TO QUANTIFY THE IMPROVED RESPONSE OF STEEL PLATE EMBEDDED AND JACKETED R.C.C. BEAM IN FLEXURE

Final Year Project UG-2016

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This is to certify that the

Final Year Project Titled

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has been accepted towards the requirements for

the undergraduate degree

in

CIVIL ENGINEERING

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"In the name of Allah, the most beneficent, the most merciful"

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ABSTRACT

In the developing world, often during construction, rapid modifications are required in designs to fulfil the demands of the strength of the structure to make it structurally safe and sound. Because of increasing population and a small amount of ground surface we are moving from small buildings toward high rise structures. As we advance in construction, there are certain limitations where the engineer cannot increase the cross-section of a beam to enhance its strength, this limitation is because modern structures need maximum space available and mainly because of aesthetics to be provided inside the structure. This situation has led us to provide Composite Beams which can be used to overcome the deficiency in the loading capacity of the structure and rigidity of the structure.

To improve structural strength against loading and ductility of the structure against earthquake, various techniques are used like FRP Plates, Steel Plates etc. But a more economical of all these options is to use galvanized zinc-coated steel plate which can be jacketed around the member to increase the flexural capacity and can be embedded inside the member to increase the ductility of the structure. So, the structure gives better performance than conventional beams under different types of loading.

1. Introduction

1.1. Background

Since the invention of Reinforced Concrete in 1849 by Joseph Monier, due to its versatility, speed of construction, sustainability, availability of raw materials and its easiness to cast, it quickly became the first choice of building materials by the civil engineers of 19th century. Many reinforced concrete structures were built in this era and many more in the following decades up to the current date. The whole world, as well as our country Pakistan, has many ancient reinforced concrete structures.

In this modern era, the construction field is developing rapidly because of increasing population and for that structural engineers are compelled to design greater floor space comparatively with least amount of ground surface, therefore, we are moving from low rise buildings toward high rise structures. As we advance in construction sometimes there are limitations for engineers that they cannot decrease the height of a floor from that provided by architecture this means that they cannot increase the depth of a beam, this limitation is because modern structures need greater floor height and mainly this is because of aesthetics to be provided to the structure. Due to increased number of floors and limited spacing, conventional RCC beam needs to take a greater load and the beam depth cannot be increased, this has led toward the Composite Beams and Steel plates embedded in conventional RCC beams are used to overcome this modern structure crisis.

For rapid development, the concept of the composite beam will be used in which a thin steel plate is embedded inside the R.C.C beam and a thin steel plate will be jacketed outside the beam.

1.2. Problem statement

Often in industrial and construction projects change in the design loads and availability of space is very common during construction (up-gradation of plants, increasing capacity etc.). Sometimes the changes are communicated to site engineer at the time when members are ready to be concreted. Apart from that sometimes there's a limitation of space when casting massive concrete sections.

Heavier loadings and large spans in a structure require massive concrete sections for structure's integrity and durability. Larger sections occupy greater space and require strong and sophisticated formwork techniques which are costly as well as time taking. Sometimes structures may require strengthening to cater to the increased loading, natural hazards and material deterioration.

Following are some of the methods for strengthening RC beams:

- Enlarged cross-sections
- External prestressing
- Externally bonded plates (Steel and FRP)

1.3. Methodology

To analyze the performance of jacketing of steel plates and embedment of steel plates in a beam, the following steps are taken:

1. Selection of materials
2. Casting of beams to test in flexure
    a) 6” x 6” x 5’ conventional RCC beam.
    b) 6” x 6” x 5’ RCC beam with U shaped embedded steel plate.
    c) 6” x 6” x 5’ RCC beam with wrapped steel plate.
3. Testing of beams
4. Developing the moment-curvature curve from loading and deflection obtained while testing.
5. Selection of a silo substructure
6. ETABS modelling and plastic hinges definition
7. Non-linear time history analysis in ETABS 17
8. Compilations of results
9. Conclusion

1.4. Objectives

The objective of this research is to determine the following aspects:

1. To study the strength of conventional RC beams and compare it against the strength of steel plate embedded RC beams and steel plate jacketed RC beams in flexure.
2. To study the improvement in the ductile behaviour and seismic response of the structure with different beam models.
3. To draw a comparison between jacketing and embedding using steel plates to determine which method gives better results.

1.5. Utilization

By using the results obtained from this research, the external jacketing of steel plate or embedding of steel plate in a beam can be done at the design phase to strengthen the structures. It enhances the confinement of the members and improves the ductility of the structure. It is very economical and easily available in the market. It can be implemented in place of massive concrete sections, in high rise structures, in active seismic zones where the structural strength, cost of massive formwork installation and massive space availability are quite big issues.

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2. Literature Review

2.1. Introduction

In this modern world where the governments are trying to avoid city expansions by going towards high rise structures, those structures require massive concrete beams and columns to cater to the loading requirements. To avoid massive concrete sections and strengthen the structures, jacketing of beams and columns is not new. And the addition of steel plates in a beam may lead to more ductile behaviour of the beam. There is a lot of research carried in jacketing of beams with steel plates but the research lacks in case of embedding beams with steel plates. Following are some strengthening methods followed by some researchers and the conclusion that have been drawn which enabled us to proceed in the right direction for the project.

2.2. Strengthening Methods

Structures need to be strengthened to fulfil the increased demands of design loading and to cater for the strength of structure lost over the time because of seismic activity, change in operating requirements, improvement of the safety factors, reduced durability or structures exceeding their lifetime. There are many traditional methods for strengthening structures such as use of an enlarged area, exterior jacketed steel plates, external prestressing, shotcrete etc.

2.2.1. Enlarged Sections

To improve the strength of structures, beams and columns needed to be strengthened. One of the most common methods is to destroy the existing section and rebuild the new section but sometimes additional steel reinforcement and the concrete cover is added to the existing section to improve the strength. These enlarged sections require extra formwork which takes greater time due to longer curing time, adding extra costs to the project, a proper dense mix is difficult to achieve in such constrained conditions, and adhesion of concrete to the old section is also a major issue. (Miller et al., 2001).

2.2.2. Shotcrete

Spraying the concrete on the reinforced and prepared surface of a member is also a way to provide strengthening of the structure. Several admixtures are used to improve the strength and adhesion, to reduce water requirement and shrinkage. There is no need for any formwork for shotcrete and it can be done on large areas in a short period. But the amount of materials wastage is enormous because of the sprayed materials, which also make the operation quite messy and gives the surface a rough and uneven texture. (Mukherjee & Joshi, 2005).

2.2.3. Externally Jacketing of Plates

1. FRP Plates

Externally jacketed fibre-reinforced polymer composite plate is a technique of beam strengthening in which different composite materials are externally bounded on beams in layered form. FRPs are easily available and lightweight but have greater strength when compared to weight. External jacketing of FRPs were used for strengthening in building and bridge structures (Barnes and Mays 1999).

2. Steel Plates

Steel plates are commonly used to strengthen the structures. Using steel plates to externally jacket the beams is a commonly used procedure because the properties of steel are well defined and engineers have developed a confidence in using it. By using steel plates, the strength of reinforced concrete members is enhanced by externally bonding the steel plates with epoxy to the sandblasted concrete surface or by anchoring to the concrete sections, or by embedding the steel plates inside the concrete sections.

a) Jacketed Steel Plates

External jacketing of steel plates is usually done to increase the strength of the beams by bolting, injecting epoxy between beams and plates(Jumaat et al., 2006). Ali Demir, Emre Ercan and Duygu Dönmez Demir tested strengthening of RC beams with externally wrapped steel plates. Jacketing of steel plates is an easy phenomenon, where the cost of the steel plate is also low when compared at price to performance. Jacketing of beams also has minimum disruption to the use of the structure. These factors make jacketing of beams using steel plates a convenient and easy method to increase the strength of RC beams as compared to other methods. Steel plate and bolting provides additional external reinforcement to the concrete section but also improves the stiffness of the composite section. (Miller et al., 2001).

b) Embedded Steel Plates

Embedding of steel plates in RC beams usually shows an increase in flexural capacity of reinforced concrete sections. To enhance the flexural strength of the beam, embedded steel plates with perforated holes may be used to enhance the strength and ductile behaviour. Embedded steel plates will also act as reinforcement and it will also enhance the stiffness of the composite section.

2.2.4. Advantages of Steel Plates

Steel plates have been widely used in different parts of the world to provide ductile behaviour to RC structures, to bear loads, to resist earthquake loads, to sustaining seismic activities, to cast composite sections and in retrofitting of different structural members such as beams and columns etc. Some of the uses of steel plates are mentioned below:

- Steel plates have high tensile strength when compared to the weight that makes them suitable for lightweight structures. In this way, they do not contribute much to the dead load of the structure itself.
- Steel has high strength, economical when compared to other metals, have a long service life and ductile behaviour.
- Steel can be moulded and cast in various shapes depending upon their utility. They can have shapes like cylindrical shells, spheres and horizontal layers.
- In the application of retrofitting, steel plates find its application in important historical buildings where the shape of the structure could not be changed or it can also be used where there is lack of space by providing jacketing. (Rabinovitch & Frostig, 2003).
- Steel sheets are costly than traditional rebars, but their service life and low maintenance cost make it economical altogether. Steel plates are lightweight which makes them easier to transport.

2.2.5. Disadvantages of Steel Plates

- We know that steel is susceptible to corrosion, once steel gets in contact with water, corrosion starts and it leads to the reduction in strength. Besides durability issues, steel plates are heavy and sometimes it becomes difficult to install them. Joint formation process in steel plates also creates trouble. (Khalifa & Nanni, 2000)
- When testing the externally bonded steel plate beams, the actual measured load capacity is found to be lesser than the theoretical ultimate load capacity. (Byung Hwan Oh, 2003)
- The composite beams strengthened with steel plates shows dominant shear cracking as the shear span to depth ratio decreases. (Byung Hwan Oh, 2003)
- Strengthened beams show a slight increase in the ultimate capacity with the increase of epoxy thickness which may be because of thicker adhesive which delays the plate separation from the beam. (Byung Hwan Oh, 2003)
- Strengthened beams show higher fatigue resistance at the same fatigue load level than the non-strengthened beams. (Byung Hwan Oh, 2003)
- Plate bonding using epoxy leads to a premature failure between the separation of plates and concrete beam and sometimes the rip-off of the concrete along the tensile reinforcing bars. (Jones 1988; Roberts 1989; Hamoush 1990a; Oehlers 1990; Zhang and Wood 1995; Oh 2001).

- Externally jacketing of beams with the steel plates can increase the flexural strength of beams by up to 15%. (Swamy et al, 1987-1989)
- The anchoring of strengthened beams with steel plates affects the ultimate strength and failure mode of the beam. But the anchor bolting cannot prevent the debonding of plates from strengthened beams. (Jones et al, 1988)
- Premature failure in strengthened beams relates to plate thickness and to the end anchorage which cannot prevent the failure. (Hussain et al, 1995)
- RCC beams were tested to fail in torsion which was then repaired by adhesively bonding steel plates and tested again. They showed a 33% increase in strength over the original beams and they all failed in flexure, showed 25% less deflection than the original beams, when subjected to identical loading. Externally reinforced beams before loading showed a 43% increase in strength and failed in flexure. (Jerry W. Holman and John P. Cook, 1984).

2.3. Failure Modes

2.3.1. Conventional Beams

There are different possible modes of failure of a simply RC beam as well as beam strengthened with Steel Plates. As steel is good in tension, it is provided in tension side of the beam, while concrete is good under compression. Steel shows ductile behaviour and concrete shows brittle behaviour. In case of under reinforced beam, a tension failure is indicated, while in case of over reinforced beam compression failure is indicated. We prefer under reinforced beam because in this way steel will yield first and the beam failure will be ductile. If we design the beam over reinforced, the compression concrete will fail first and the failure mode will be brittle and sudden.

I. Flexure Failure

Flexure design of the beam depends on the moment induced due to loading. To avoid flexural failure, the moment capacity should be greater than the induced moment in the beam due to loading. Longitudinal steel is used to enhance the flexural capacity of the beam. By increasing the longitudinal steel, the flexural strength will increase. Sometimes, due to very thin sections, steel is also provided in the compression zone.

Figure 1. Flexure Failure

II. Shear Failure

In shear failure, the failure is because of the high shear strength at the ends of the beam. If the shear capacity of the beam is exceeded by shear stress applied then the beam will fail in shear. Shear stirrups are provided in the beams to avoid shear failure of the beam. According to ACI code, to avoid shear failure in the beam, the clear span of the beam should be at least more than 4 times the effective depth of the beam.

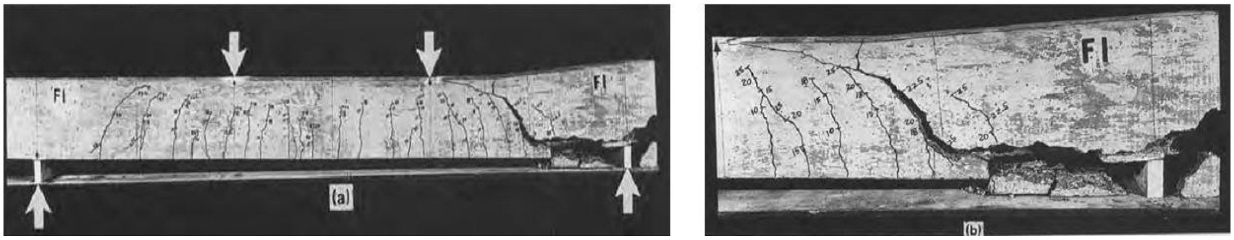

Figure 2. Shear Failure

2.3.2. Strengthened Beams

Strengthened beam with CFRP and Steel Plates shows following possible modes of failures.

I. Peeling/Debonding Failure

Peeling cracks normally occurs when the steel plates are not provided throughout the clear span. This failure starts from the ends of steel plates because dowel action of the stirrups causes the weakest plane forms right under the longitudinal steel reinforcement initiating peeling cracks. (Leung, 2001).

Figure 3. Peeling Failure

II. Diagonal Shear Failure

Shear span to depth ratio (a/d) determines the shear failure mode. The beams with a small (a/d) experience dominant shear failure with smaller flexural cracks. Strengthened beams also show diagonal cracks in shear failure, they are caused by the increase of flexural capacities because of using steel plates. The diagonal cracks appear along with the separation of steel plates. The beams with thicker plates show more shear cracking and greater separation.

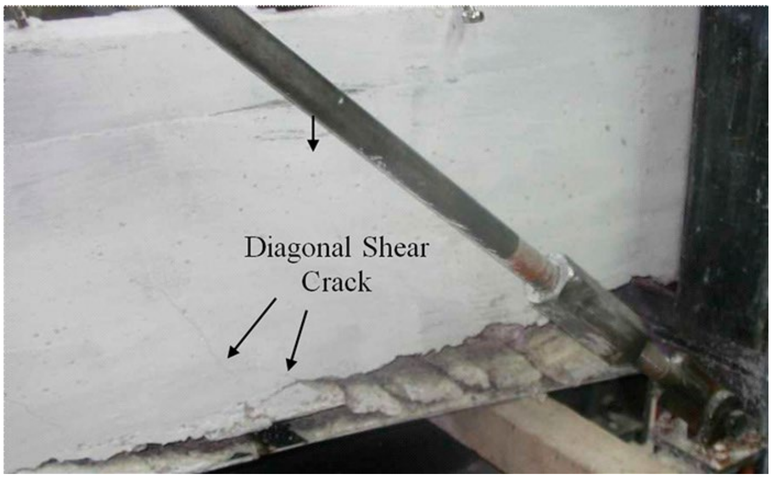

Figure 4. Diagonal Shear Failure

III. Other possible Failures

The plate is attached with bolts can be detached if bolts are not tightened properly or the cracks formed during jacketing of holes can help propagate diagonal shear cracks.

3. Experimentation

3.1. Introduction

A concrete mix of 1:1.5:3 was used to cast ASTM standard cylindrical cylinders, they were cast to determine compression strength of concrete. After testing of those cylinders at 28 days, compression strength greater than 3000psi was achieved. After that 3 beams were cast using the same mix and having 4#2 bars as longitudinal reinforcement and #2 bars are used as shear reinforcement with a spacing of 3” c/c. The cross-section of each beam was 6” x 6” and span length of 5’.

1. 6” x 6” x 5’ conventional RC beam
2. 6” x 6” x 5’ RC beam with Embedded steel plate
3. 6” x 6” x 5’ RC Beam with jacketed steel plat

3.2. Materials

3.2.1. Steel

In all the samples of RC beams, 6.35mm (#2) Grade 40 steel was used as longitudinal and lateral reinforcement as shown below in reinforcement cages made for standard beams on the left and deep beams on the right.

Figure 5. Steel Reinforcement Cage 1

Figure 6. Steel Reinforcement Cage 2

3.2.2. Steel Plate

Zinc coated steel plate is a steel sheet of thickness 0.25mm was used because of its ductility and local availability. It is also both corrosion and abrasion resistant because of zinc galvanization. It was used as an embedded U-shaped steel plate and as externally jacketed steel plate.

Figure 7. Zinc Coated U-Shaped Steel Plate

3.2.3. Concrete

M20 grade concrete (compressive strength of 20MPa=3000psi) was used with a concrete mix design of 1:1.5:3 (cement:sand:gravel) by weight. This mix design was selected keeping in view the compressive strength typically used in Pakistan for multistory buildings.

Figure 8. Concrete Cylinders

3.3. Testing

3.3.1. Cylinders Testing

Compression tests were performed on cylinders after 28 days of curing using a 2000kN capacity Compression testing machine following ASTM C39 with a loading rate of 0.15MPa/sec.

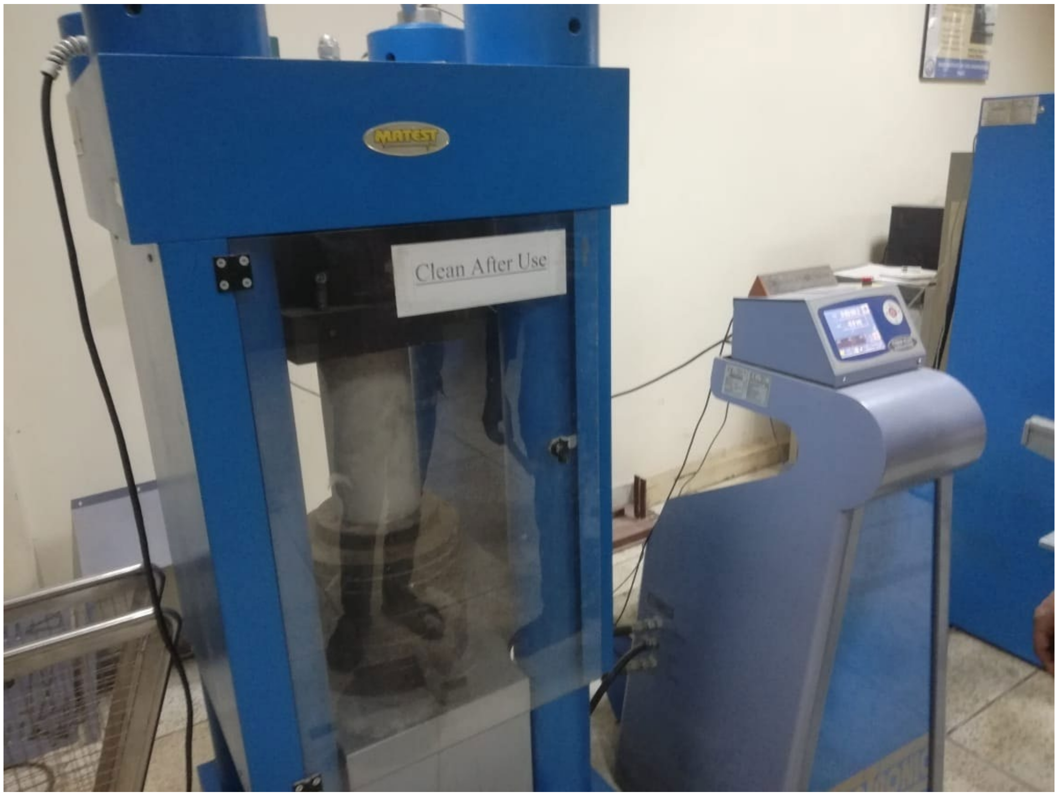

Figure 9. Compression Testing Machine

3.3.2. Beams Testing

For flexure tests on beams, tests were performed as 3-point loading in a hydraulic machine. LVDT was used to measure the axial deformation. The figure shows the flexure test setup and specimen undergoing the test. Progress of the test was monitored on the computer screen and all the load-deformation data was stored.

Figure 10. Beam Testing Assembly

3.3.3. Compression Testing Results

The data that has been observed by testing all the 3 beams against flexure was in loading vs deflection form. Following graph shows the comparison between of 3 beams between loading and deflection.

From the graph, it can be observed that the jacketed beam took maximum load while the embedded beam took less load than a conventional beam.

Load vs Deflection

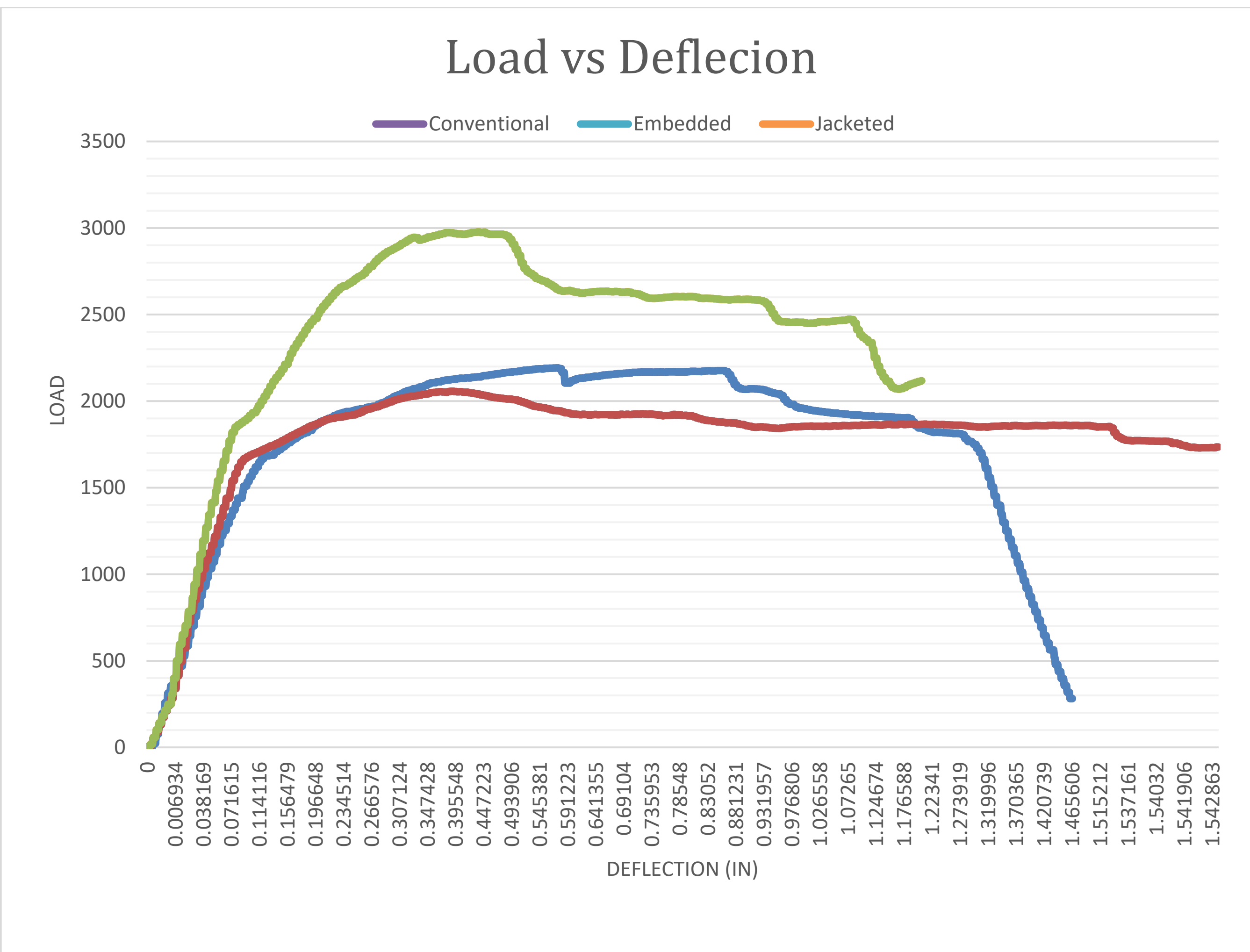

Figure 11. Loading vs Deflection

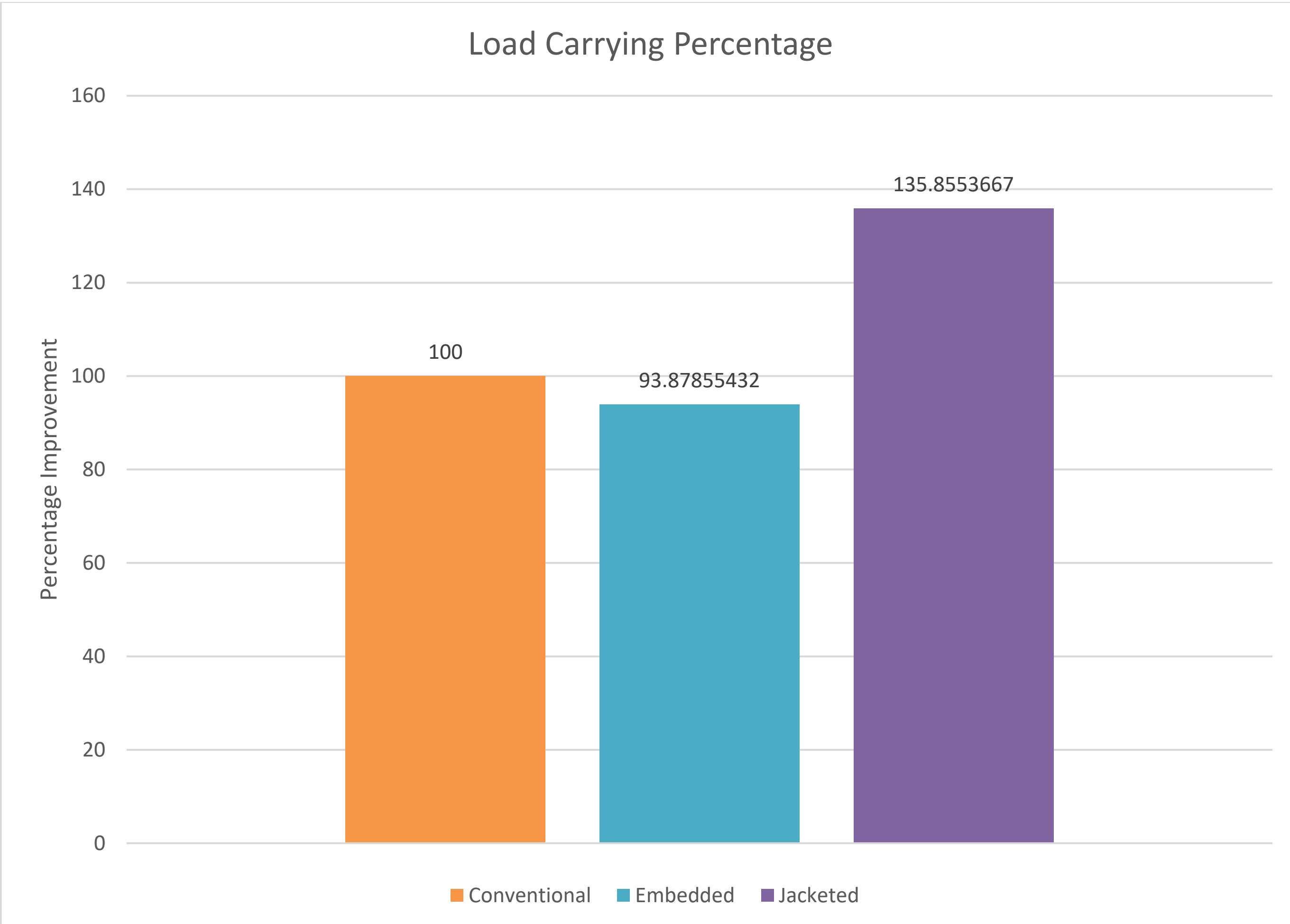

Figure 12. Load Carrying Percentage

It can be observed that the behaviour of all the samples is almost the same and linear until the elastic limit (proportional limit) is reached. RC beam sample with Embedded U-shaped steel plate has more strain ductility than the RC Conventional sample. When comparing the RC conventional beam sample with Embedded U-shaped steel plate beam sample, a considerable increase in the ductility can be observed. From the above graph, it can be observed that embedded beam carried 6.12% less load than conventional beam and jacketed beam carried 35.85% more load than the conventional beam.

The data of loading vs deflection that was obtained while testing beams in flexure is used to define the Moment Curvature(M-phi) Curve. Loading was used to obtain the moment by using the method of sections while curvature was obtained by using double integration method. The rotation was also obtained from curvature as both are interconvertible quantities for further use in defining plastic hinges.

Moment vs Curvature

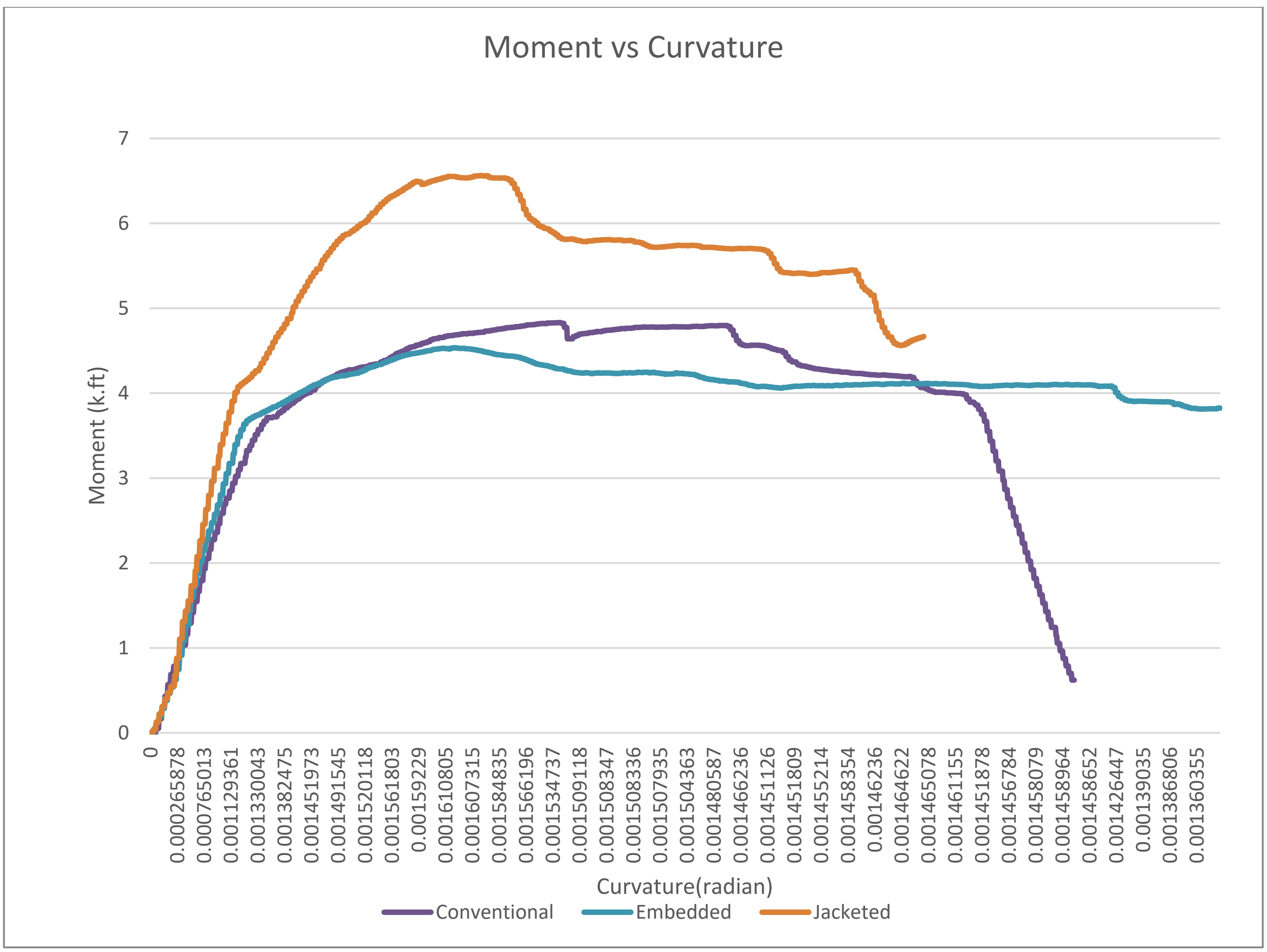

Figure 13. Moment vs Curvature

4. Structural Modelling and Analysis

4.1. Gravity Analysis

Before going into the modelling, gravity analysis should be done. Gravity analysis must be performed before time history analysis, If the substructure will be able to withstand gravity load, then time history analysis should be performed otherwise it will be waste our time and results will not be desirable.

Gravity load means load acting due to gravity forces which will include vertical forces. Gravity load, in general, includes the weight of the structure, occupancy load (Table, chairs, and human beings etc.) and snow load imposed on the structure. All these loads must have a defined path through which loads will transfer safely. There are multiple engineering structures which are interconnected with each other and provide a path to transfers loads from roof to foundations safely. An engineer should design those structures accordingly.

Load transfer path is as follows:

1. Initially, Slab load will transfer to beams which are lying under slabs. Beams should design accordingly so that they can bear the load coming from the slab.
2. Beams will carry the load from slab and then transferring that load to the column lying underneath it. The beam will transfer load from the ends to the columns.

3. The column will carry the load from slab and beams and then transferring that load to the foundation lying underneath of columns.
4. Foundations will transfer the load coming from slab, beams, and columns into the ground.

4.2. Formation of a basic model

Modelling was done on ETABS. The responses of beams were evaluated in ETABS and the following procedure was followed.

1. First, the material was defined. The materials defined were
   - 3000 $^{lb}/_{in^2}$ strength of concrete
   - 40 $^{kip}/_{in^2}$ strength of steel bars
   - 222 $^{N}/_{mm^2}$ tensile strength of steel plate
2. The strength of zinc-coated steel plate, concrete and steel bars were obtained from a laboratory test.
3. Then the cross-sections of beams were defined. The beams cross-section was $6" \times 6"$.
4. Then the dead load, live load and super dead load were defined and applied to the beams, after that the earthquake data for time history analysis was inserted.
5. In the end, the plastic hinges were defined and the analysis was performed.

4.3. Seismic Analysis

Seismic analysis is necessary for the understanding of seismic responses of a structure. Seismic analysis is a branch of structural analysis, which is the measurement of earthquake response of a building structure. This is part of the structural architecture, earthquake engineering, or structural evaluation and redesigning method in regions where earthquakes are prevalent. Analysis can be classified further based on the behaviour of structure as:

- Linear static analysis
- Nonlinear static analysis
- Linear dynamic analysis
- Nonlinear dynamic analysis

4.3.1. Linear static analysis

It is also referred to as an equivalent static method. This method is used for standard structures with the structure being restricted in height. This accounts to a small (approximate) extent for the dynamics of a house. The method needs less effort in computing. The design base shear is measured for the entire structure in the first phase. Second, it is then spread around the building's height. The lateral forces thus obtained at each level of the floor are distributed to individual elements that resist the lateral load.

4.3.2. Nonlinear static analysis

It is a practical method in which analysis under fixed vertical loads is carried out. After this lateral force will be steadily increased to estimate the structural pattern of deformation and damage. It is the seismic analysis approach in which structure behaviour is defined by a capacity curve that describes the relationship between base shear force and roof displacement. It's often referred to as pushover analysis.

4.3.3. Linear dynamic analysis

Where higher mode effects are not significant, static procedures are acceptable. It is generally true for standard, short buildings. Therefore, a complex procedure is needed for tall buildings, buildings with torsional irregularities, or non-orthogonal structures. It is also known as the response spectrum method. The method of working of this analysis is that direct peak response of structure during an earthquake is obtained. This is quite an accurate analysis of structural designs applications.

4.3.4. Nonlinear dynamic analysis

The nonlinear dynamic analysis uses the combination of earthquake records with a comprehensive structural model, allowing results with comparatively low uncertainty to be obtained. The comprehensive structural model subjected to an earthquake record generates estimates of component deformations for each degree of freedom in the model in nonlinear dynamic analysis. This analysis can also be called as time history analysis. When an evaluated structural response is nonlinear this analysis is important for structural seismic analysis. It gives a linear or nonlinear evaluation of dynamic structures behaviour corresponding to different load conditions which may vary as per specific times. Dynamic equilibrium equations which are $K\,Ut + C\,{}^{d}/_{d(t)} + M\,{}^{d^2}/_{dt}\,U(t) = r(t)$ solved either by the model or double integration methods. It is a step by step procedure of analyzing the dynamic response of structure against specific load which may vary along the time. To perform this analysis a representative earthquake data was taken. Based on this earthquake time history data structure was evaluated.

4.4. Modelling and Analysis in ETABS

4.4.1. Modelling in ETABS

Real case substructure of Bestway Cement Silo was modelled in ETABS, the structural drawing of the substructure of the silo is shown in figure 14 and figure 15 the developed model in ETABS is shown in figure 16.

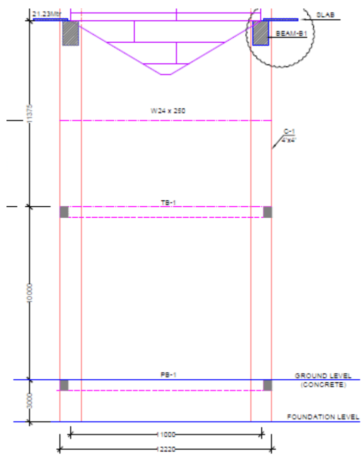

Figure 14 Silo Substructure Elevation

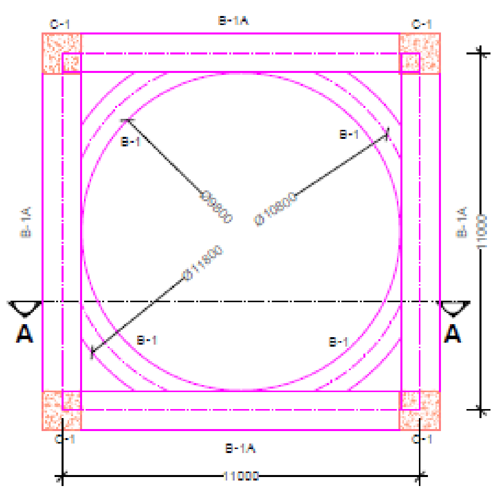

Figure 15. Silo Substructure Top View

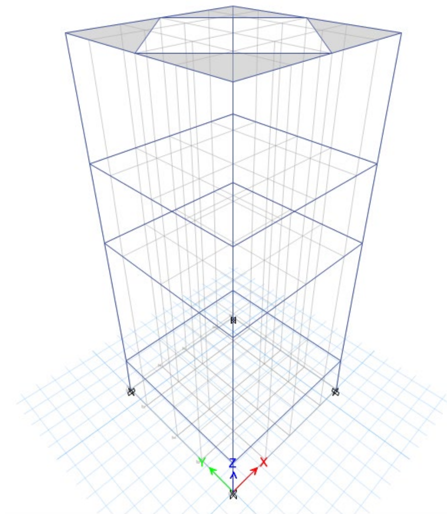

Figure 16. Silo model in ETABS

The beam B-1A was redesigned to an enlarged section (new design) and all models are modelled, analyzed and compared which are discussed below.

Five models were developed for five different proposed beams which are mentioned below.

1. Old Design

This is the beam which already exists and needed to be redesigned, the cross-section of the old design beam is shown in figure 17.

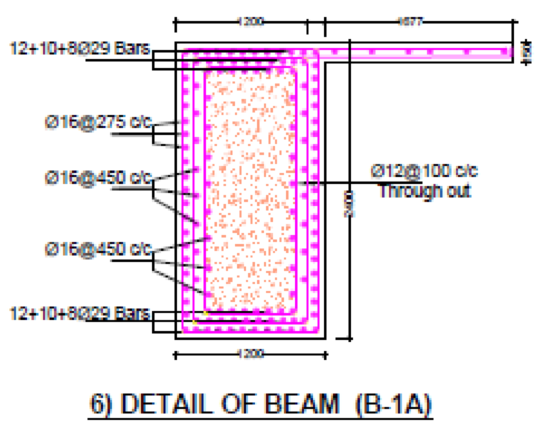

Figure 17. Old Design Cross Section

2. Old Design with Embedded I section

This is a modified beam with embedded I section inside the old design beam. The cross-section is shown in figure 18.

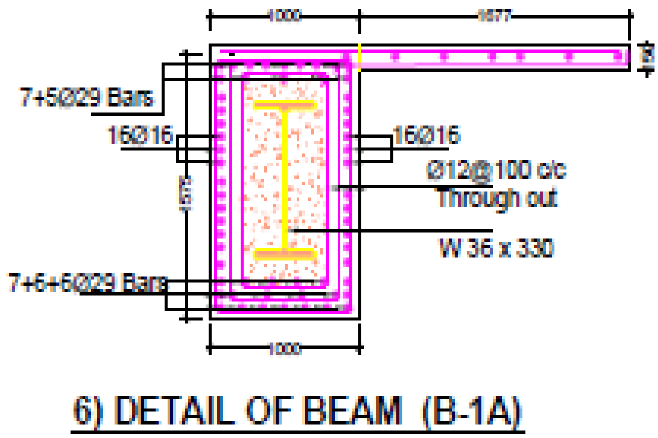

Figure 18. Old Design with I section Embedded

3. Old Design with Embedded U Zinc Coated Steel Plate

This is a modified beam with an embedded steel plate inside the old design beam. The cross-section is shown in figure 19.

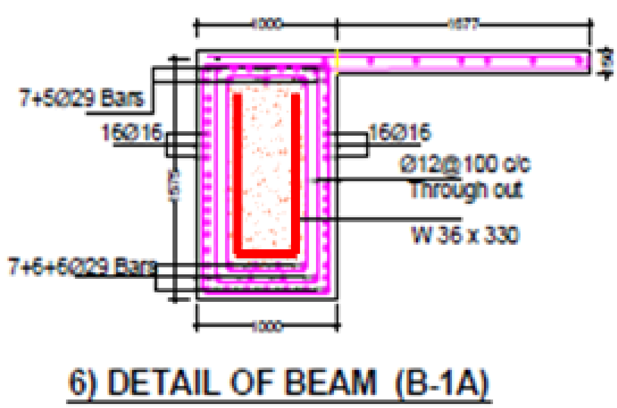

Figure 19. Old Design with Embedded U Zinc Coated Steel Plate

4. Old Design with Jacketed Zinc Coated Steel Plate

This is a modified beam with jacketed steel plate around the old design beam. The cross-section is shown in figure 20.

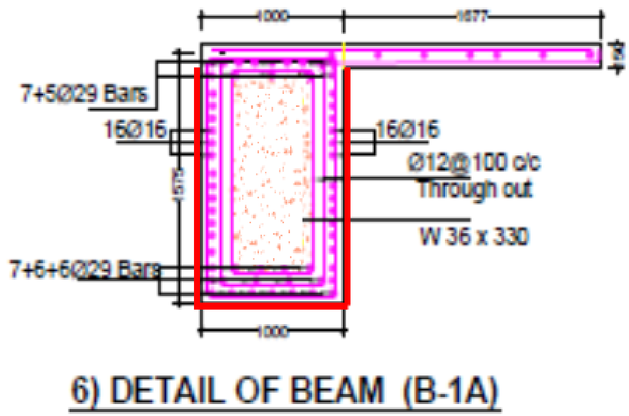

Figure 20. Old Design with Jacketed Zinc Coated Steel Plate

5. New Design

This is the new design in which the cross-section of the beam was increased to increase the strength, figure 21 shows the cross of the newly designed beam.

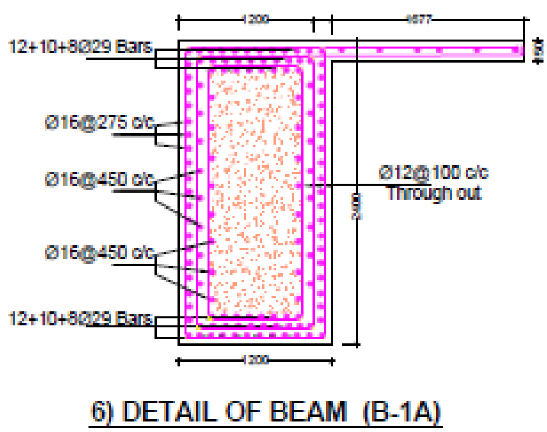

Figure 21. New Design

4.4.2. Analysis In ETABS

We performed time history analysis on all the five beam models, the procedure we used is mentioned below:

1. Calculated Moment from the loading by using the method of sections
2. Calculated Curvature and Rotation from Deflection by using Double Integration Method
3. By using Bilinear Idealization, Plastic Hinges was defined in ETABS for each variation. (Embedding, Jacketing). The following figure 22 shows the plastic hinge assigned to the jacketed and embedded steel plate beam.
4. Assigned plastic hinges to the beams and Columns

Point	Moment/SF	Rotation/SF
E-	-1.146	-0.12655
D-	-1.188	-0.0778
C-	-1.269	-0.05022
B-	-1	0
A	0	0
B	1	0
C	1.269	0.05022
D	1.188	0.0778
E	1.146	0.12655

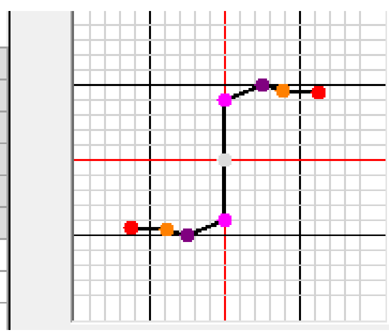

Figure 22. Plastic Hinge

5. Used data from history to perform Time History analysis, the following figure 23 shows the earthquake acceleration concerning time, the peak acceleration of the earthquake is .3549 at the time 9.55 second.

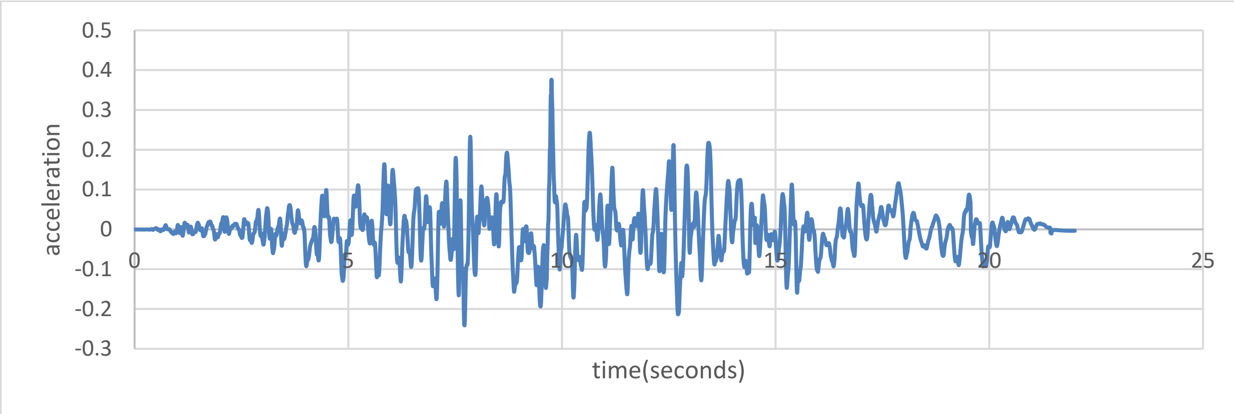

Figure 23. Earthquake Data

Derived the following results from the analysis and compared the 5 models using those results.

- Maximum Story Displacement
- Maximum Story Drift
- Overturning Moment
- Story Shear
- Plastic Hinge Response

5. Comparison

5.1. Maximum Story Displacement

Story displacement can be defined as "It is the displacement of a story concerning the base of a structure". This can be seen from Figure 24 that the old design showed the maximum story displacement and embedded I beam model shoed the minimum story displacement than the other 4 models.

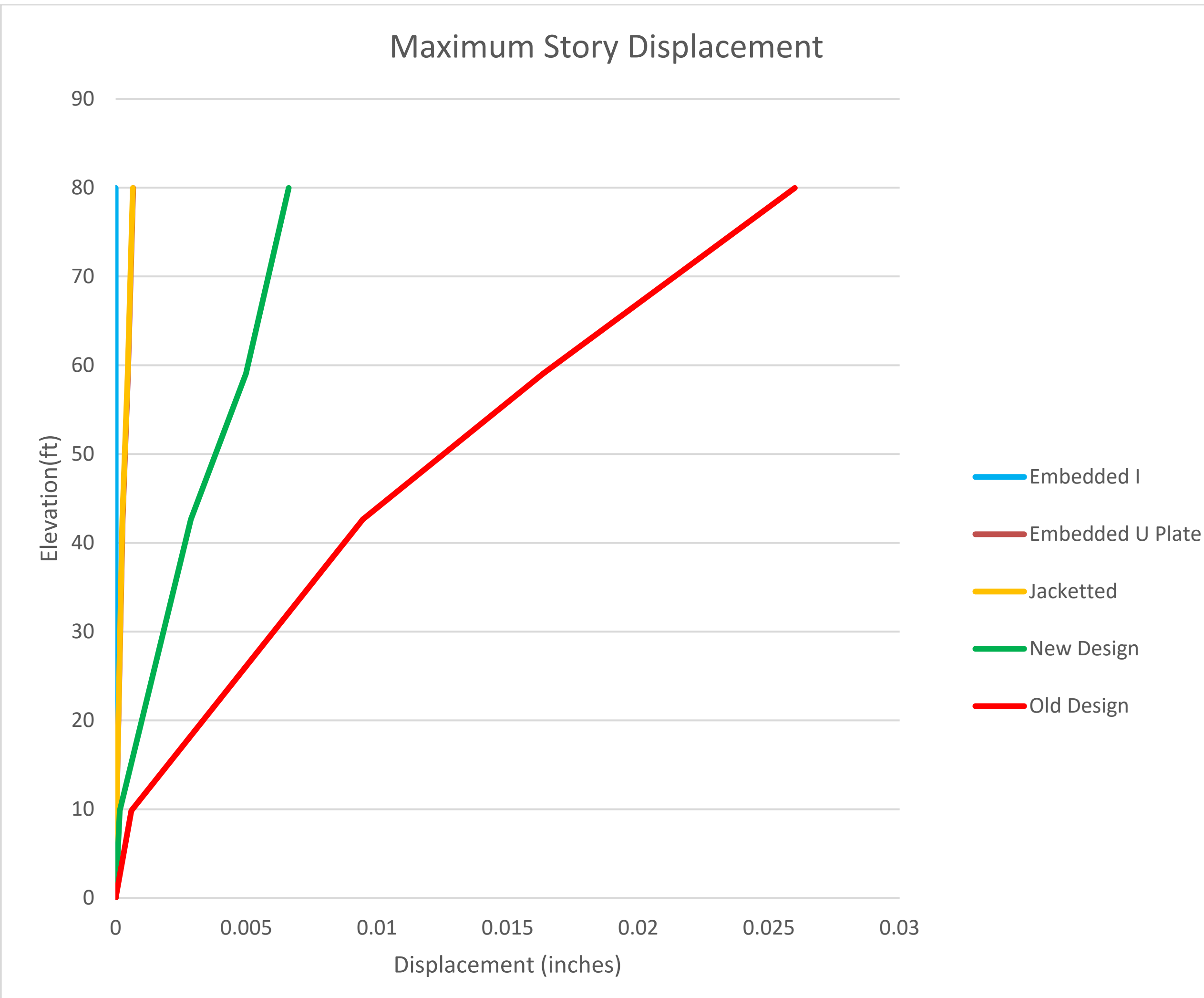

Figure 24. Maximum Story Displacement

This Figure 25 shows the percentages of maximum story displacement with Old design as standard. It can be observed that

- New design beam model showed 74% less story displacement than the old design beam model.
- Embedded steel plate and jacketed beam model showed 97% less story displacement than the old design beam model.

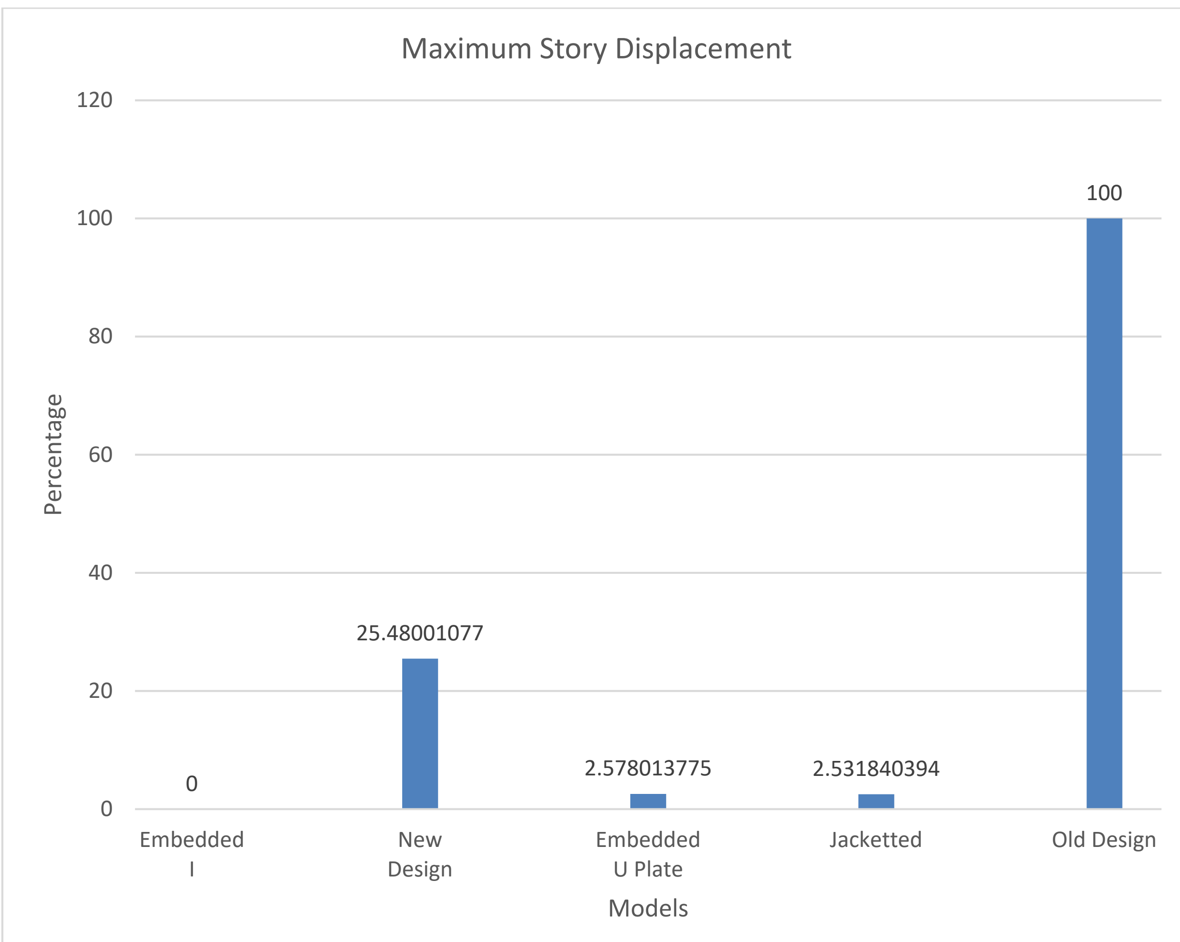

Figure 25. Maximum Story Displacement Percentage

5.2. Maximum storey drift

Story drift can be described as "This is the displacement of one story over the other story". This Figure 26 shows that the maximum story drift of old design beam model is highest and embedded I beam model shows the lowest story drift among all 5 models.

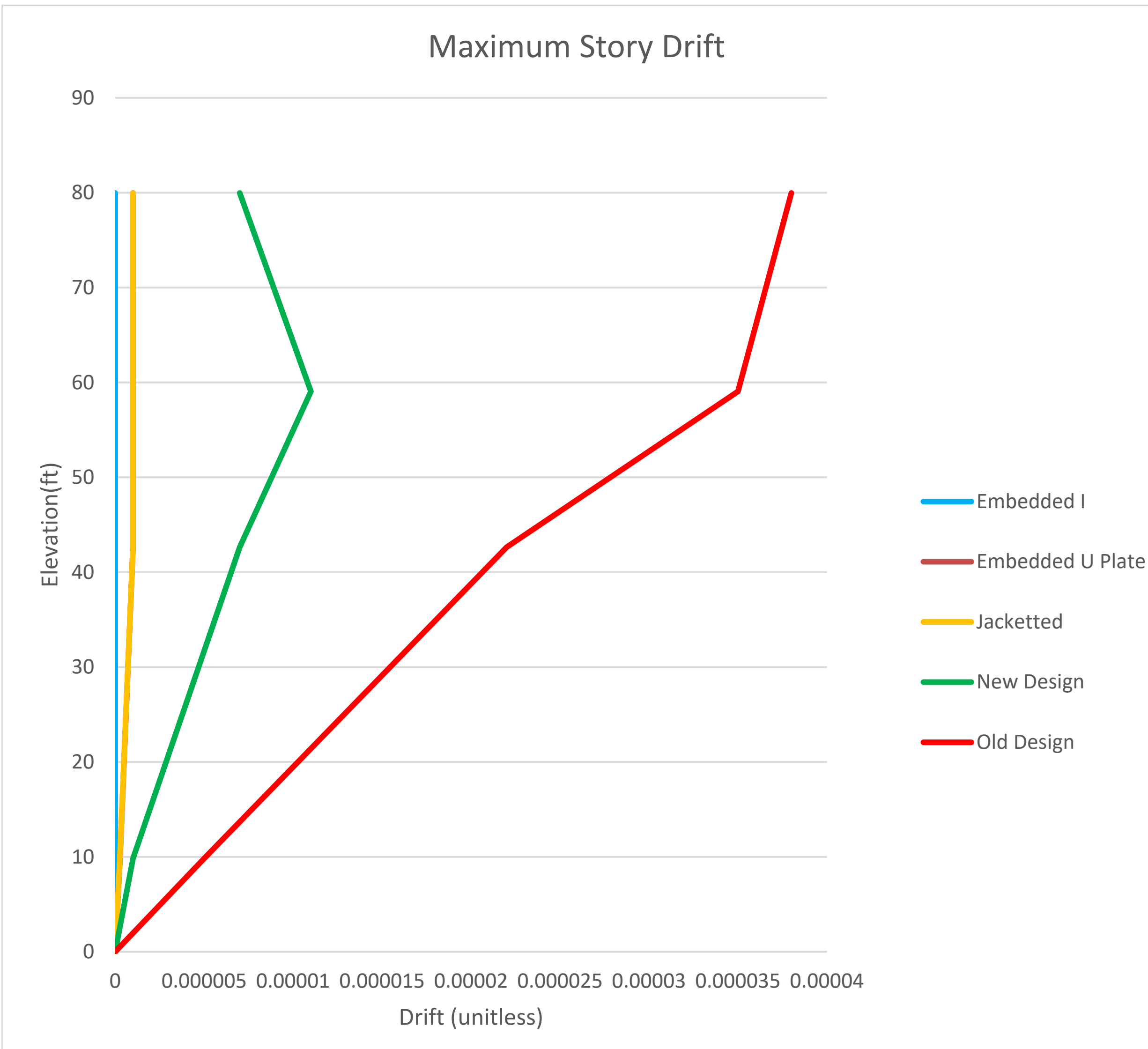

Figure 26. Maximum Story Drift

This Figure 27 shows the percentages of maximum story drift with Old design as standard. It can be observed that

- New design beam model showed 72% less story drift than old design beam model.
- Embedded steel plate and jacketed beam model showed 97% less story drift than old design beam model.

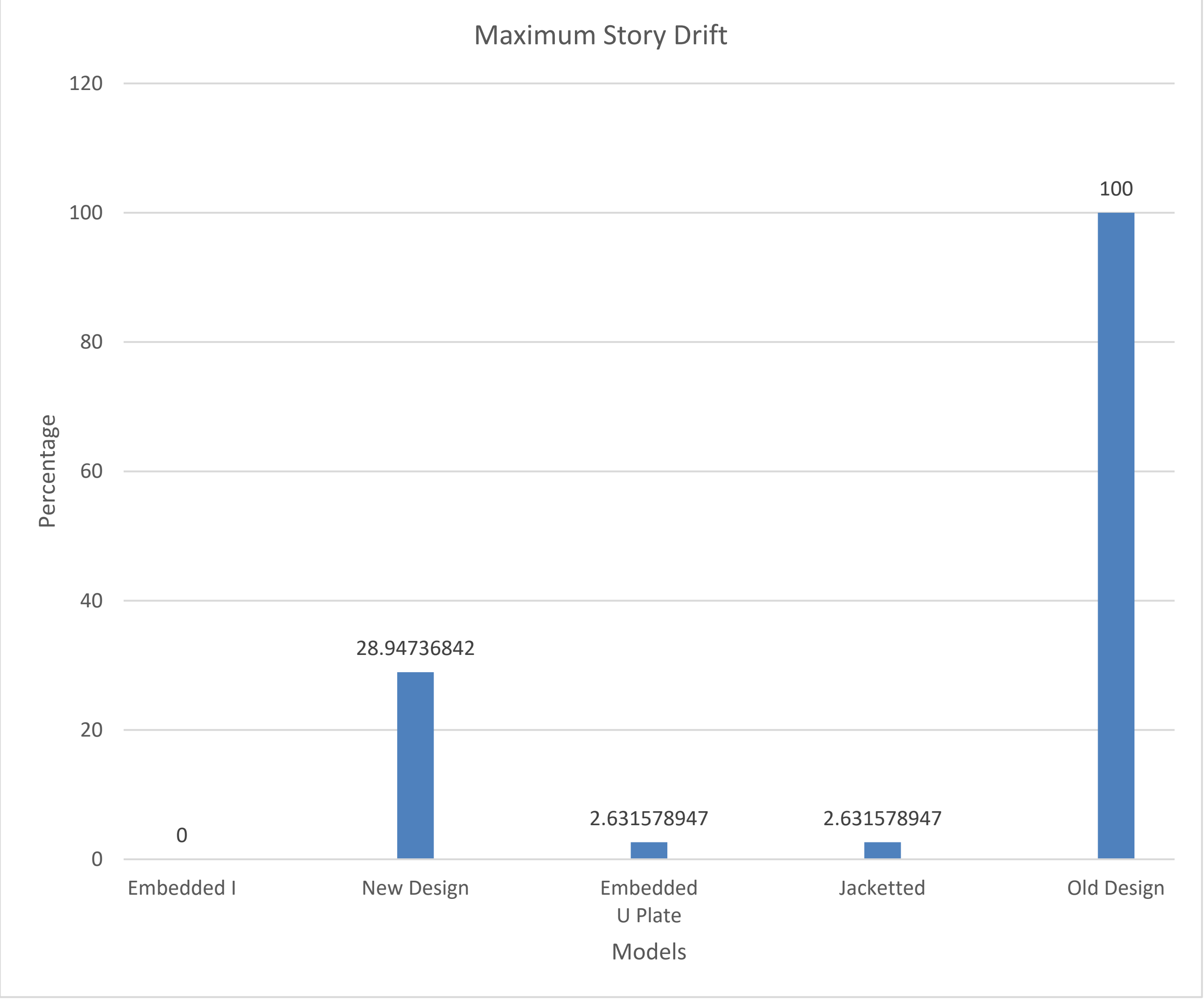

Figure 27. Maximum Story Drift Percentage

5.3. Overturning moment

It is Force times the perpendicular distance of the line of action of the force F from the base of the body. If this moment is greater than the moment due to self-weight about the baseline the structure will overturn. This Figure 28 shows that the overturning moment of the old design beam model is highest and embedded I beam model shows the lowest overturning moment.

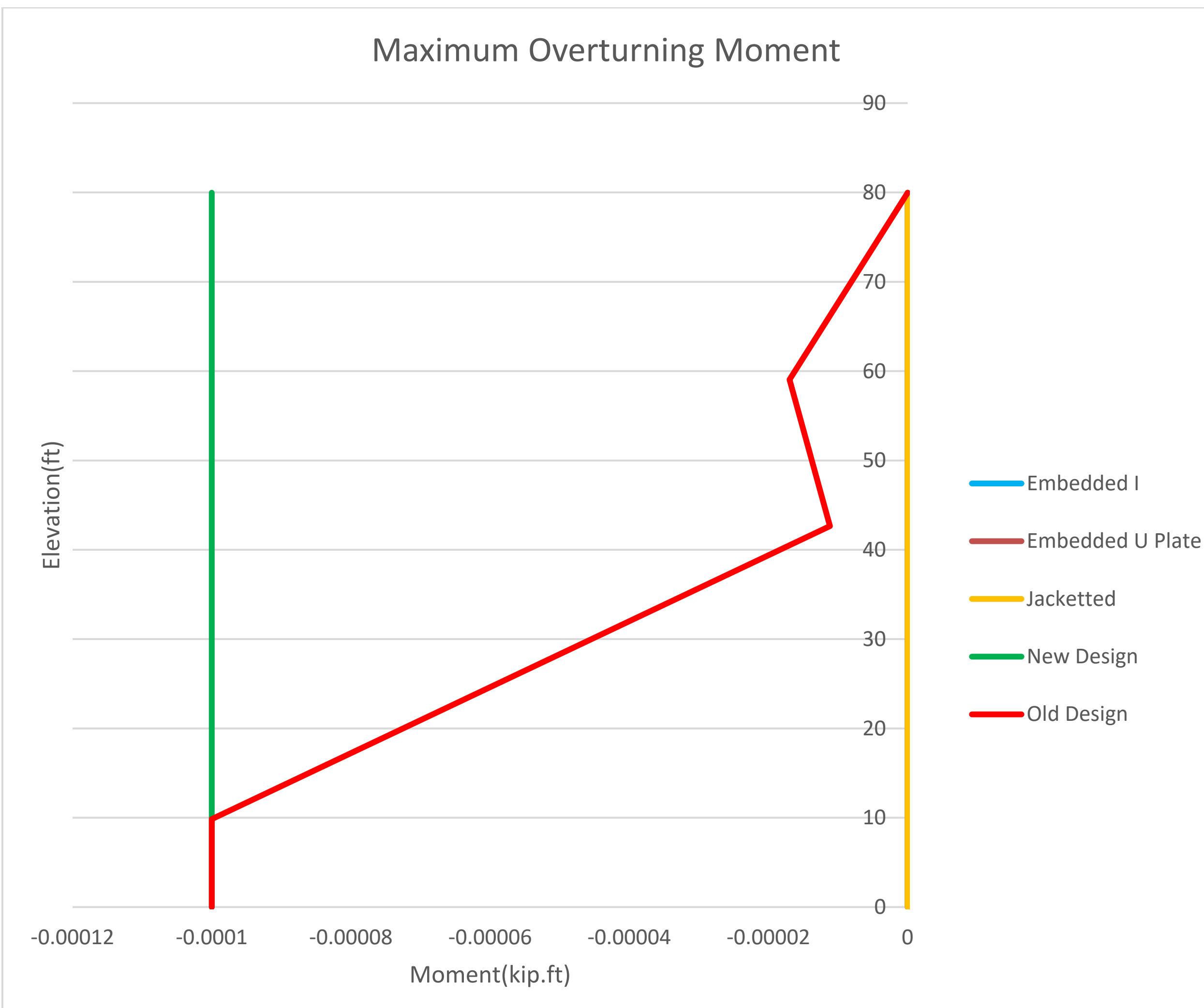

Figure 28. Maximum Overturning Moment

This Figure 29 shows the percentages of the overturning moment with Old design as standard. It can be observed that

- New design beam model shows 32% less overturning moment than old design beam model.
- Embedded steel plate and jacketed beam model showed 86% less overturning moment than old design beam model.

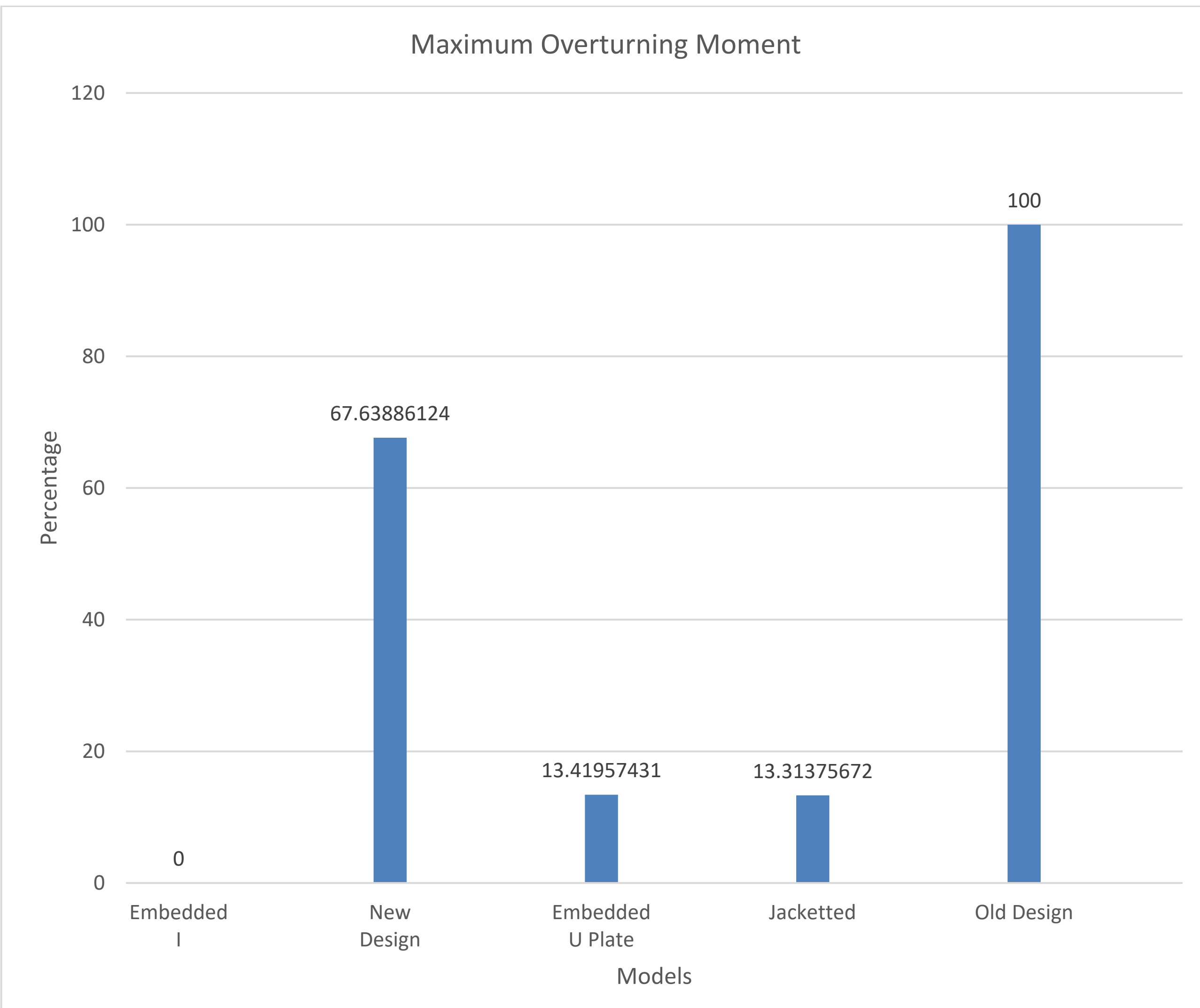

Figure 29. Maximum Overturning Moment Percentage

5.4. Story shear

Story shear indicates how much lateral load is acting per story, either wind or seismic. The lower you go, the bigger your shear gets. This Figure 30 shows that the new design beam model shows the highest story shear and the embedded I beam model shows the lowest among all 5 models.

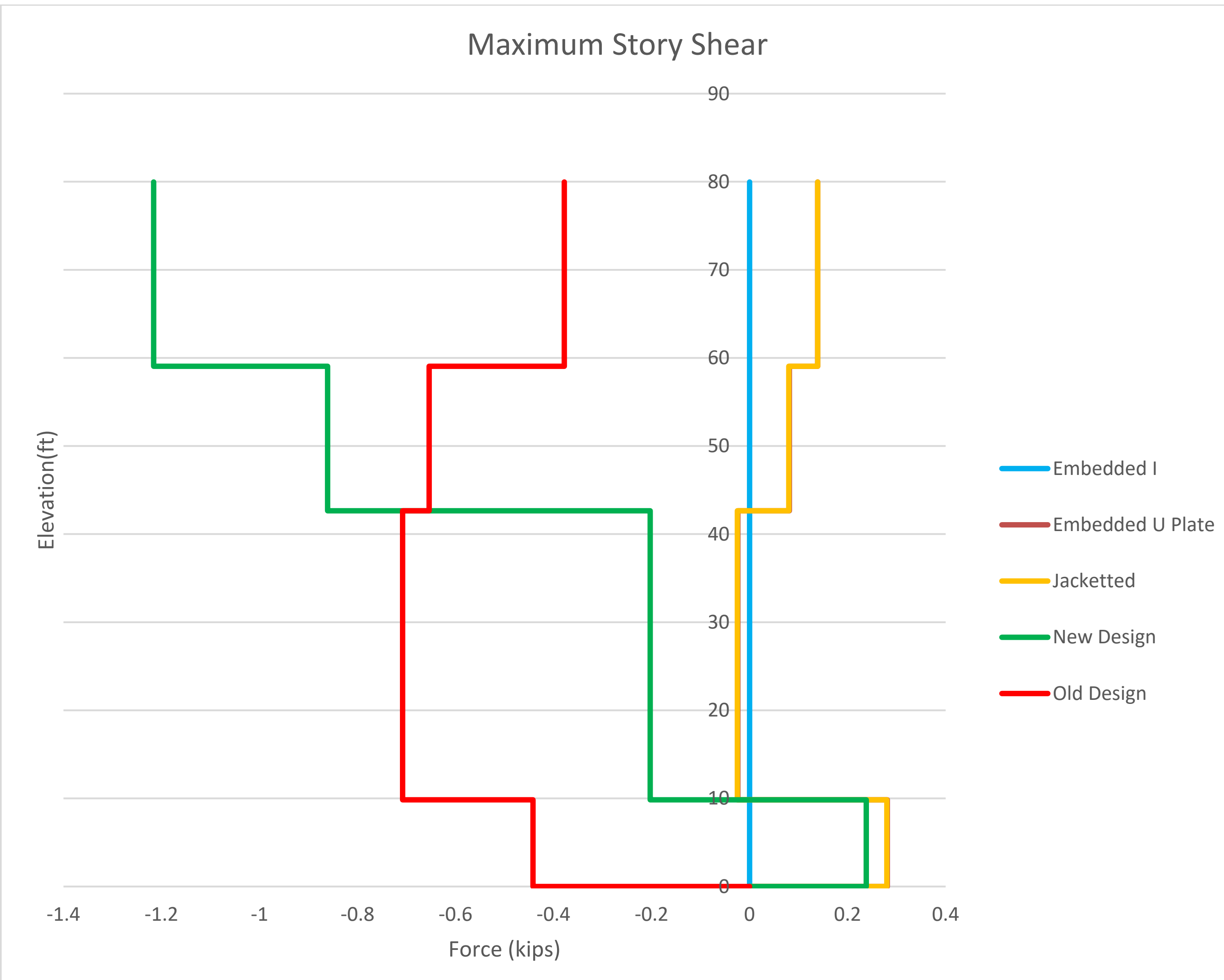

Figure 30. Maximum Story Shear

This Figure 31 shows the percentages of story shear with Old design as standard. It can be observed from the graph that

- New design beam model showed 71% more story shear than old design beam model.
- Embedded steel plate and jacketed beam model showed 61% less story shear than old design beam model.

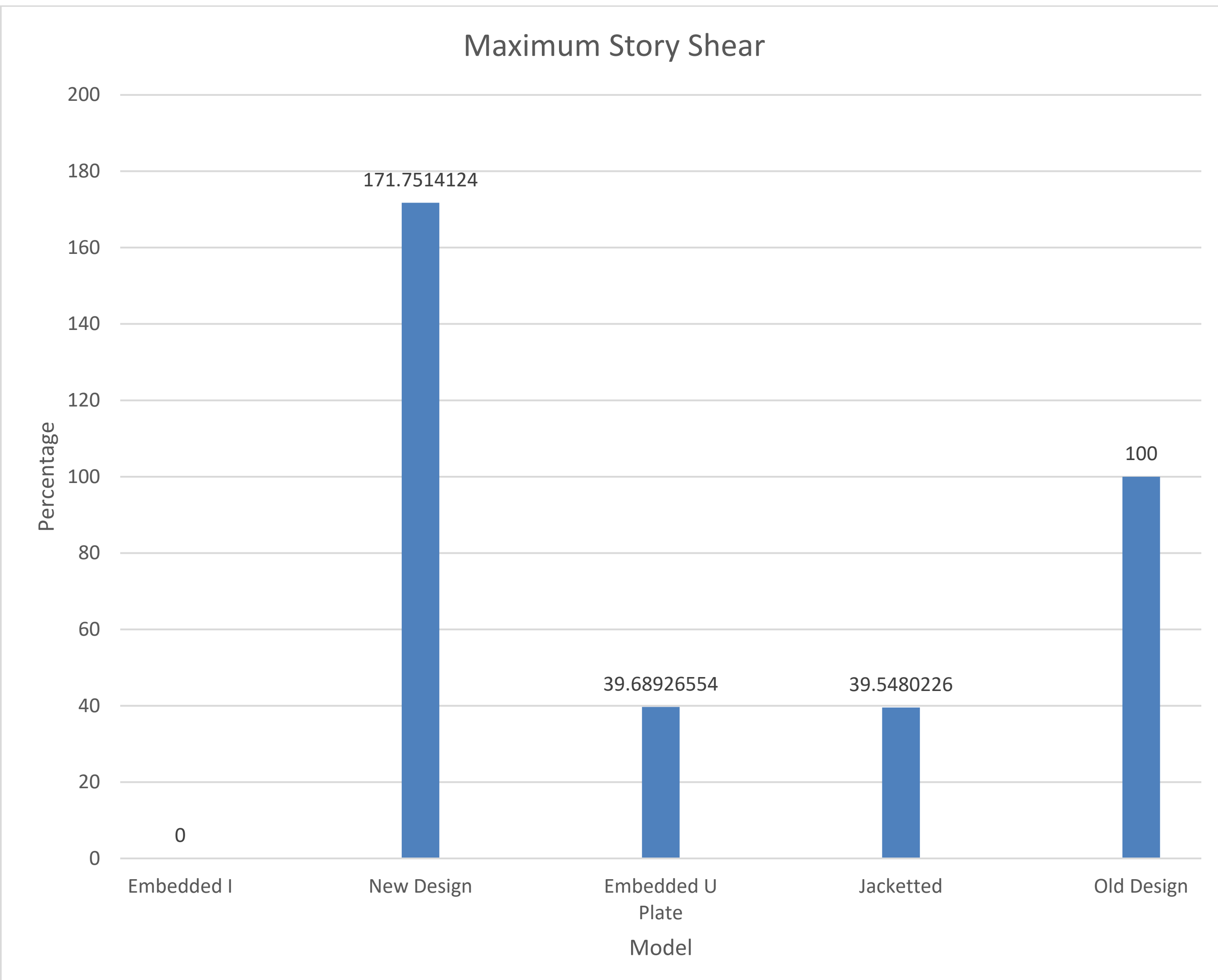

Figure 31. Maximum Story Shear Percentage

5.5. Plastic hinge response

A plastic hinge, in structural engineering, refers to the deformation of a part of a beam wherever plastic bending happens. This Figure 32 is called a backbone curve which represents the energy absorbed by a structural member.

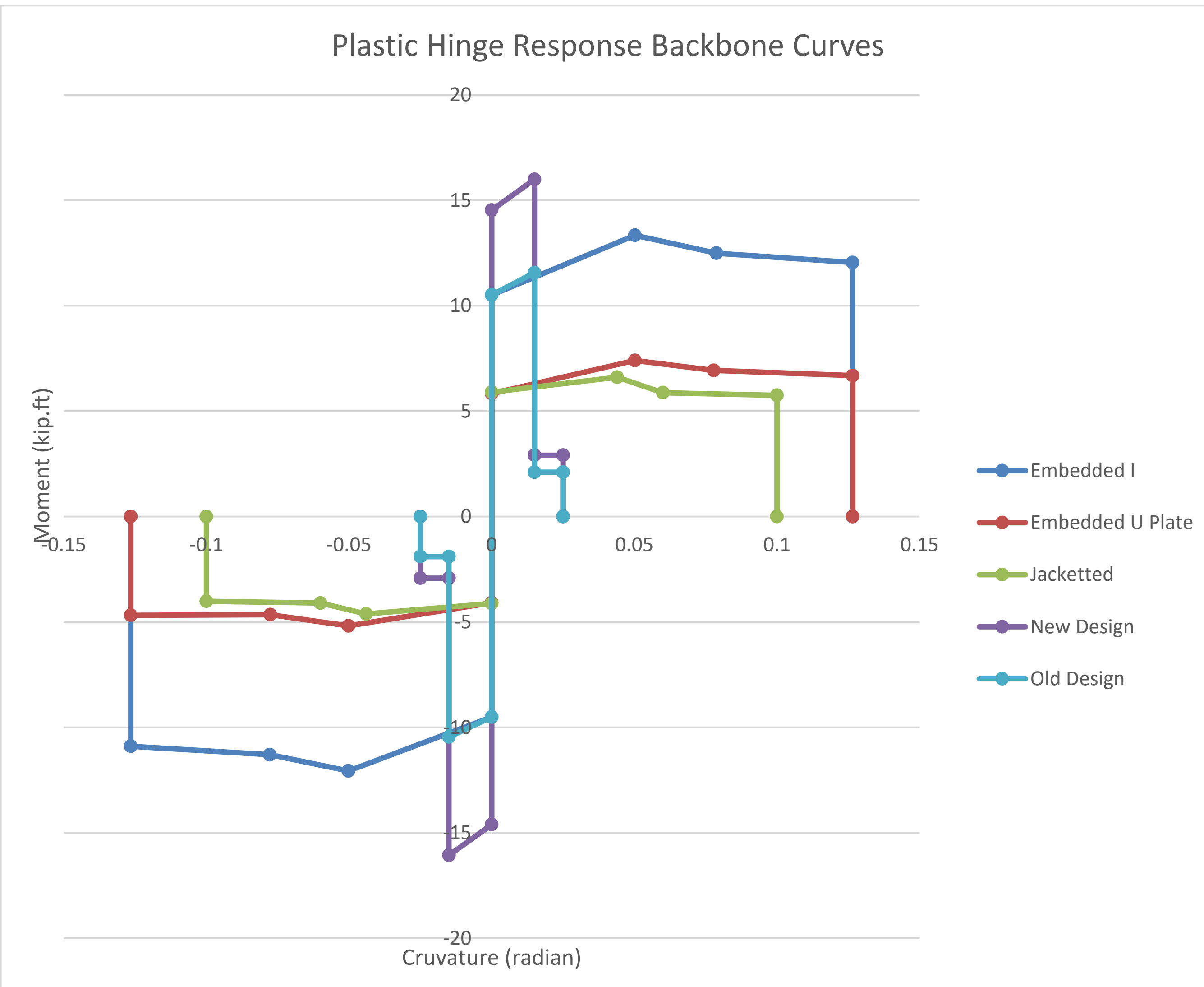

Figure 32. Plastic Hinge Backbone Curves

This Figure 33 shows the percentages improvement in energy absorption with Old design as standard. It can be observed that

- Embedded I beam model showed 732% more energy absorption than old design beam model.
- The embedded steel plate model showed 310% and 210% more energy absorption than old design beam model and jacketed model respectively.

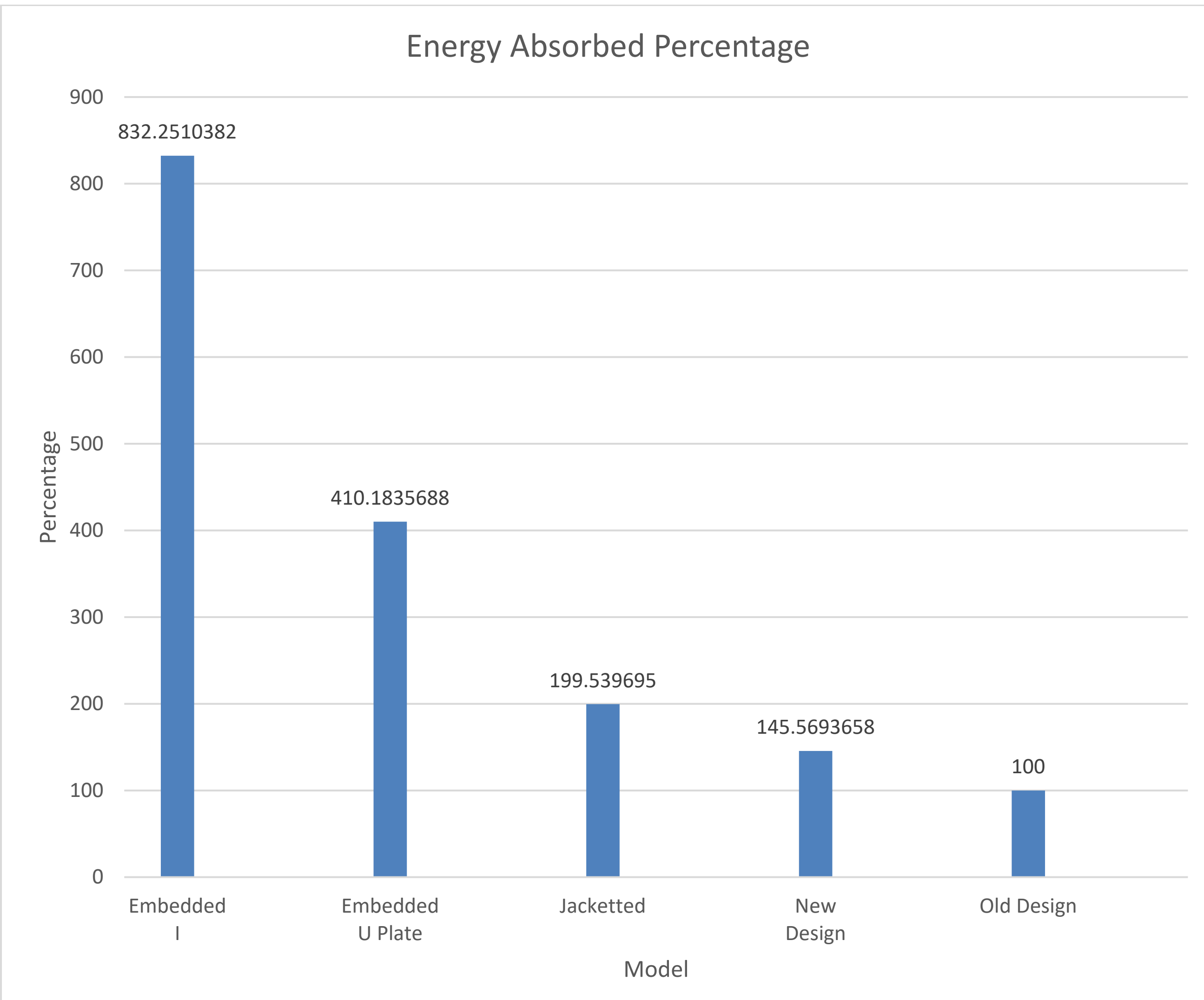

Figure 33. Energy Absorbed Percentage

This Figure 34 shows the amount of energy absorbed by each model, the embedded I beam model showed the maximum energy absorption of 2.957 and old design beam model showed the lowest energy absorption of .355.

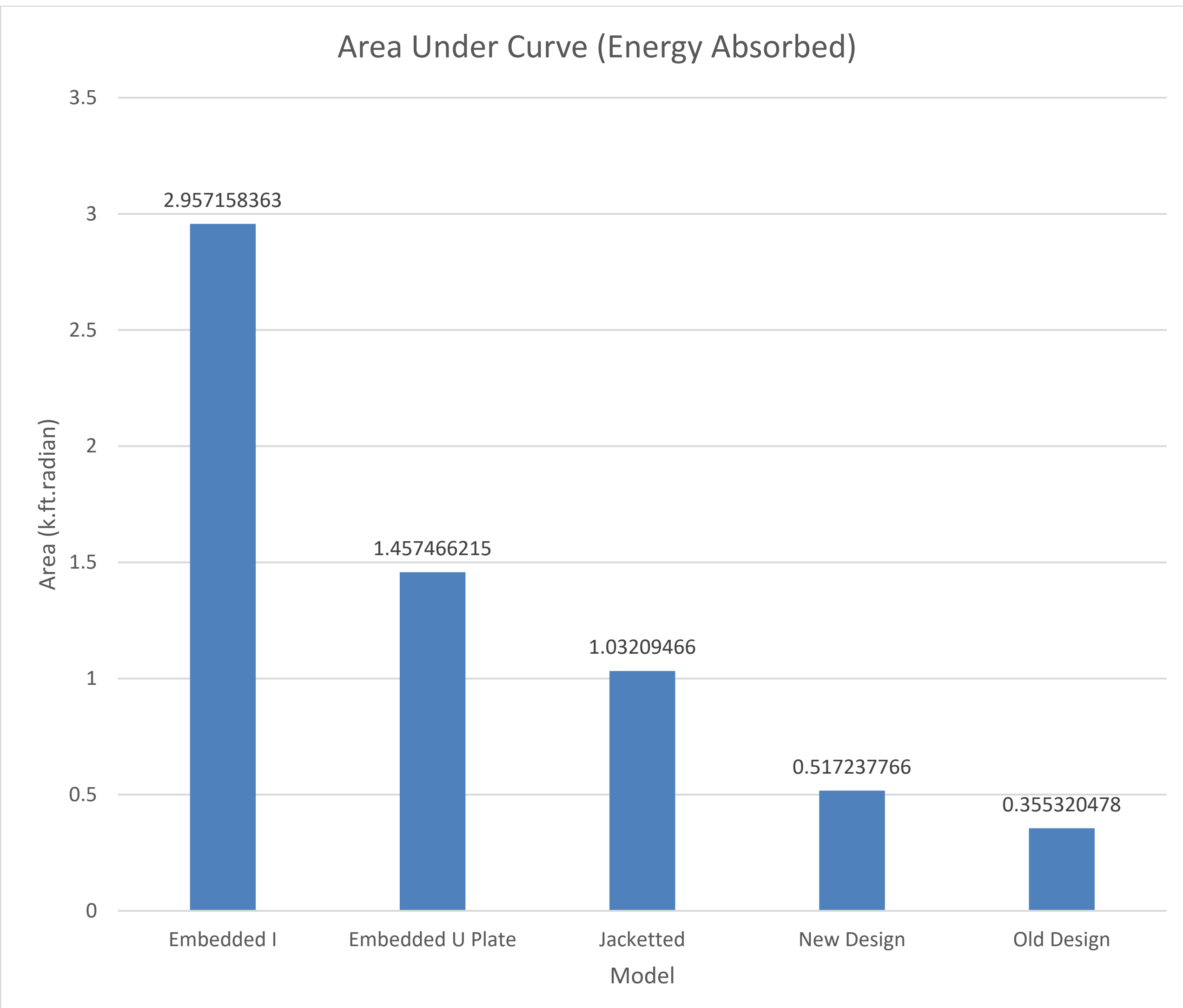

Figure 34. Area under Plastic Hinge Curve

5.6. Observations

By comparing embedding U plate and jacketing plate in the beam of silo substructure, the results are:

- The jacketed model gives $\mathbf{0.04\%}$ less story displacement than embedded U plate model.
- The Jacketed model gives the same story drift as Embedded U Plate model.
- The Embedded U Plate model has $\mathbf{0.1\%}$ more overturning moment than Jacketed model.
- The Jacketed model gives $\mathbf{0.14\%}$ less story shear than Embedded U Plate model.
- The Embedded U Plate plastic hinge absorbs $\mathbf{210.64\%}$ more energy than the Jacketed plastic hinge.

6. Conclusions

By observing the results from testing of beams in flexure and analysis in ETABS, the following conclusions have been drawn:

- Jacketed beam withstands **35.85%** more load and behaves rigid and makes the whole structure behaves rigid.
- Embedded beam withstands **6.12%** more load and shows ductile behaviour and can absorb **210.64%** more energy.
- The Jacketed model gives **0.04%** less story displacement and **0.14%** less story shear than Embedded U Plate model.
- The Embedded U Plate model has **0.1%** more overturning moment than Jacketed model.
- More ductility and load caring capacity can be achieved in a structure by using embedded steel plate combinedly with R.C.C beam than the conventional beam.
- More strength can be achieved by using a jacketed steel plate around a conventional beam.

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