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# Effect of Different Bracing Systems in Reinforced Concrete Frames under Cyclic Loading

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***Abstract: Reinforced concrete (RC) framed structures are widely used as load transferring system in residential and commercial buildings. Even though the RC frames are designed for gravitational and seismic forces, but they are week under severe seismic events. The main disadvantage of the framed structures is inefficient bracing systems designed in it. This investigation is conducted mainly to study the effective bracing system in the RC framed structure to transfer the seismic force. This research aims to study the seismic performance of RC frames influenced by the various types of cross bracings under cyclic loading. The finite element analysis software package ABAQUS is used to investigate the braced RC frames analytically. The research scheme consists of three RC frames; the bare frame, the bare frame with single X-bracing (X frame), double X bracing (D-X frame) along the height. The structural parameters include, load-displacement hysteresis envelope, stiffness degradation and energy absorption were studied to analyze the performance of bracings. The results showed that the X frame and D-X frame noticeably increased the lateral strength, stiffness and energy dissipation properties compared to the bare RC frame. The results also indicated that the addition of X bracing along the height significantly enhanced the structural parameters of the RC frame.***

***Keywords : Bracings, Cyclic Loading, ABAQUS, Stiffness, Energy Dissipation.***

## I. INTRODUCTION

In recent decades frequent occurrence of earthquake and demand of high rise buildings due to rapid urbanization created pressure on improving the performance of high rise buildings under seismic forces. Seismic Analysis is a part of structural analysis and is the calculation of the response of a building structure under earthquakes. In regions where earthquakes are frequent, seismic analysis is mandatory. During an earthquake, a large amount of energy stored in the rocks beneath the earth released due to the movement of rocks.

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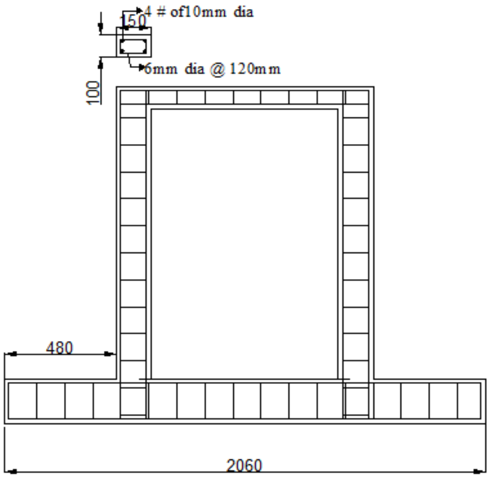
This stored energy travels in the form of waves and affects the earth's surface. This large amount of energy can damage the structures on the surface of the earth. To reduce the damages of structure, the structural elements need to dissipate this energy with effective performance in load-carrying capacity.

To make high rise buildings stronger and stiffer, which are more sensitive to lateral forces, the cross-sections of the member increase from top to bottom this makes the structure uneconomical owing to the safety of the structure. The behavior of the buildings during an earthquake depends not only on the size of the members and amount of reinforcement but to a great extent on the placing and detailing of the reinforcement [1, 10, 12]. Therefore, it is necessary to provide a bracing system to improve the lateral stability of the structure. The horizontal forces produced due to seismic action and wind load are reduced by using bracing systems. This bracing system transmits the horizontal forces to the foundation. The bracing members either carry tension or tension and compression. These members arranged in many forms. Such systems decrease the shear force and bending moment in the columns. A braced frame is a structural system commonly used in structures subject to lateral loads such as wind and seismic pressure. Many types of braced members are used in structures subjected to lateral loads and they are generally made of structural steel and concrete, which can work effectively both in tension and compression. In the structural system, the beams and columns carry the vertical loads and the bracing system carries the horizontal or lateral loads. Cross-bracings (X-bracings) created by two diagonal concrete members crossing each other. These bracings enhance the resistance to tension and the resistance to deflection depending upon the direction of loading. In past decades several pieces of research were conducted to study the bracing system adopted in Reinforced concrete frames. These researches were mainly concentrated with single X-bracing, diagonally stiffened bracing with different materials [2-12]. In this paper, the investigations were made to study the effect of the number of reinforced concrete X-bracing provided along with the height.

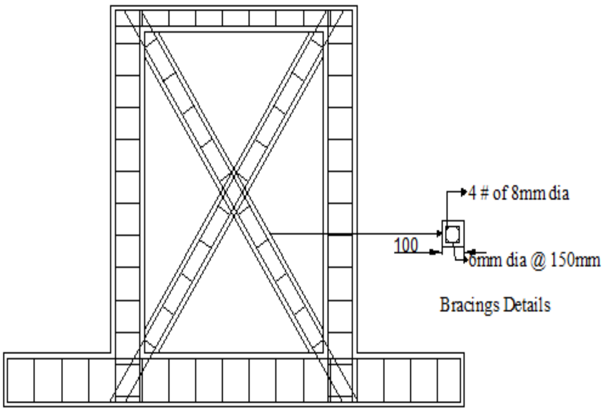
## II. SPECIMEN DETAILS

Reinforced Concrete (RC) frame with a single bay was considered for the analytical investigation. The reinforcement configuration for the bare single bay frame was taken from the results of STAAD.Pro Software. The loading and design specification was followed according to the Indian Standard code provisions. To investigate the influence of different bracing systems in RC frames, two different bracings were considered in this study.

The conventional bare frame is designated as a bare frame, the bare frame added with diagonal RC X bracing is designated as X Frame and the bare frame added with two RC X bracing along the height is designated as D-X Frame. The Configuration of various bracing adopted in these studies is shown in Fig 1. The tested cube compressive strength of concrete was 28.56 MPa with young's modulus and Poisson's ratio was respectively as 22500 MPa and 0.2. The tested tensile strength of steel is 514.56 MPa with young's modulus and Poisson's ratio was respectively as 215000 MPa and 0.3.

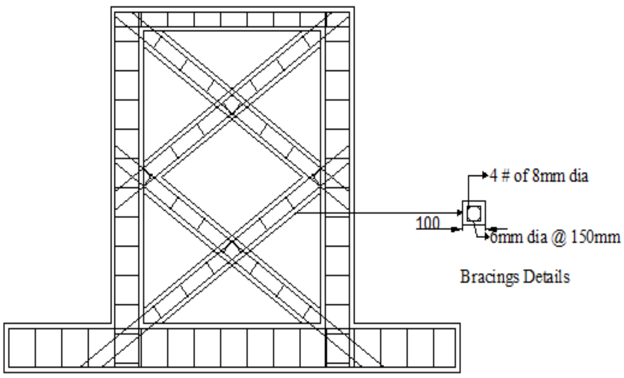



**(a) Details of Bare Frame**




**(b)**

**(c) Details of Bare Frame with Single X-Bracing**




**(d) Details of Bare frame with double X bracing (VX) Bracing along with vertical direction**

**Fig.1.The specimen dimension and details.**

## III. FINITE ELEMENT MODELLING

The Finite Element Analysis software tool ABAQUS was utilized to perform the analytical investigation of the RC frame under cyclic loading. The Abaqus/ Standard Algorithm was used to simulate the quasi-static cyclic loading. The concrete element of the bare frame was modeled by using 10-noded tetrahedral elements (C3D10) combined with hourglass control are used to achieve high accuracy in results. The reinforcements were modeled with 2-noded linear truss elements (T3D2). To increase the accuracy of results mesh size of concrete was selected as 20mm and steel reinforcements were messed with 15mm size accordance with sensitivity analysis results. The embedded method was used to model the interaction bond between the concrete and reinforcements interface. The bare frame consists of 4817 nodes, X Frame consists of 31305 nodes, V-X frame consists of 31235 nodes. Support conditions are used to rigidly fixed at the bottom and side faces of the base beam in the frame with restraints conditions. The cyclic loading was applied at the top beam using the lateral displacement cycles as amplitude data. The lateral displacements cycles were created using the 0.5 times multiples of yield displacement and increased up to the failure of the specimen. The yield displacements were calculated using Indian standard codal provisions. The frames were loaded until the failure of specimens were identified. The failure was identified when specimens behave with excessive distorted.

### A. Material modelling in Abaqus

The material property of concrete was modeled using the concrete damage plasticity and steel reinforcement was modeled using the plasticity model which is inbuilt in Abaqus software.

For the concrete damage plasticity model, the parameter includes a dilation angle of 30º, the eccentricity of 0.1, the shape factor Kc of 0.667, fb0/fc0 value of 1.16, the viscosity parameter of 0.001 was used.

The stress versus inelastic strain and damage parameter versus inelastic strain was also used concerning the Genikomsou A S et al [13].

The modulus of elasticity E, Poisson's ratio μ, density ρ for the concrete were taken from the tested results as 22500Mpa, 0.2 and 2430kN/m$^3$.

Similarly, modulus of elasticity E, Poisson's ratio μ, density ρ for the steel were taken from the tested results as 215000MPa, 0.3 and 7890kN/m$^3$.

## IV. RESULTS & DISCUSSION

### A. Load-displacement relationship

The load-displacement hysteresis envelopes for various specimens are shown in fig.3. Table 1 shows the analytical results yield load, yield displacement, ultimate load and ultimate displacement.

From figure 3 the bare frame experienced more pinching characteristics than the other two braced frames. The bare frame experienced more displacement due to insufficient lateral confinement offered in it.

The X frame and D-X frame showed an increased yield load by 2.57 and 3.48 times than the bare frame respectively.

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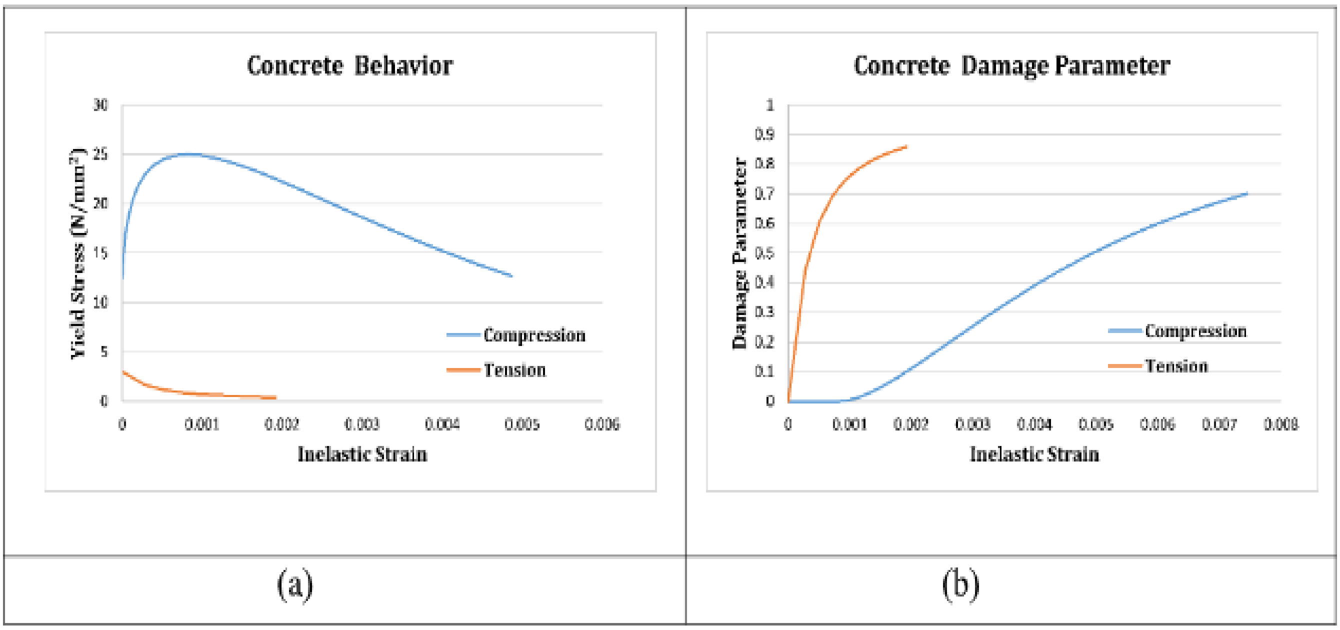



**Fig.2. a) Concrete uniaxial stress-strain behavior; b) Concrete damage parameter**

Similarly, the X frame and D-X frame showed an increased ultimate load by 2.06 and 2.68 times than the bare frame. The bare frame, the X frame and the D-X frame attained yield stage at the lateral displacement of 5.06mm, 3.01mm and 2.54mm respectively. But comparing the bare frame, the X frame and D-X frame specimens controls the lateral displacement economically higher at yield and ultimate stages. The failure displacement of bare frame, X frame and D-X frame took 5.14, 4.85 and 4.96 times the yield lateral displacement respectively. Comparing ultimate displacement to the yield displacement, all the specimens showed a similar displacement response after the yield level. The resistance offered by the bare frame to the shearing stress was very less compared to the X frame and the D-X frame was the major reason for the higher magnitude of lateral displacement and lower magnitude of lateral force observed in the bare frame. Considering the X frame and D-X frame, the bracing configuration adopted in it causes higher resistance to the shearing stress helps to experienced higher lateral force and lower lateral displacement under the cyclic loading. This showed that the X frame and D-X frame specimens behaved well compared to the bare frame. The results also clearly show that using higher counts of X bracing along the height of the frame like the D-X frame seems a more effective lateral force transferring system than the other bracing frame system.

## B. Energy Dissipation and Ductility

The energy dissipation and ductility are the important parameters for the performance-based design of structures under seismic forces. The ability of a structural element to survive under severe earthquake were analyses using the energy dissipation and ductility parameters. The area measured under the load-deflection envelope is energy dissipation capacity and the ratio of ultimate displacement to the yield displacement is called ductility [11]. The energy dissipation and ductility parameters are listed in Table1. Fig. 4 shows the energy dissipation versus the lateral displacement curve. The ductility of the bare frame showed an enhanced behavior than the X frame and D-X frame due to high lateral displacement experienced by it. The ductility of the X frame and D-X frame was slightly reduced by 6% and 3% compared to the bare frame. The ductility of the X frame and D-X frame

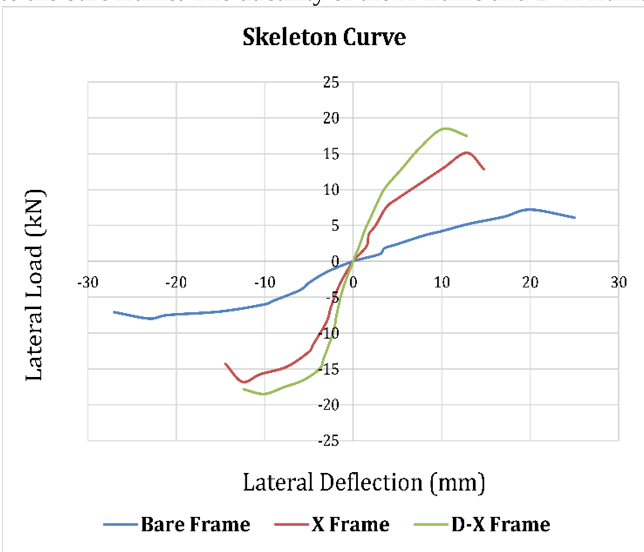



**Fig.3. Load-Displacement Envelope**

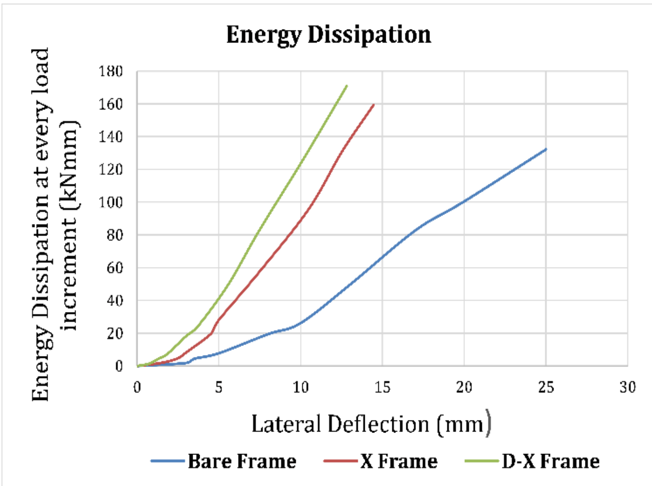



**Fig.4. Energy Dissipation**

**Table- I: Structural Parameter Results**

| Specimen | Yield load (kN) | Yield Displacement (mm) | Ultimate load (kN) | Ultimate Displacement (mm) | Yield energy absorption | Ultimate energy absorption (kN mm) | Ductility | Stiffness (kN/m) |
|---|---|---|---|---|---|---|---|---|
| Bare Frame | 2.64 | 5.06 | 6.6 | 26 | 6.41 | 132.2 | 5.14 | 1.30 |
| X Frame | 6.79 | 3.01 | 13.57 | 14.6 | 9.5 | 159.2 | 4.85 | 4.51 |
| D-X Frame | 8.84 | 2.54 | 17.68 | 12.6 | 10.95 | 170.86 | 4.96 | 6.96 |

was slightly reduced due to the high resistance offered by the lateral displacement in the inelastic stages. Even though the X frame and D-X frame shows slight less behavior in ductility but those specimens were high enhanced the energy dissipation property. The energy dissipation property up to the yield stage of the X frame and D-X frame was increased by 48% and 71% compared to the bare frame. This enhancement was due to the higher resistance offered to lateral displacement with a higher lateral force transferring capacity. Similarly, energy dissipation property in the ultimate stage of the X frame and D-X frame was increased by 20% and 29% compared to the bare frame. This is due to a comparatively higher increment in lateral displacement with higher lateral force capacity experienced by the specimen. This showed that the elastic and inelastic performance of the X frame and D-X frame was greatly enhanced due to the addition of X bracing along with the height of the frame.

### C. Stiffness

Stiffness is one of the major parameters to estimate the strength of the element. The element behaves with a higher load-carrying capacity to higher resistance to the lateral displacement causes good stiffness properties. Table 1 list the initial tangent stiffness properties of the various specimens. The secant stiffness to the lateral displacement analysis was performed to identify the stiffness degradation performance. The secant stiffness was calculated by the lateral force to its corresponding lateral displacement. Fig 5 shows the stiffness degradation curve. From the curve, initial stiffness of the bare frame, X frame and D-X frame the initial stiffness of the specimens was 1.8 kN/mm and 8.4 kN/mm respectively.

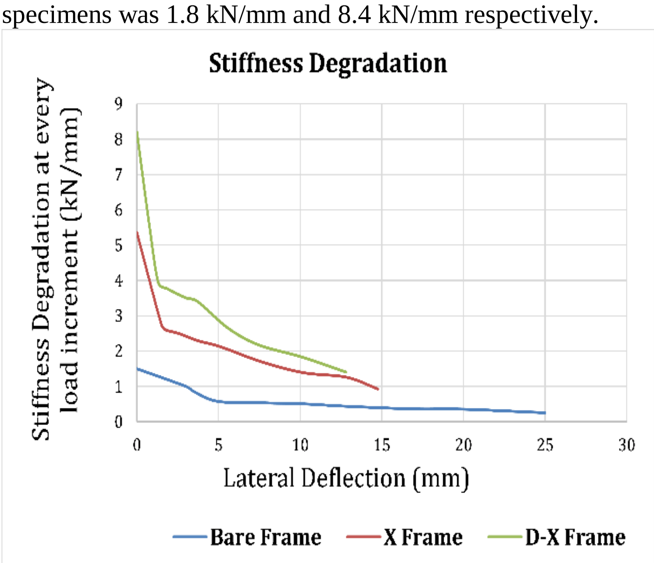
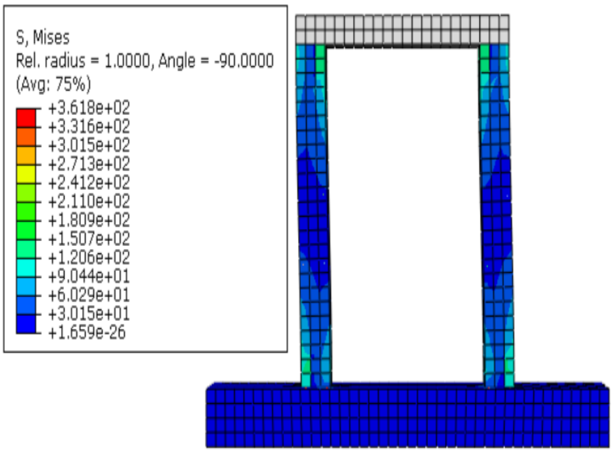
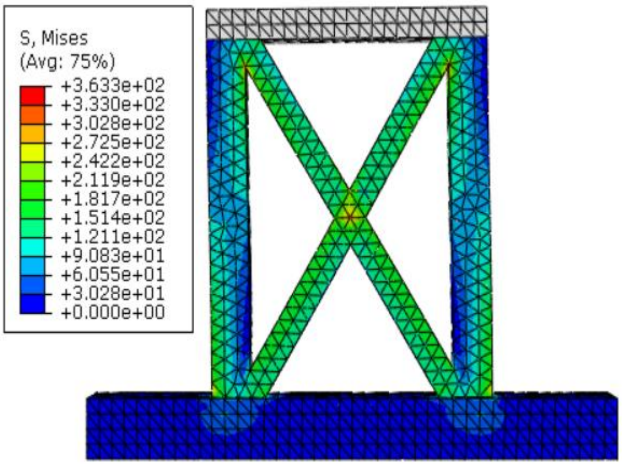



**Fig.5. Stiffness Degradation**

Similarly, initial stiffness of the bare frame, X frame and D-X frame the initial stiffness of the specimens were 0.25 kN/mm, 0.93 kN/mm and 1.4 kN/mm respectively. The initial tangent yield stiffness of the X frame and D-X frame specimens were showed 3.46 and 5.34 times higher than the bare frame specimens. This result shows that the addition of X bracings would greatly enhance the stiffness properties. From figure 5, the rate of stiffness degradation of the X frame and D-X frame was greatly reduced than the bare frame due to the increased bracing effect offered the braced frames. The results clearly showed that the addition of X bracing effectively increases the stiffness and resistance to the stiffness degradation properties to the frame structures.




**(a) Stress of the bare frame**




**(b) Stress of the X Braced frame (F2)**

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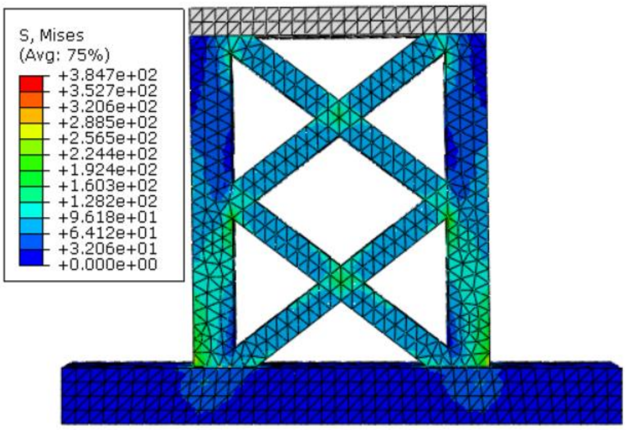


**(c) Stress of the D-X braced frame**

**Fig.6. Von Mises Stress of the different bracing system**

## V. CONCLUSION

The results of quasi-static cyclic tests on three frame specimens were carried out and presented in this paper. The finite element analysis tool Abaqus software was used to analyses the specimens to predict the hysteresis envelope of the frame specimens. Based on the analysis results the following conclusion was made.

1) The bare frame experienced more pinching effect causes more lateral displacement response with less lateral force carrying capacity, but the frames with X bracing showed resistance to pinching effect resulted in a great enhancement in the lateral force-carrying.

2) The ductility of the X bracing specimens showed a slight decrement compared to the X frame and D-X frame due to the increased resistance offered to the lateral displacement property.

3) The energy dissipation of the X frame and D-X frame were greatly increased due to the enhanced performance of lateral force capacity correspondence with less lateral displacement.

4) The stiffness property and resistance to the rate of stiffness degradation properties were highly improved in the X frame and D-X frame specimens due to the effective bracing system provided in it.

5) The addition of more numbers of X bracing along with the height of Frame specimens greatly influences better performance in the lateral force carrying capacity, stiffness, energy dissipation and ductility property.

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