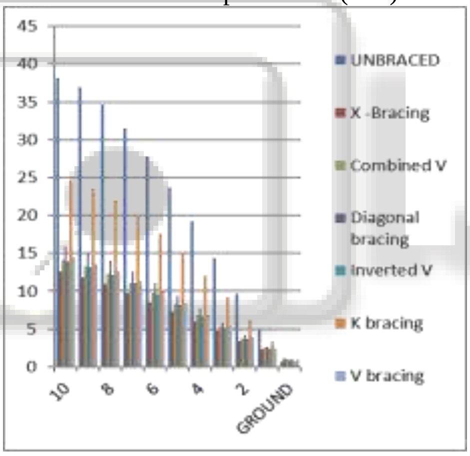

Fig. 10: Maximum Lateral Displacement (mm) in Y Direction

B. Story Drift

It can be observed from the graph that the story drifts are reduced to largest extent for X type of bracing systems, while these are maximum for the system without bracing.

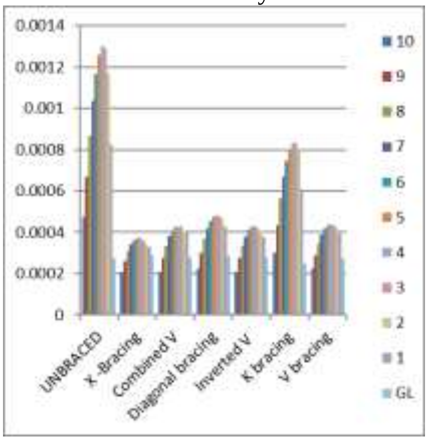

Fig. 11: Story Drift in X- Direction

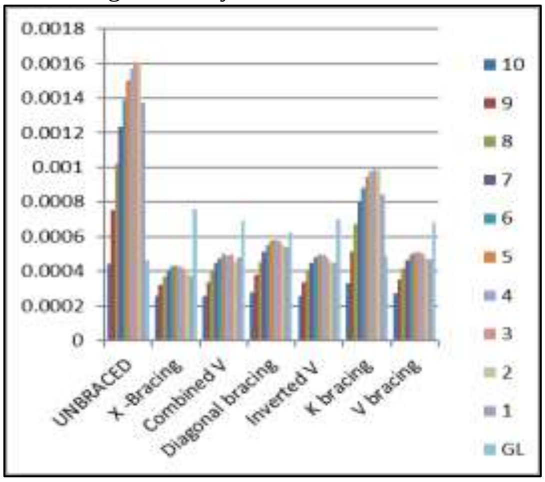

Fig. 12: Story Drift in Y-Direction

C. Axial Forces

It can be observed from the graph that the axial forces are maximum for X type of bracing systems, while these are minimum for the system without bracing. The axial forces are increased sequentially for bracing type K bracing, diagonal bracing, V type, combined V, Inverted V and X bracing. Axial force at the ground floor level column for the system with X bracing is 2075.9 kN while these are minimum for the system without bracing i.e, 1380.9. The percentage increase in axial forces when compared un-braced and X bracing is 50.32%.

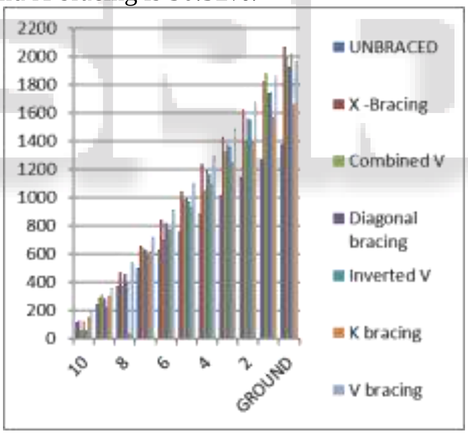

Fig. 13: Axial Forces

D. Base Shear

it is observed that the Base Shear is maximum for X type of bracing systems, while it is minimum for the un-braced system. The Base Shear are increasing sequentially for K bracing type, diagonal bracing, V type, combined V, Inverted V and X bracing.

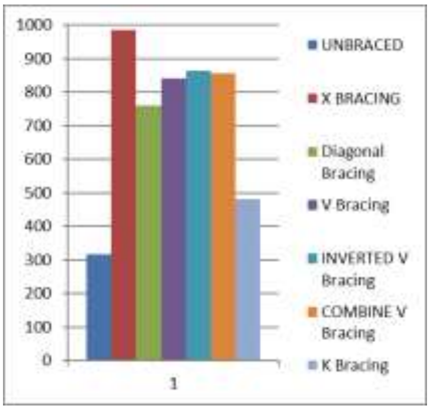

Fig. 14: Base Shear in X-Direction

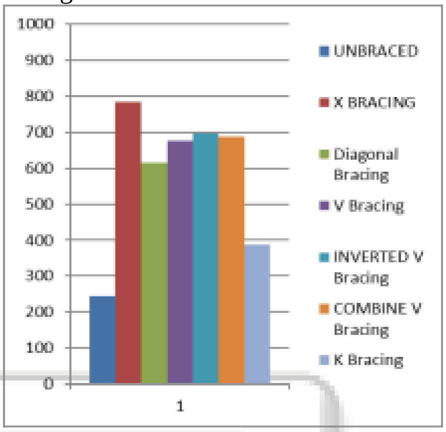

Fig. 15: Base Shear in Y-Direction

VI. CONCLUSIONS

After the analysis of the structure with different types of structural systems, it has been concluded that the displacement of the structure decreases after the application of bracing system. The maximum reduction in the lateral displacement occurs after the application of cross bracing system. The lateral load is transferred to the foundation through axial action. The performance of cross bracing system is better than the other specified bracing systems. Steel bracings can be used to retrofit the existing structure. Total weight of the existing structure will not change significantly after the application of the bracings. It is concluded that arrangements of bracing systems has considerable effect on seismic performance of the building. From all six arrangements of bracing system, arrangement with X bracing system gives better performance. Steel bracings can be used as alternative techniques for retrofitting.

Following are the conclusions of the study,

1) Steel bracing system shows the efficient and economical measures for RC multi-story buildings located in high seismic regions.
2) Lateral displacements and storey drifts are minimum for inverted V braced frame as compared to V braced frame.
3) Top roof displacement for the system with X bracing is reduced by 66% in X direction and 67.01 % in Y direction as compared to that of without bracing system.
4) Stiffness of the building is increases.
5) Story drifts and lateral displacements reduces using X type of bracing systems.
6) The axial force is maximum for X bracing system is up to 50%.
7) The concept of using steel bracing is one of the advantageous concepts which can be used to strengthen or retrofit the existing structures.
8) Steel bracings also reduce flexure and shear demands on beams and columns and transfer the lateral loads through axial load mechanism.
9) The building frames with X bracing system will have minimum possible bending moments in comparison to other types of bracing systems.

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