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A STUDY FOR IMPROVING POST BUCKLING BEHAVIOUR OF CONCENTRIC BRACING BASED ON NUMERICAL METHOD

Abdul Gafoor K K and Dr.Shajil N

Abstract— The use of special concentrically braced frames has increased since the 1994 Northridge and 1995 Hyogoken–Nanbu Earthquakes. However, past performance suggests limited ductility and energy dissipation in braced frame systems due to buckling of conventional braces. The conventional concentric bracing tends to develop local buckling when subjected to moderate or severe earthquake. This makes it impossible to use the full capacity of the braces in the energy dissipation exerted on the structure. The paper presents a study for improving the post buckling behaviour of concentric bracings. In order to address this limitation, concentrically braced frames with aluminum used as auxiliary element at the middle of the bracing is studied to evaluate their seismic performance in comparison to traditional systems. The cyclic plasticity of aluminum is of great importance for the design of aluminum structures in regions with high seismic risk, where extremely large plastic strain loading is involved. Numerical analysis on bracings was carried out through ANSYS16.1 software. The result of this study indicate the better performance the structural system in terms of ductility and energy dissipation capacity compared to the common concentric braces. The suggested system can be utilized to reduce the capacity of bracing connection which results in reduced costs of the project.

Index Terms— Aluminum, ANSYS 16.1, auxiliary element, conventional bracing, energy dissipation, local buckling, post buckling.

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1 INTRODUCTION

Earthquakes are one of the catastrophic natural hazards. An Earthquake is the shaking of Earth's surface, as a result of sudden release of energy in the Earth's lithosphere which indeed creates seismic waves. One of the most significant facts about the earthquake is that we cannot predict it.A series of devastating earthquakes during the last few decades has created considerable interest in the minds of all concerned about the subject of earthquake resistant design. According to the revised provisions of IS 1893 (Part 1): 2016, the seismic zones of India become more vulnerable and divided into four zones. So, it is important to design the structures with seismic resistance. The structure should be strong enough to withstand both vertical and horizontal lateral forces acting on it. High rise structures are very sensitive against lateral loads produce due to wind and earthquake. From the recent earthquake studies, the performance of structures during past earthquakes is not up to the mark.

In order to address this limitation braced structures are one of the mostly used resistant systems in various steel buildings. This is because of their high stiffness and lateral strength. But the conventional bracing face severe problem during a moderate or heavy earthquake. Under these earthquakes, the structure enters the inelastic zone and thus the braces that are pressurized begin to buckle locally. This makes it impossible to use the full capacity of braces in the energy dissipation exerted on the structure.

In past there have many studies conducted on the structural behavior the bracing systems. Moghaddam and Estekanchi studied on the behavior off-center bracing system (OBS). In that the tensile element is not straight and when a lateral load is exerted on the system, its initial geometry changes. The nonlinearity degree of OBS systems is mainly dependent on the diagonal tensile eccentricity and relative stiffness of the braced elements. Also found that the load-deformation diagram of OBS follows a nonlinear hardening pattern with two yielding points. Then they subjected the singlestory and two-story OBS structures to the seismic loading using this pattern. The results of these analyses indicated that the OBS structural system has a behavior similar to that of the Base Isolation system and has a good strength against lateral loads. Bazzaz et al. have used a ductile annular steel element to improve behavior of these systems (OBS-C systems). The results of this study have exhibited higher ductility and greater energy dissipation of this structural system with respect to the OBS system. In another study which has been performed to make comparison between OBS-C systems and diagonal bracing systems with ductile steel rings i.e. DBS-C, the better behavior of OBS-C system in terms of ductility and energy dissipation capacity has been

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- *Abdul Gafoor K K is currently pursuing masters degree program in Structural engineering in Thejus Enginering College, Kerala Technical University,India, E-mail: bdlgafoor4@gmail.com*
- *Dr.Shajil N is currently professor in Civil Engineering in Thejus Engineering College, Kerala Technical University, India.*

observed. Buckling restrained bars (BRB) are another invention in the field of bracing in which engineers conducted many researches. This system includes the casing and core. The main demerit, buckling in compression has removed. It appears to provide a symmetric hysteresis behavior comparing to the conventional bracing structural system which means that it have significant capacity in terms of ductility and energy dissipation. All-steel buckling restrained braces of are a new type of buckling restrained bracings that uses steel elements as fillers instead of mortar. Sh. Hosseinzadeh, B. Mohebi presented steel buckling restrained braces, which feature a square steel rod as a core and hollow steel sheaths are used as a core buckling restraining element. The satisfactory brace geometries that minimized instability of the core section while maximizing energy dissipation capacity were then identified. Bi-linear FE-derived back-bone curves of the selected BRBs were subsequently used in the representative truss elements to retrofit three 4-, 8-, and 12-story frames. The advantages of these braces were highlighted by drawing performance comparisons against ordinary braces. Nonlinear static and dynamic responses of the frames with all-steel BRBs were also assessed in terms of parameters such as maximum inelastic deformation demand

This study suggests a method for improving the post-buckling behavior of braces. For this, a fuse is used in the middle of the brace to modify the post-buckling behavior of concentric braces. This fused section is supported by an auxiliary element. The auxiliary element is aluminum alloy.The results of experimental and numerical researches of this study indicate the better performance of this structural system in terms of ductility and energy dissipation capacity compared to the common concentric braces. The suggested system can be utilized to reduce the capacity of bracing connection which results in reduced costs of the project.

2 CONCEPT OF BRACING

Bracing systems are one of the lateral load resisting system which can Be used as a component in RC buildings for increasing stiffness and strength to protect buildings from lateral forces. Generally, it is provided as diagonal members that together with the beams form the web of the vertical truss with the columns acting as chords. The horizontal components of the axial, tensile and compressive actions in the web members help to resist horizontal shear on the building.The difference between the unbraced and braced frame can also be studied along with it.

2.1 Unbraced Frame

A column may be considered unbraced in a given plan if lateral stability of the structure as a whole is provided by columns only. These columns are designed to resist lateral loads. These columns are less resistant to Earthquake than braced column.

In the case op unbraced frame the shape of the horizontal load – displacement hysteresis loop is greatly affected by the amount of vertical loads on the column. When the vertical loads are larger, the instability phenomenon appears in the hysteretic behavior. However maximum horizontal restoring force increases in each cycles of seismic load. This phenomenon is based on the facts that the axial compressive strain cumulated in columns associated with the alternating plastic bending under constant axial force results in the increasing resisting moment of the column sections due to strain hardening, and in addition, the residual P . Δ moments exist in the frame when the reversed loading begins. On the other hand, when the vertical load is not applied, the frame instability doesnot occur and hysteresis loop which is similar to Masing's model is observed. The fig 1 explains how the unbraced frame behaves under lateral load in comparison to braced frame.

2.3 Braced Frame

A braced frame is a structural system commonly used instructures subject to lateral loads such as wind and seismic pressure. In this case the hysteresis loops are quite different from those of from unbraced frame owing to the effect of the post-buckling behaviour of compressive brace of the behaviour of tensile brace which has the residual buckled deflection. The instability effect of the constant vertical load on the overall behaviour of the frame does not seem significant in comparison with the case of unbraced frame, since the restoring force of a braced frame is much larger than that of the unbraced framebecause of the tensile force.

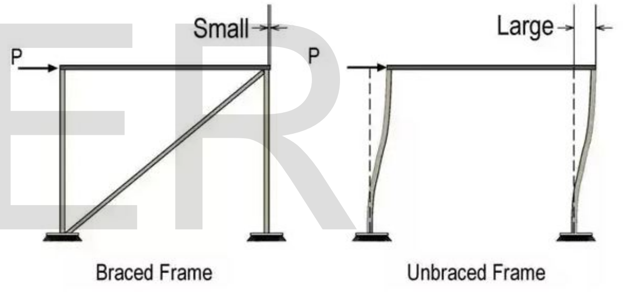


Fig. 1. Braced frame and unbraced frame deformation comparison

3 SCOPE OF STUDY

In the modern world high rise buildings are inevitable. But these are highly vulnerable to earthquakes. Since the earthquakes are unpredictable, best way to save the loss of lives and property of humans is to design the building earthquake resistant. Structural and non structural damage in high rise structures caused by earthquake forces can be resisted by earthquake resistant design techniques. Scope of my study is to find out the best earthquake resistant design technique comparing the best bracing system using aluminum alloy as an auxiliary element with conventional bracing system. The cyclic plasticity of aluminum is of great importance for the design of aluminum structures in regions with high seismic risk, where extremely large plastic strain loading is involved.

4 ALUMINUM

Aluminum has not been widely used for structural purposes compared to structural steel, mainly because of its low mechanical properties and high manufacturing cost. Although use of aluminum in non-structural components is quite familiar, there are only a small number of buildings, primarily in the USA, with a load-carrying structural system made of aluminum alloys. Nowadays, as a result of technological advancements, aluminum has become a very competitive material compared to steel, in terms of both mechanical properties and cost. Aluminum has been increasingly used in space, building, and other structures owing to its light weight and high durability. The cyclic plasticity of aluminum is of great importance for the design of aluminum structures in regions with high seismic risk, where extremely large plastic strain loading is involved. For seismic loading, strain amplitudes can vary in a wide range, which makes it necessary to calibrate the plasticity model at the full strain range.

The aluminum has many advantages over the structural steel. The most countable of it is that, it have only one third of weight of that of steel. That means steel is typically 2.5 times denser than aluminum. This help to reduce the total load of the structure which is effective in the design of whole structure. Steel is a very tough and resilient metal but cannot generally be pushed to the same extreme dimensional limits as aluminum without cracking or ripping during the spinning process. This is how aluminum is a very desirable metal because it is more malleable and elastic than steel.While malleability is very important for manufacturing; aluminum's greatest attribute is that it is corrosion resistant without any further treatment.

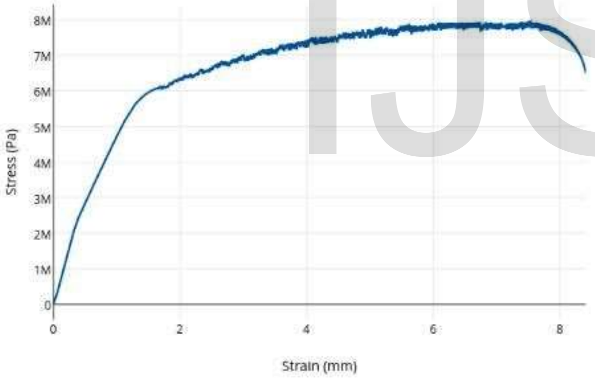
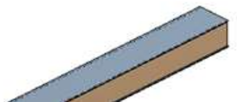


Fig. 2. Stress- strain realtion of aluminum alloy

5. METHODOLOGY

5.1 To Find Basic Model

The conventional box model as in Fig.3 is of ST37-2 steel based on standard of DIN 17100 with a stress-strain curve as shown in Fig.5, has been used. This stress-strain curve, as shown in Fig.5, the yield and ultimate stress values of this steel are 294 MPa and 385 MPa respectively. Also their corresponding strains are 0.0025 and 0.1571 respectively. The above model have a length of 2 meters, are made using two plates of 118 ∗ 3 and 102 ∗ 3 mm. Welding method used to connect all four plates together continuously.



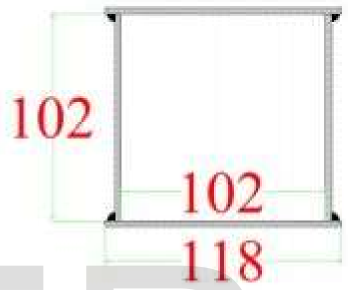


Fig.4 Cross-section of the workshop model

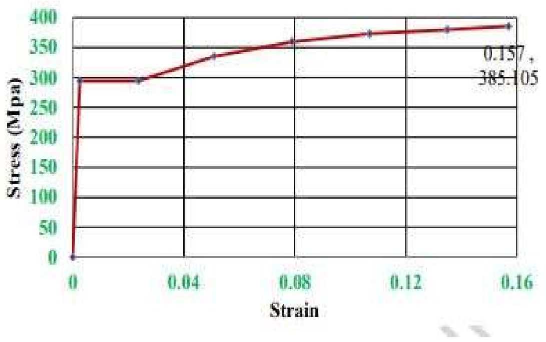
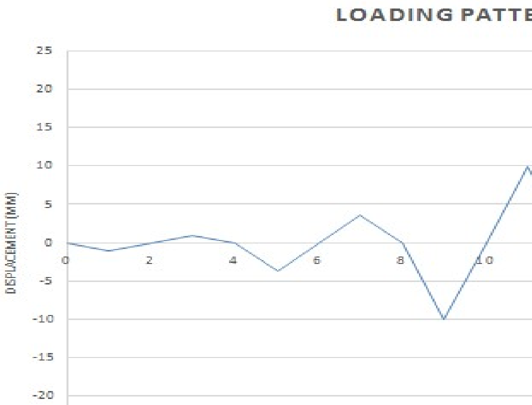


Fig.5 Stress strain relation of steel material



To investigate the behavior of the models studied in this paper, the loading pattern is used as shown in Fig. 6.

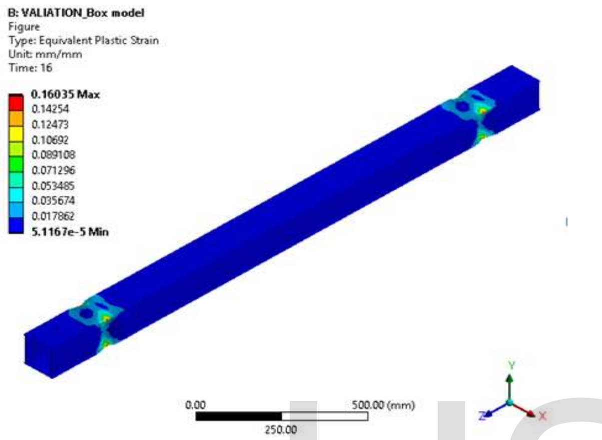


Fig. 7. Local buckling in conventional model

As seen in the curve, this model has not been able to show a desirable behavior at compressive load. According to this curve Fig.8, the first deterioration in this model occurred at a compression load of 389kN and a corresponding displacement of 4.38 mm. This failure, as shown in Fig. 7, has occurred as a local buckling and near to the end load location of brace. After this and as expected, strength of the Box model severely dropped at the pressure zone in the subsequent loading cycles. In the tensile area, the first yield in this model has taken place at the load of 390 kN and in the corresponding displacement of 2.18 m. The maximum tensile capacity happened in this model is 393.87 kN at the displacement of 20 mm.

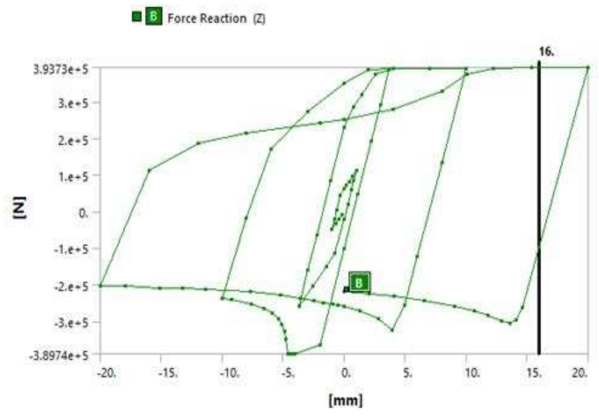


Fig. 8. Hysteresis curve of Box model

In order to improve the performance of concentric braces behavior in compression zone after buckling of the brace a basic model of bracing has to be found. For this, three types of model have made by changing the section cross section of the conventional brace. In all of the models the brace section is similar to each other but the middle section area is about 60% of the brace section area of the conventional model. According to Ali Kachooeeb and Mohmmad Ali Kafi, so the final load bearing capacity of the modified model is 60% of it in Box model or-conventional model. Following are different model on which primary studies have carried out inoder to fix basic specimen.

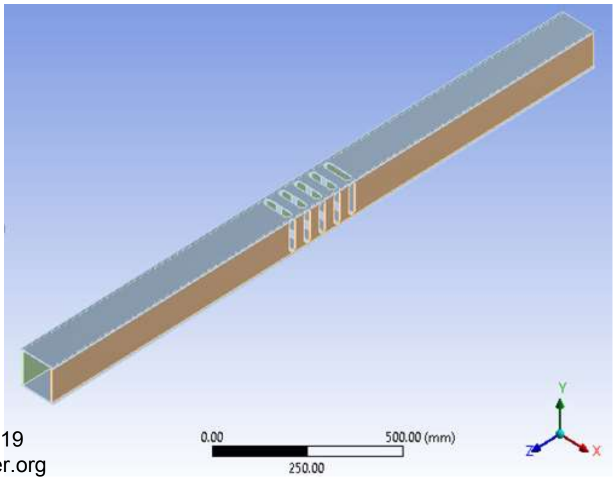
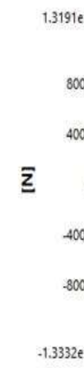


Fig. 8. Veritical Slits.



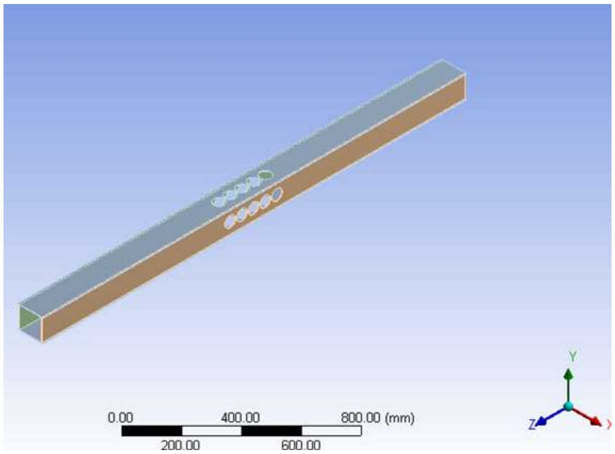


Fig. 9. Circular Slits

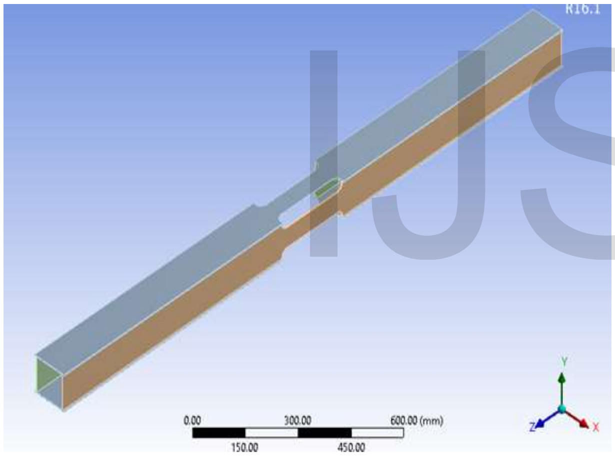


Fig. 10. Fuse section.

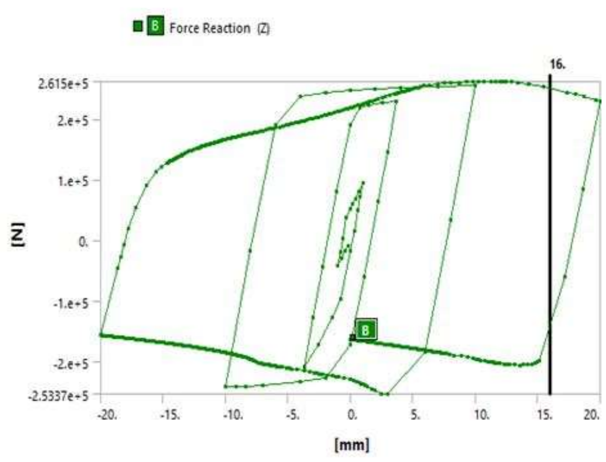


Fig. 12. Circular Slits.- Hystersis loop

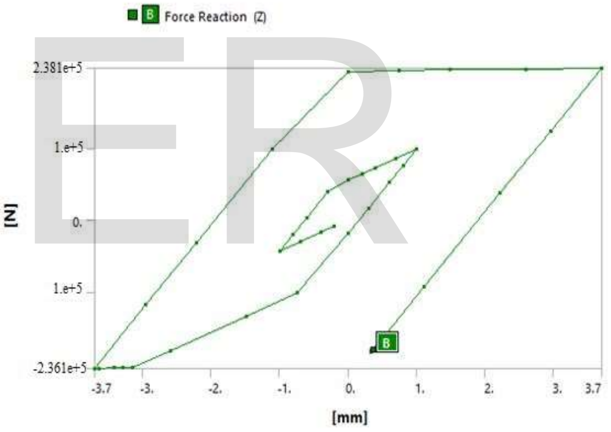


Fig. 13. Fuse Section – Hystersis loop

From the above curves, we can observe that almost all models have only around 60% load carrying capacity as that of the base box model. We can also conclude that of these three model fuse section model fails in earlier cycles of load application. This can be explained from the following representation of distribution of stress across the hollow section.

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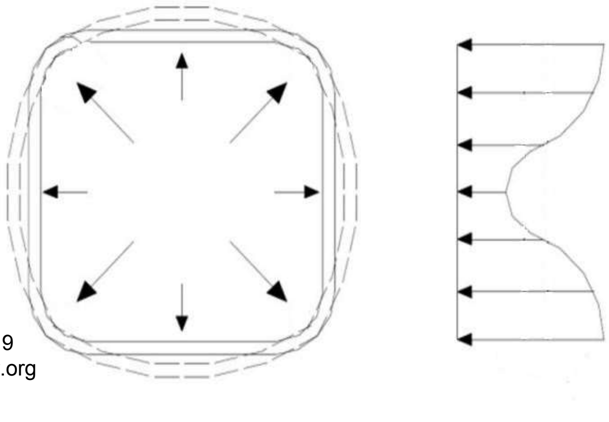


In the case fuse model, it is observed that it could only take fewer amounts of cycles of load compare to others. The reason of that failure can be explained by stress distibution detailed in Fig.14.In that stress concentration is more at the corners of the section. In fused section we removed the most stress withstanding corner portion. On account of that it under go earlier failure comparing to vertical slit (Fig.8) and circular slit (Fig.9) models. So for the further studies of bracing we choose fused section bracing as the base model since it is more critical section.

5.2 Using Auxiliary Element

In the next study , researches are conducted on the fuse model by giving internal and external support as an auxiliary element. According to studies of Ali Kachooee and Mohmmad Ali Kafi, the length of these internal and external elements should be at least 150 mm more than the fuse length plus the transition zones of fused section.

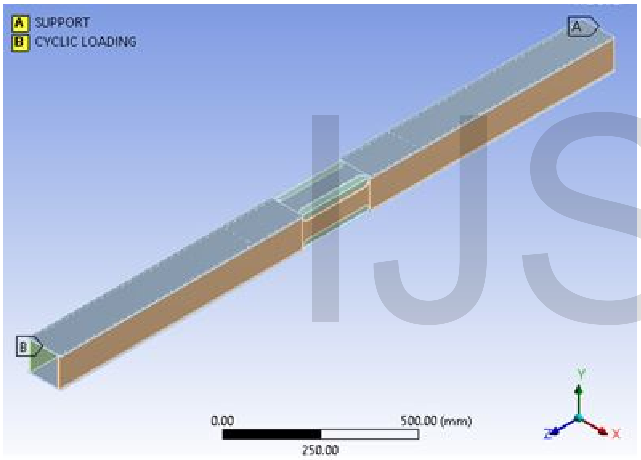


Fig15. Model with Internal Auxiliary element

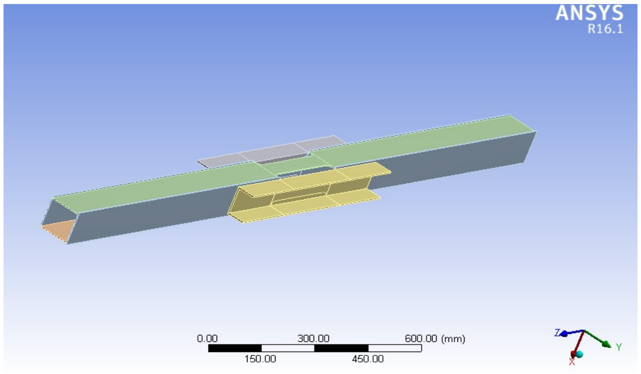


Fig16. Model with two external auxiliary elements

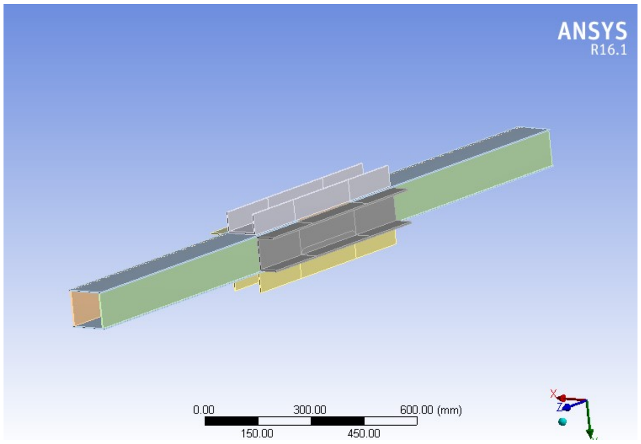


Fig17. Model with four external auxiliary elements

The Fig 15 shows model shape by using the internal auxiliary element. Auxiliary element is made of inner rectangular tube. The Fig 16 shows the shape external auxiliary element. In these models, a 100 ∗ 100 ∗ 6 box is the inner auxiliary element and standard 60 channels are the external auxiliary elements and the length of all these elements was selected to be 600 mm. The studies of these models are carried out pby comparing its hysteresis behavior obtained on the application of cyclic load applied as shown in Fig 6.

6. ANALYSIS RESULT

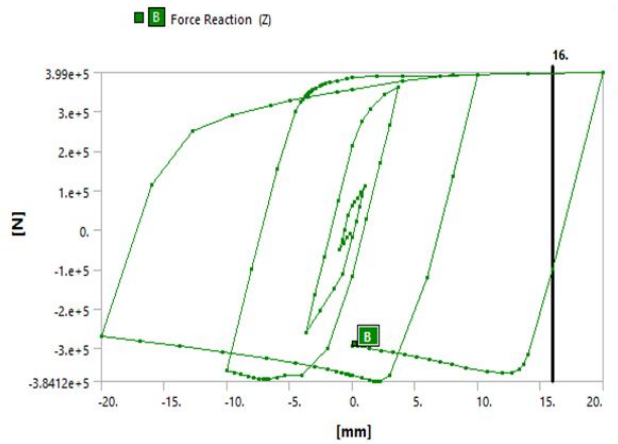
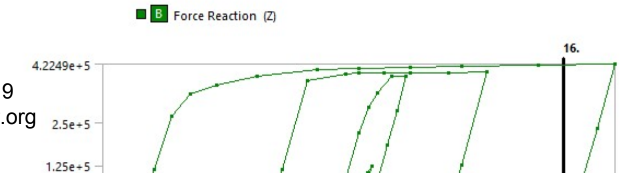


Fig18. Hysteresis loop of Model with Internal Auxiliary element



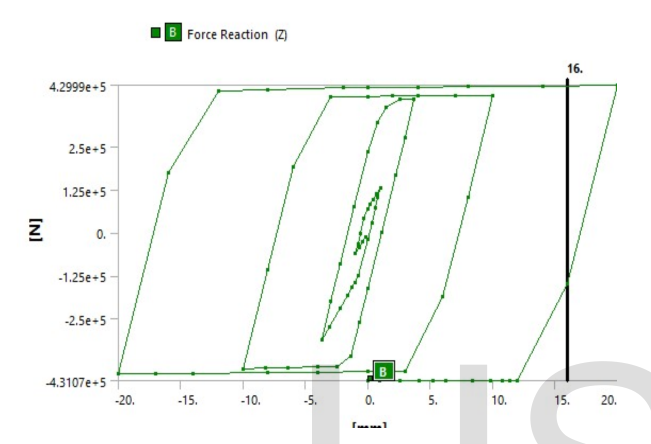


Fig14. Hystersis loop of Model with four external Auxiliary element

On the application of cyclic load we could obtain hysteresis loop of each model. The Fig 18 to Fig 20 shows the hysteresis behavior of each model. In all the model shows entirely different behavior as that of the conventional model.The comparitive study of these three model are carried out by using maximum deformation and maximum load that these models can take. These comparison are taken when the steel have under gone its maximum strain limit of .003mm.

Tension- +ve Cycle of Hysteresis Loop

Model	Cycles	Deformation (mm)	Load (kN)
Internal Auxiliary Element	15	26.38	399.00
Two External Auxiliary Element	15	22.16	422.29
Four External Auxiliary Element	15	20.85	429.99

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Compression - -ve Cycle of Hysteresis Loop

Model	Cycles	Deformation (mm)	Load (kN)
Internal Auxiliary Element	11.801	5.60	384.10
Two External Auxiliary Element	15.35	15.66	402.45
Four External Auxiliary Element	15.69	10.02	430.17

Maximum load is taken by the model with four external auxiliary elements. It is inferred that the auxiliary elemnt helped to take more load. Average deformation is almost similar in all the three cases. The hysteresis loop of the model with four external auxiliary elements is is very wide. This implies that it have more energy dissipation capacity. In this model there is no drop in the load carrying capacity. Since aluminum can be pushed to the same extreme dimensional limits as aluminum without cracking or ripping asthat of the structural steel could be. This advantage is quite useful in the using of the aluminum as a substitute to the steel.

7. CONCLUSION

By providing the modified model it could increase the ductility and absorption of seismic energy than that of the conventional bracings. To conclude these we have made three different modifications to the convetional bracing. For these entire models we applied cyclic loading. Initially we have reduced the load carrying capacity of the model with auxiliary element by 40% from that of the conventional box model. All the models are created and analysed in the ANSYS 16.1 software. After the analysis following results are concluded:

i. After the introduction of the auxiliary element the strength of the bracing has increased, since load carrying capacity have inceased in all the three models even we have reduced loading carrying capacity by 40%

ii. When taking the average deformation of the entire three models show comparatively similar behavior. This implies that ductility base of the three model are similar. It is around 7 times higher than that of the conventional model. It is less in conventional model because there occurs local buckling in the earlier stage itself.

iii. The increased ductility will also help us to know the energy capacity of these bracing. Increased ductile behavior means more energy dissipation.All the three model shows symmetrical hysteresis curves

iv. The model with 4 external auxiliary elements has more load carrying capacity.

v. Since weight of the aluminum is less comparing to structural steel, it will be helpful in the design of the structure.

Finally, as per the results obtained in this study, it can be said that the modified bracing systems could be used as different design technique and implemented instead of the conventional braced structures. These braces, due to symmetrical hysteresis curves used as a suitable alternative for conventional convergent braces. It is important to note that these braces are easier to make and do not need complex technology. This issue will reduce the cost of constructing braces on camparing with other reviewed systems. It can also be retrofitted to the existing frame structures to increase the seismic resistance of these structures.

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