Analysis of Retrofitting of a Reinforced Concrete Frames Using Steel Bracings

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Abstract: *Earthquake is one of major natural disaster in which many structures damage and collapse due to unacceptable or improper design against seismic motion. The government and some other NGOs are also working in the field to create awareness for the seismic designing of new construction building especially in seismic susceptible areas but they are not considering the seismic resistance of the old buildings as it should be considered. The main objective of this project is to protect the new as well as the old buildings by designing it as earthquake resistant structure. Retrofitting is the procedure of improvement that enables the old structure to resist the force of consideration where Seismic Retrofitting is the improvement over the old structures that enables the structure to resist seismic action. The concept used in this project is base isolation. 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 bracing is provided for peripheral columns. An existing multi-storey building is analyzed for seismic zone III as per IS 1893-2002 using ETABS 2015 Software.*

Keywords: Earthquake Strengthening, Retrofitting, Steel Braced RC Structures, Seismic Performances, Analysis.

INTRODUCTION

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.

OBJECTIVE OF THE WORK

- **To evaluate the effect of wind load on braced and unbraced structures.**
- **To introduce X bracing retrofit techniques to the structure.**
- **To analyse the responds of building after introducing retrofitting.**
- **To compare evaluation of wind load efficiency of X bracing for steel structures.**

LITERATURE REVIEW

- **Lee et al. (2010)** retrofitted the beam-column joint using carbon fiber reinforced polymer (CFRP) to enhance the strength and stiffness of the beam-column joints. A total of three interior beam column joints were tested for the purpose. They were designated as JI0 (prototype), and JI1- JI2 (strengthened specimens). Retrofitting method for specimens JI1 and JI2. To avoid the de-bonding of the CFRP laminate, anchorage was used for one of the specimens, JI2 only but it was not used in specimen JI1. The experimental results showed that the behaviour of the specimen JI1 strengthened with CFRP was similar to that of specimen JI0 with only a 4% increase in ultimate strength. This indicates that the CFRP retrofitting without anchoring did not significantly improve the shear resistance of the retrofitted beam-column joint. While in JI2 specimen, with appropriate anchoring, it was found that anchoring had an important role in preventing the premature de-bonding of CFRP and thus upgrading the shear resistance of the retrofitted beam-column joint.

- **Bousselham (2010)** presented a review of published experimental studies on the seismic retrofitting of reinforced concrete beam-column joints using FRP. In total fifty-four tests carried out worldwide were considered for the review. The author observed that, the test results showed enhancement, due to FRP bonding, in terms of strength, ductility, and energy dissipation, whereas degradation in stiffness was observed with FRP retrofitting. The experimental results clearly show the important role of mechanical anchorage systems in the mode of failure. In comparison to the effectiveness of carbon versus glass fibers, the study concluded that glass fibers sheets proved marginally more effective than carbon fiber sheets.

- **Sharma et al. (2010)** tested full scale reinforced concrete structures to failure and then repaired and retrofitted using a combination of GFRP and CFRP. The structure shown in the figure was tested earlier using pushover loads till failure, then retested after retrofitting. It was reported that the structure was not able to reach 90% of the base shear in comparison to original the structure and the stiffness of the retrofitted structure was reduced. De-bonding was quite obvious due to unevenness of the surface. Although, due to prevention of spalling of concrete, the joint behaviour did improve but the failure of the structure could not be prevented.

- **Li and Chua (2009)** studied the experimental results of the effects of different methods of wrapping of the CFRP and GFRP sheets for strengthening non-seismically designed interior beam-column joints, subjected to seismic loadings. Figure shows the proposed FRP strengthening methods. A comparison of strength, stiffness and energy dissipation capacity of retrofitted ones showed a tremendous increase as compared to control specimens and it was found that the use of CFRP strips on strong-column weak-beam it was effective in improving the flexural strength. It was also noted that beam retrofitting in the form of FRP U-wrapping was necessary in preventing shear failure in the beam. These proposed strengthening schemes were very helpful in eliminating or delaying the shear mode of failure.

- **Ludovico et al. (2008)** performed experimental tests on the seismic behavior of a full-scale reinforced concrete structure retrofitted by GFRP laminates to find the effectiveness of different retrofit methods. The structure was designed for typical housing building in earthquake-prone areas of Europe, wherein, the structures designed had poor detailing, lacked a sufficient number of rebars, and had insufficient confinement with weak joints. In order to prevent brittle shear failure of the beam-column joints due to increased ductility of the columns, further FRP retrofit was designed on beam-column joints according to the approach proposed by Antonopoulos and Triantafillou in 2002**.** It was observed that the retrofitted beam- column joints were almost undamaged after the testing, while the original beam-column joints (without retrofit) showed significant damage on columns.

- **Gergely et al. (2000)** showed the experimental results of fourteen 1/3-size scale RC concrete T- joints with FRP composite materials. Four specimens were tested in as-built condition and the other were externally reinforced with CFRP sheets. It was observed that the failure of the control specimens was identical and diagonal tension cracks in the joint region were also observed. The FRP retrofitted specimens showed an increase in the maximum composite capacity but this load level could not be sustained. This showed the failure of specimens at lower loads with bending moments more than the element's capacity. Excellent performance was shown by water jetting the concrete surface with high strength adhesive, but there was no evidence of better joint shear improvement by using an elevated temperature cure system. Debonding of the inclined FRP sheets was also observed from the top and bottom of the joint. Debonding occurred at stress levels of only 1/5th of the composite's capacity. Because the concrete in the joint could resist the diagonal compression forces, there were no significant compression stresses in the inclined composite layers.

- **Akguzel and Pampanin (2010)** tested the effects of axial load with variation on the column due to lateral sway of the frame on the performance of jacketed RC beam-column joints. For this purpose, four 2/3-scale exterior RC beam-column joints, including one as-built and three retrofitted with different configurations, were tested under changeable axial load. RC joints were retrofitted using GFRP sheets as per the configuration. On testing the GFRP retrofitted specimen under axial load, a few hairline cracks were observed in both the column faces as well as in the joint area. No debonding or damage in the joint of the GFRP sheet was observed. In other specimens which were tested under the varying axial load systems, a hybrid failure mechanism was observed. A gradual debonding of the GFRP sheet in the joint area and damage to the joint concrete core was observed.

- **Mukherjee and Joshi (2005)** examined the performance of FRP in up progression of RC joints, with adequate and deficient reinforcements, after rehabilitation of damaged joints. Two sets of joints, one with adequate steel reinforcement and proper detailing of reinforcement at the critical sections known as ductile specimens and another set of specimens with deficient bond lengths of the beam reinforcements at the joint with the columns, known as non-ductile specimens, were tested. All the specimens were strengthened by using carbon and glass FRP materials. The control specimens were used after testing to evaluate the rehabilitation of joints with FRP known as rehabbed specimens. It was observed that the ductile specimens showed higher load at yield in the FRP reinforced specimens than the control specimen and, for the same tip load, the tensile force in steel was lower in the CFRP retrofitted specimen than in the GFRP specimens.

- **Ghobarah and El-Amoury (2005)** compared the results of retrofitted RC beam-column joints with existing joints designed as per the pre-seismic codes to assess the efficacy of the proposed retrofitting techniques. A total of six RC joints, cast with non-ductile reinforcement detailing, were subjected to replicate seismic forces. Specimens T-B12 and T-B11, having as inadequate anchorage length of the bottom beam bars, were retrofitted with CFRP sheets attached to the bottom beam face. Specimen T-SB8-TSB7 having no steel ties installed in the joint region in addition to inadequate anchorage length of the beam bars were retrofitted by GFRP sheets at the joint zone with steel rods or plates. The retrofitted techniques shown excellent results for eliminating the brittle joint shear and steel bar bond-slip failure modes. In the cases of specimens TB-12 and TB-11, CFRP sheets were very effective in replacing the anchorage deficient beam bars when an adequate anchorage system of these sheets was provided. In case of specimen T- SB8 andT-SB7, GFRP retrofitting was found to be an effective system to provide confinement with shear strength to shear-deficient joints.

- **Prota et al. (2004)** tested eleven one-way interior RC beam-column joints with three different levels of axial load and used CFRP rods in combination with externally bonded sheets in an attempt to shift the failure first from the column to the joint, then from the beam-column joint to the beam. The CFRP sheets were placed in epoxy-filled grooves prepared near the surface. The failure modes could not be controlled as planned so ductile beam failure cannot be achieved. In the case of Type-2 joints design moved the failure from the compression to the tension side of the column for low column axial load and a combined column-joint failure occurred. In case of Type-3 the addition of CFRP sheets as flexural reinforcement along the column led to a beam-column joint shear failure. In the case of Type-4, when the joint panel was also retrofitted the beam column-joint interface failed, which was attributed to extinction of the CFRP sheet reinforcement at the joint to account for the presence of a floor system. The Type-5 scheme with U-wrapping of the beam and beam-column joint showed in a failure mode similar to that of Type- 4.

- **Antonopoulos and Triantafillou (2003)** examined tests on eighteen exterior beam-column joints of 2/3-scale retrofitted with different configurations of pultruded carbon strips and with GFRP sheets. The examined variables were distribution of FRP, area fraction, column axial load, joint reinforcement (internal), initial damage level, comparative of CFRP and GFRP, sheets versus strips, and effect of transverse stub beams. All the eighteen specimens were designed to fail at joint shear, before and after retrofitting so that the contribution of FRP retrofitting could be evaluated. The result showed an increase in column axial load from 4% to 10% of its initial load capacity, 65% to 85% increase in strength and 50% to 70% increase in energy, and a 100% increase in stiffness 100% of which varied in each loading cycle.

- **El-Amoury and Ghobarah (2002)** modified the GFRP methods used by Ghobarah and Said (2002), for strengthening of beam-column joints using both inadequate anchorage of beam bottom bars with no hoop shear reinforcement. Both methods showed approximate by a 100% increase in load carrying capacity; specimen TR1 and TR2 dissipated three and six times the energy dissipated by the reference specimen, respectively. In the case of specimen TR1 the failure was due to complete debonding of GFRP from the beam and column surfaces with pullout of the bottom bars in the beam led by fracture of the weld around the bolt heads. In the case of specimen TR2 debonding was eliminated with the use of two U-shaped steel plates of the GFRP and it failed in joint shear.

- **Ghobarah and Said (2001)** used FRP to upgrade the shear capacity of beam-column joints and allowed the ductile flexural hinge to form in the beam. The RC joint T1 (control specimen) with no transverse reinforcement tested and retrofitted with one layer of bidirectional GFRP laminate in the form of a U. The free ends of the U were tied together using threaded steel rods and a steel plate driven through the joint section being re-designated as T1R.

- **Ghobarah and Said (2002)** examined 4 one-way exterior joints, originally designed to fail in joint shear with or without retrofitting by unidirectional or bi directional GFRP sheets inclined at 45 degrees. Previously damaged specimens T1R and T2R were retrofitted with mechanical anchorage provided by steel plates and threaded rods core-drilled through the joint. The GFRP sheet anchored through the joint in the case of specimen T1R was efficient until it failed in tension, but same showed no improvement in the case of specimen T4 due to a lack of threaded rod anchorage showing early de-lamination. The failure in the beam was due to the formation of a plastic hinge. No debonding or joint shear cracking was observed in the case of specimen T2R.

- **Akguzel and Pampanin (2012)** developed an analytical model for the control and FRP retrofitted reinforced concrete beam-column joints. Firstly the in-built beam-column (BC) joint components were assessed. The shear strength of the FRP jacketed beam-column joints was calculated with sum of the as-built BC joints and the composite material attached to the plain concrete. A schematic illustration with the nomenclature used in the design of the average stresses.

- **Mahini and Ronagh (2010)** developed an analytical model to calculate the ultimate load, yield load and ductility of beams using FRP retrofitting. Compression failure, tension failure, de- bonding and FRP rupture of FRP retrofitted beams were considered in the flexural failure. In derivation de-bonding was not considered as it was not observed in experimental tests. Moment and curvature graphs were drawn using a trial and error procedure for three stages of cracking i.e. pre-cracking, cracking and post-cracking. For the small differences between the two values only estimated values were established or else these values were customized by the bisection method till convergence occurred using equations. reinforced concrete beam cross-section retrofitted using FRP, where b is the width and h is the height of the section, it *was* considered as the thickness of FRP with ff as stress.

- **The Pantazopoulou and Bonacci (1992)** model was extended by the authors in the study. The stress-strain equations were provided for various stages defined by FRP debonding and concrete crushing. The developed models provided valuable information on the shear capacity of FRP retrofitted joints in terms of the quantity and design of the externally bonded fiber. Good agreement of experimental results and analytical models was found in the form of shear-strength predictions found in the literature.

- **Antonopoulos and Triantafillou (2002):** offered analytical models for analysis of RC joints retrofitted with externally bonded composite materials in the form of unidirectional strips. Stress and strain were provided in the models for the various stages.

- **Ghobarah and Said (2001):** proposed a design methodology for upgrading the joint shear capacity with fiber retrofitting of existing RC joints in moment resisting frames. In the joints the missing transverse reinforcement was replaced with the fiber.

- **Gergely et al. (2000):** proposed design for the strengthened RC joints based on the experimental results. To calculate the horizontal and vertical shear forces in the joint region the forces acting at the face of the column and the beam were considered.

- **METHODOLOGY:**
  - Existing typical floor plan developed in AUTOCAD
  - Modelling and Analysis in Etabs Importing to ETABS
  - Loads on the structure:
    - Dead load
    - Live load
  - Building retrofitted for Rc frames using bracing.
  - Design of RC frames using IS code.
  - Conclusion

  - **Existing typical floor plan developed in AUTOCAD**: Developing a 2D plan for G+6 building using Auto Cad.
  - **Modelling and Analysis in Etabs**: In this present study, existing structure is modeled as a 3-diminesional frame at braced and unbraced structure using ETABS.
  - **Loads on the structure:**
    1. DEAD LOAD: The dead loads are taken from IS 875 Part 1(Dead Loads). The dead loads comprise the weights of walls, partitions, floor finishes, false ceilings, false floors and other permanent constructions in the buildings.
    2. LIVE LOAD: The live loads are taken from IS 875 Part II (Live Loads).
  - **Building retrofitted:** The designed structure is retrofitted using bracing.
  - **Design of RC frames using IS code:** The RC frame is designed according to IS codes for concrete and steel.
  - **CONCLUSION AND RESULT**: conclusion taken from the validation of Analysis results

DESCRIPTION OF THE SAMPLE BUILDING

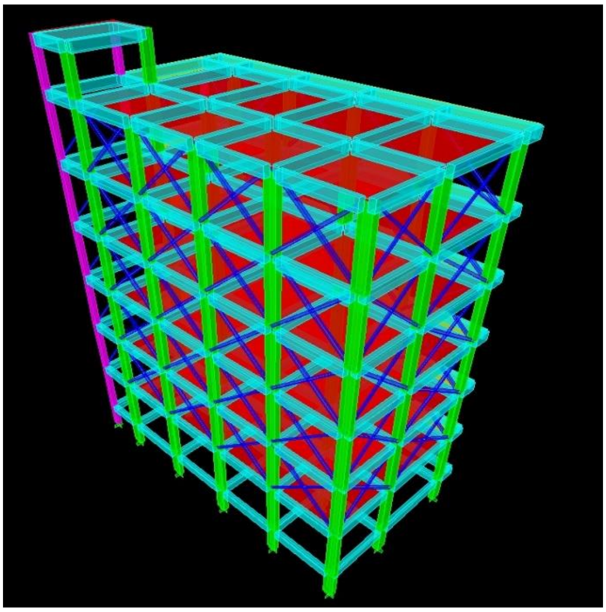
Type of frame	Reinforced Concrete Frame
RC building	6 Storey building
Storey height	3 mts
Beam size	0.23 m x 0.45 m.
Column size	0.23 m x 0.45 m
Thickness of slab	0.125 m
Thickness of brick wall over all floor	0.23 m
Steel bracing used	ISA 110X110X10 mm
Live load	2 KN/m^2
Floor finish load	1.5 KN/m^2
The unit weight of concrete	25 KN/m^2
Concrete mix	M_{20}
Unit weight of brick masonry	18 KN/m^2
The compressive strength of concrete	25 N/mm^2
Yield strength of steel	415 N/mm^2
Diaphragm	Rigid
sub-soil type	2 (medium)
Importance factor	1
Response Reduction Factor	3
Method of Analysis	Linear Static

	Analysis

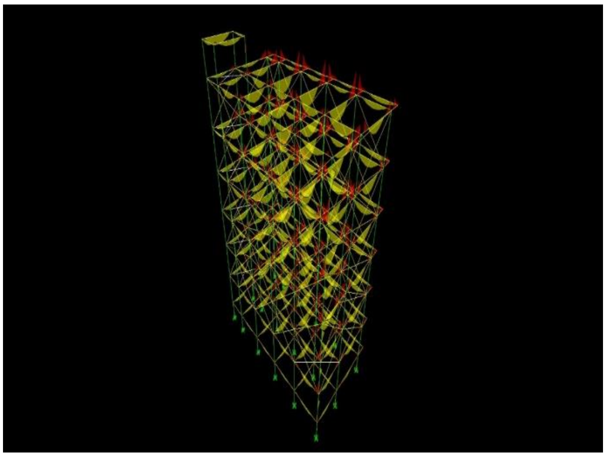
Table : Description of the Sample Building

- Wind load analysis is carried out on building models using the software ETABS 2013.
- The load cases considered in the wind load analysis are as per IS 875 – 1987.

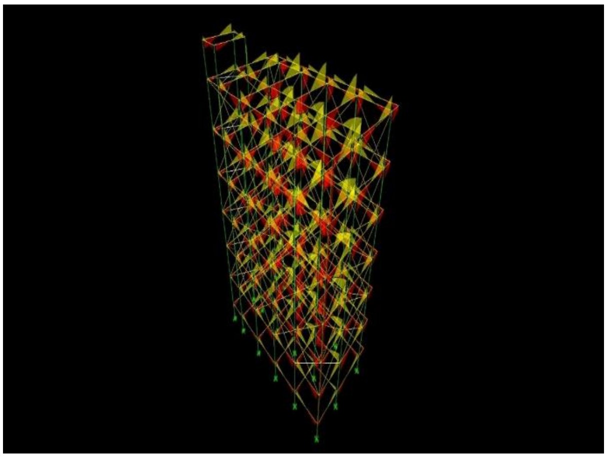
STRUCTURAL DESIGN WITHOUT BRACING



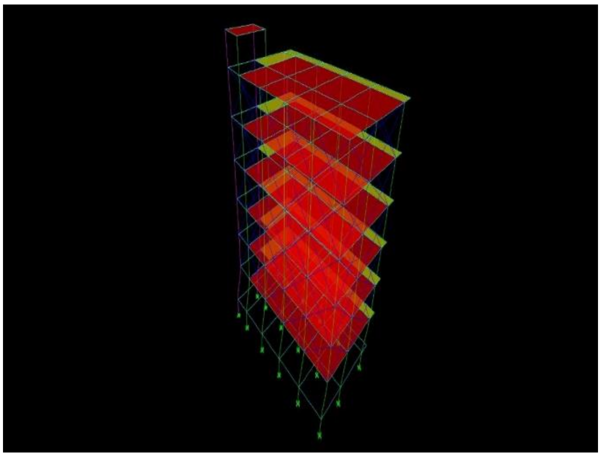
3D design of the structure



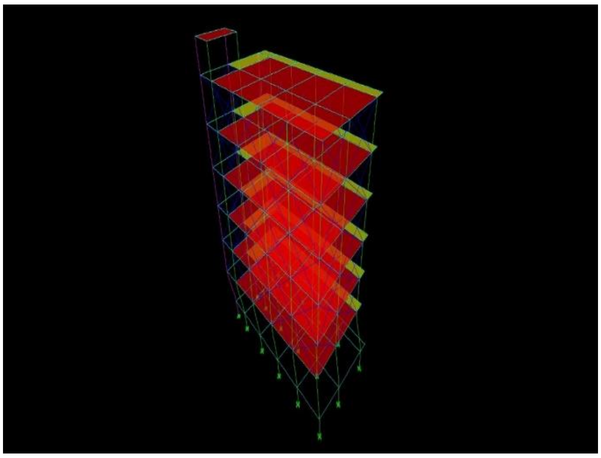
Live load of the structure



Stair case & slab loading of the structure

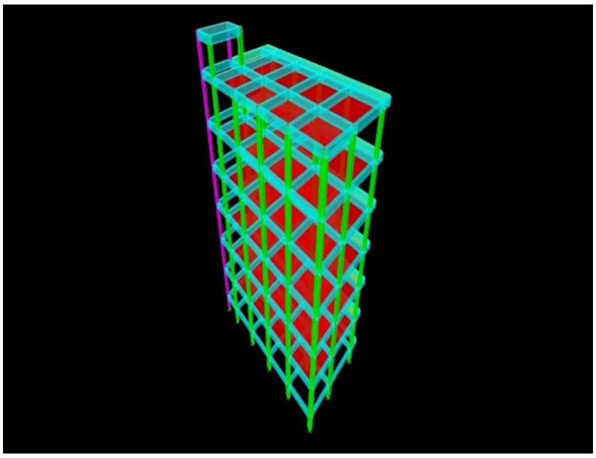


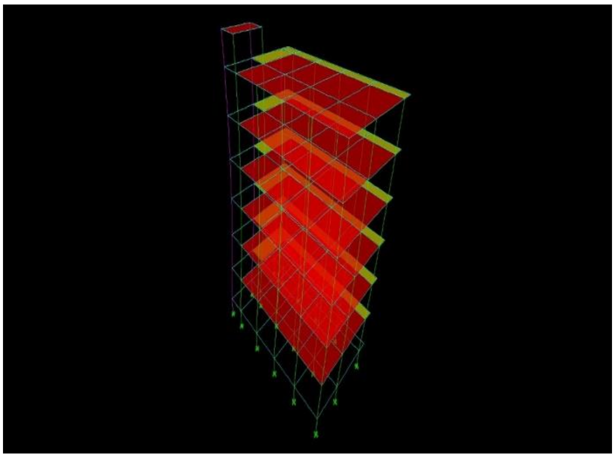
Wind load deflection in X direction

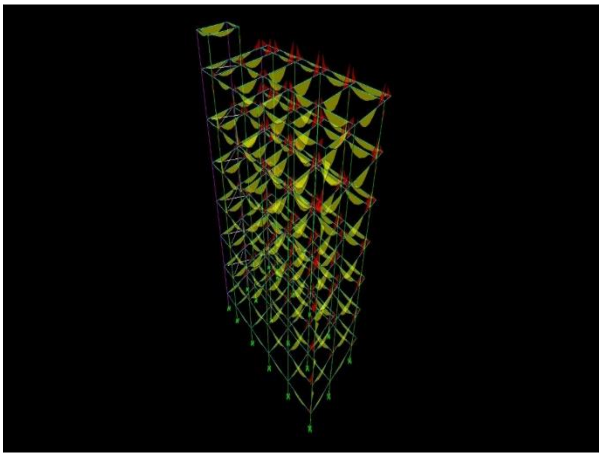


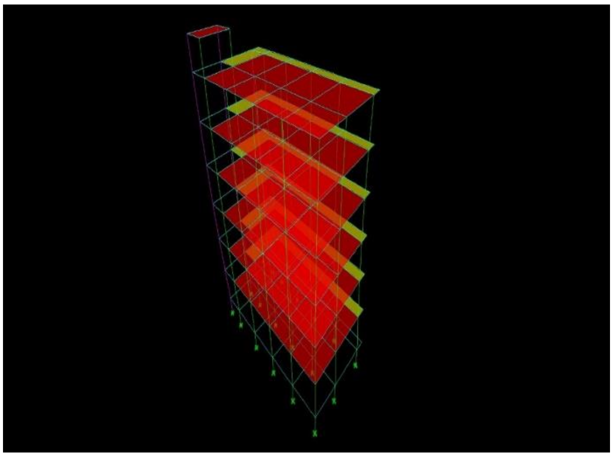
Wind load deflection in Y direction

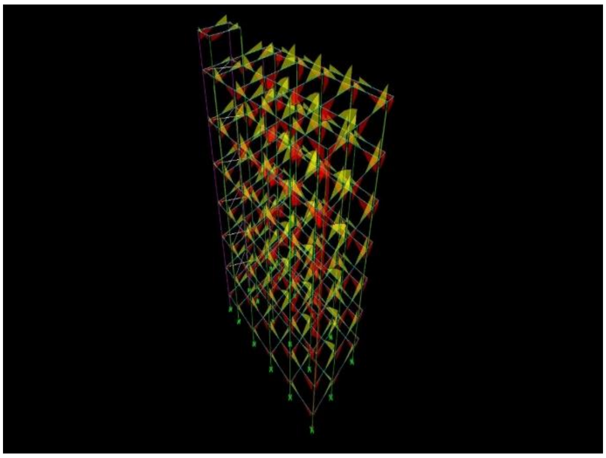
STRUCTURAL DESIGN WITH BRACING


3D design of the structure


Wind load deflection in X direction


Live load of the structure


Wind load deflection in Y direction


Stair case & slab loading of the structure

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. 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.

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 unbraced 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 wind load performance of the building. From braced and unbraced 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 sea shore regions.
2. 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.
3. Stiffness of the building is increases.
4. Story drifts and lateral displacements reduces using X type of bracing systems.
5. The axial force is maximum for X bracing system is up to 50%.
6. The concept of using steel bracing is one of the advantageous concepts which can be used to strengthen or retrofit the existing structures.
7. Steel bracings also reduce flexure and shear demands on beams and columns and transfer the lateral loads through axial load mechanism.
8. The building frames with X bracing system will have minimum possible bending moments in comparison to unbraced systems.

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