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NUMERICAL INVESTIGATION AND COMPARISON STUDY OF COLD FORMED STEEL CASTELLATED I-SECTION

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Abstract: In this study modeling and analysis of Cold Formed Steel Castellated I-Section is presented. A castellated steel beam is per definition a wide flange (WF) or I shaped steel profile with openings, to reduce self-weight and improve the effectiveness in terms of material use. Recently, extensive study on these castellated steel beams has been conducted, involving different shapes in web openings. The main goal of these research works was to evaluate and analyze its optimum opening sizes and shapes configuration. More in-depth research work to the behavior and the influence of holes to WF beams need to be conducted. In this paper, cold formed 5 number of I–beam with constant dimension and varying load studies conducted. Additional castellated beam with circular and hexagonal shaped web opening is chosen as alternate. The study involves a modification in the variation of circular and hexagonal web openings both in the horizontally direction with single and 5 number of holes. A numerical study based on the finite element method conducted with the Abaqus /CAE 6.12 software is used to analyze the elastic and buckling behavior of the beam. The obtained results are compared from the finite element analysis to optimize the section element.

KEYWORDS: Cold-formed steel, castellated i- beam, circular, hexagonal, Abaqus

I.INTRODUCTION

Cold-formed steel (CFS) section is the term used for products which are made by rolling or pressing thin gauges of steel sheets into goods. CFS goods are created by the working of thin steel sheets using stamping, rolling or presses to deform the steel sheets into a proper product at significantly cooler temperatures, often at even room temperature. The advantages of using cold-formed steel over hot rolled sections include high strength to weight ratio, precision in dimensions obtained (close tolerances), easier to produce any desired shape, use of all conventional jointing methods, easier to transport and erect. A castellated steel beam is an I-shaped beam section with a variety in shape opening in the web. The opening can be hexagonal, rectangular, circular, diamond or oval in shape. The origin of the name “castellated” is derived from the pattern of holes in the web, because castellated means “built like a castle or regular holes in the walls, like a castle”. The castellated steel beam is made by expanding a standard rolled shape in a manner which creates a regular pattern of holes in the web. At first, the chosen pattern is made along the web on a path that will be cut. The cut halve beams are separated and then welded together based on the chosen opening shape. The use of castellated steel beams nowadays has been rapidly catching attention due to its advantages. A castellated steel-beam in a structure gives the advantage of its lighter weight. Castellated steel-beams can also utilize the placement of installations. Basically, steel sections that satisfy strength requirement have difficulty in satisfying serviceability requirements. Castellated steel beams can be the way to overcome that problem by providing a greater depth, and thus a greater moment of inertia. Furthermore, the modification of web openings affects the failure modes and stability of castellated steel beams itself. Numerous researchers have been dedicating their work to studying the effect of modification of web shaped opening. In this paper, a deepen research on the behavior of castellated steel beams with circular and hexagonal shaped opening was conducted.
The aim of this study is to compared to the hot rolled sections, the use of cold rolled sections is very limited in the construction industry owing to the fact that not much research has been done in predicting the performance of cold form steel sections used as a beam at higher loads.

It has many advantages over hot rolled section like High Strength to Weight ratio. • Easy to produce any desired shape. • Precision in dimensions obtained (close tolerances). • All conventional jointing methods can be adopted. • Easy to transport and erect. • The recycling of this type of material is possible easily. • The termite-proof and rot proof sections are prefabricated. High Strength to Weight ratio. • Easy to produce any desired shape. • Precision in dimensions obtained (close tolerances). • All conventional jointing methods can be adopted. • Easy to transport and erect. • The recycling of this type of material is possible easily. • The termite-proof and rot proof sections are prefabricated.

Common applications includes:- • Roof and wall systems (industrial, commercial, and agricultural buildings) • Steel racks for supporting storage pallets • Structural members for plane and space trusses • Frameless Stressed skin structures: Corrugated sheets or sheeting profiles with stiffened edges are used for small structures.

Fig 1.1: Roof Structure (a) (b) Fig 1.2: (a) Parking Roof Castellated Beam Structure, (b) Cable Carriage Racks

Buckling: If it compresses a slender member it will fail at stresses much lower than yield. Buckling Analysis is an FEA routine that can solve all the difficult buckling problems that cannot be solved by hand calculations. Linear Buckling (LBA) is the most common Buckling Analysis. The nonlinear approach, on the other hand, offers more robust solutions than Linear Buckling.

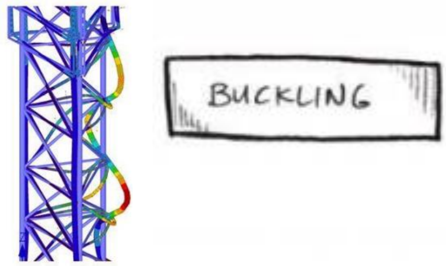


Fig 1.3: buckling

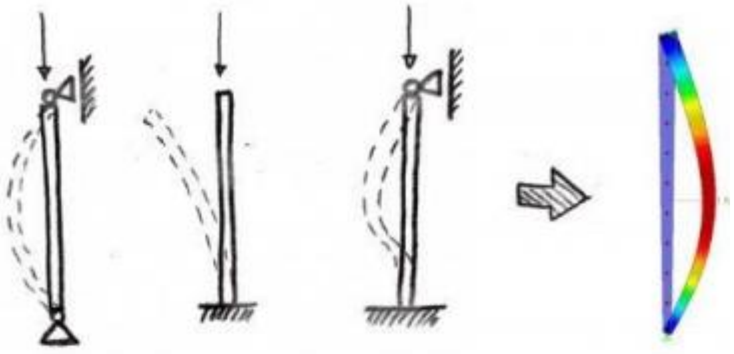


Fig 1.4: buckling

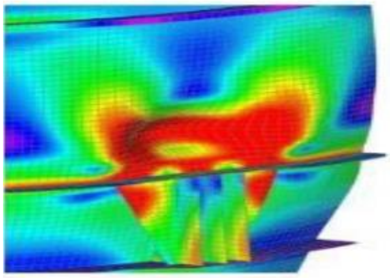


Fig 1.5: linear buckling Analysis Nonlinear Buckling

Fig 1.6: Nonlinear buckling Analysis

The main modes of failure beams are as follows

- **Local buckling**: Local buckling is an extremely important facet of cold formed steel sections on account of the fact that the very thin elements used will invariably buckle before yielding. Thinner the plate, the lower will be the load at which the buckles will form. If a beam with a very slender web, it can happen that the web will buckle on its own, before the beam will fail due to buckling (or LTB in bending). This failure of a slender part may mean failure. However, often (especially in welded steel I-sections in bending) it can lead to another state of equilibrium where the beam is still working. Such conditions are usually called as “post-critical capacity” or “post-critical work”.

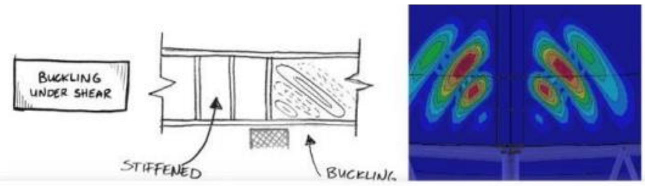


Fig 1.7: local buckling under shear.

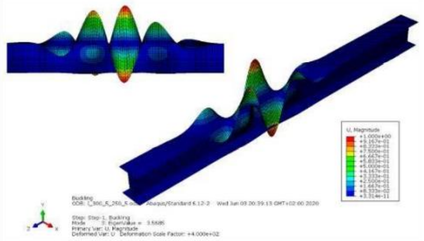


Fig 1.8: local buckling Analysis

- **Global buckling**: is a buckling mode where the member deforms with no deformation in its crosssectional shape, consistent with classical beam theory.

- **Lateral and Torsional Buckling** When the beam is in beginning, half of the cross-section is compressed, while the other half is in tension. The compressed part wants to “buckle” while the tension part tries to stabilize the whole beam. In the end, the beam will “twist” and fail if it won’t be supported laterally in a proper way. Think about it like about “normal buckling, but in bending not compression”.

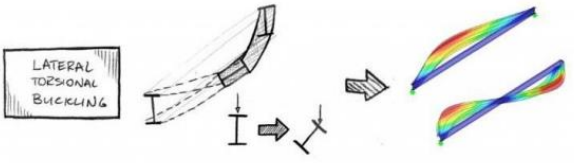


Fig 1.9: Lateral and Torsional buckling

- **Plastic failure:** We can think about it as a “stress failure”. In essence, a part is loaded with so much, which the material fails to carry stresses it is subject to, like a concrete brick in a hydraulic press. There is no stability influence. If it compresses a concrete cube in a hydraulic press, it won’t buckle.
- **Stability failure**: This is the “pure buckling failure”. Since in this case buckling happens in “purely elastic range” plastic capacity of the material is irrelevant (as long as it is high enough to keep buckling within elastic range). In fact plastic failure and stability failure can “cooperate” to cause failure sooner than any single one of them could.

Benefits of Nonlinear Buckling:

- Analysis is nonlinear, which means it can take “second order effects” into account.
- Imperfections will work as intended! Since “second order effects” are accounted for, implementing imperfections actually may sense. They will work as intended increasing the deformations of the model in subsequent load iterations.
- Nonlinear material may be added, if buckling will happen while part of the model are yielding, we can easily add nonlinear material properties to take that into account.

This is why Nonlinear FEA is in high demand. It can simply design stuff accurately, without guessing and over-conservative assumptions.

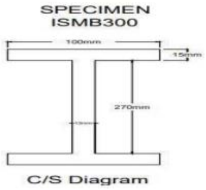


Fig.1.10 Cross Section of Reference I-Beam

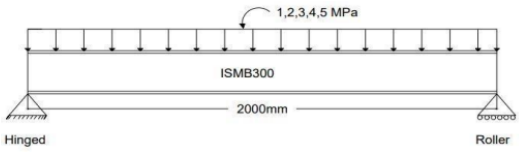


Fig.1.11 Plan of Reference Beam (ISMB300)

II. LITERATURE REVIEW

D. Kerdal was studied the structural behavior of castellated beams are reviewed and a number of different possible failure modes identified. Several of these do not occur with plain webbed beams since they are a direct result of the different way in which shear is transferred through the perforated web. Examples are a Vierendeel mechanism; web post buckling due to shear and web weld rupture. Failure by either the formation of a flexural mechanism or by lateral-torsional instability is essentially similar to the equivalent modes for solid web beams. Methods for predicting the loads at which each of these types of failure occurs are evaluated against the available experimental data and the limitations in a number of these analytical approaches is discussed. It is concluded that both lateral-torsional instability and the formation of a flexural mechanism may be handled by an adaptation of established methods for plain webbed beams, providing the cross-sectional properties are those corresponding to the centerline of a castellation. Currently available methods for the determination of collapse in the other modes, while rather less accurate, are adequate for design except in the case of web post buckling due to compression.

Ehab was investigates the behavior of normal and high strength castellated steel beams under combined lateral torsional and distortional buckling modes. An efficient nonlinear 3D finite element model has been developed for the analysis of the beams. The initial geometric imperfection and material nonlinearities were carefully considered in the analysis. The nonlinear finite element model was verified against tests on castellated beams having different lengths and different cross- sections. Failure loads and interaction of buckling modes as well as load–lateral deflection curves of castellated steel beams were investigated in this study. An extensive parametric study was carried out using the finite element model to study the effects of the change in cross-section geometries, beam length and steel strength on the strength and buckling behavior of castellated steel beams. The parametric study has shown that the presence of web distortional buckling causes a considerable decrease in the failure load of slender castellated steel beams. It has also shown that the use of high strength steel offers a considerable increase in the failure loads of less slender castellated steel beams. The failure loads predicted from the finite element model were compared with that predicted from Australian Standards for steel beams under lateral torsional buckling. It has shown that the Specification predictions are generally conservative for normal strength castellated steel beams failing by lateral torsional buckling, conservative for castellated steel beams failing by web distortional buckling and quite conservative for high strength castellated steel beams failing by lateral torsional buckling.

Mei Liu was presented numerical investigations on the behavior of a Bolted Castellated Steel Beam (BCSB) with octagonal web openings. Instead of welding the upper and the lower Teesections of a Castellated Steel Beam (CSB) together in the factory, they were connected using high strength bolts at the construction site. Thus, the upper and the lower Tee-sections can be transported separately, especially being convenient for a castellated steel beam with great section height. The residual stresses in the web-post induced by welding could also be avoided. The shear buckling behavior of the web- post in a BCSB with octagonal openings was studied using a verified finite element model. The buckling mode and the buckling strength of the web-post in a BCSB were compared with those of a traditional Welded Castellated Steel Beam (WCSB). Research results showed that web-posts in a BCSB with octagonal web openings had as good structural performance as those in a WCSB. Studied parameters of the BCSB included the bolt diameter, the width-to-thickness ratio of the web-post and the bolt layout. To increase the buckling strength of the web-post, a BCSB using stiffened

connection plate was proposed. The Strut Model for predicting the buckling strength of the web-post in a traditional WCSB was employed for calculating that in a BCSB. Comparisons of buckling strengths obtained by Model predictions and finite element simulations showed that the Strut Model could be used Strut to predict the web-post buckling strength of a BCSB.
Mahmoud T. Nawar a , Ibrahim T. Arafa were estimated and promoted the static resistance of CSBs to enhance their ductility and dissipate blast energy through large deformation kinematics. Quasi- static experiments on CSBs were performed to investigate the effect of end connections and different strengthening techniques (closed holes and vertical stiffeners) on the static resistance of CSBs. Load-deflection and strain data were recorded for each specimen up to failure. Moreover, a Finite Element (FE) model was developed and verified against tests. Good matching through all phases of resistance was obtained between the FE and test results. An extensive parametric study was carried out to predict the full static resistance of CSBs under the effect of cross-section geometries. Different ranges of spans were investigated to determine the minimum effective spanto-depth ratio. By providing vertical stiffeners as well as bolted head plate connections, CSBs obtained a larger capability of deformation through the tension membrane stage to resist blast loads under simultaneous high tension and shear forces.

III. METHODOLOGY

Modeling and analysis was carried out for the Elements considered in this study using ABAQUS/CAE. ABAQUS FEA is a software suite for finite element analysis and computer-aided engineering, originally released in 1978. The name and logo of this software are based on the abacus calculation tool.

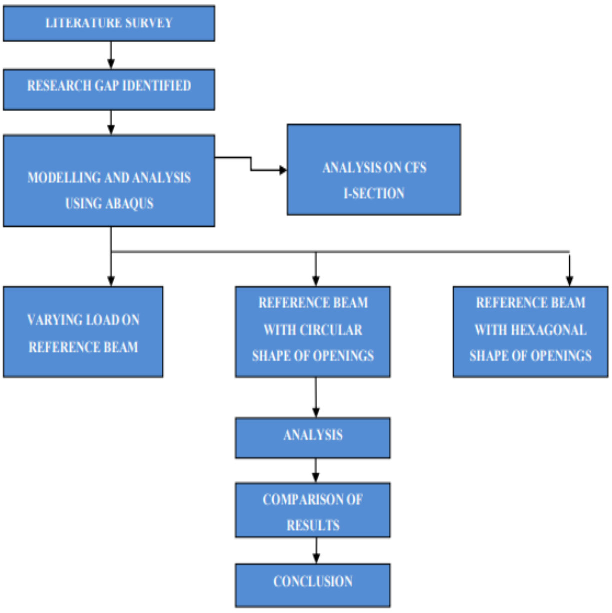


Fig.3.1 Schematic diagram of methodology

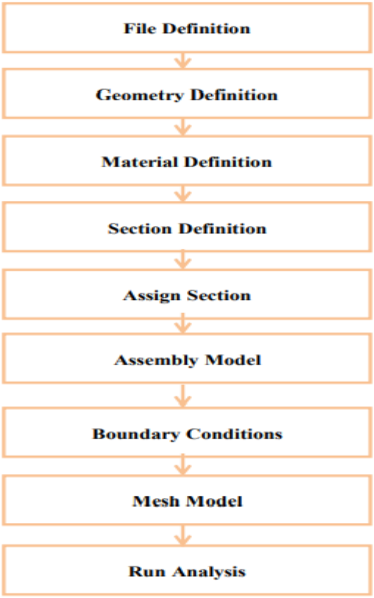


Fig.3.3 Schematic diagram of Analysis steps

IV. MODELLING AND ANALYSIS

Numerical investigation was carried out to estimate the capacity and behavior of castellated steel beams under load conditions using the finite element analysis tool ABAQUS. The results from the numerical investigation of reference beam with circular and hexagonal openings of castellated steel beams already done. Finite Element Analysis (FEA) is a numerical method for solving engineering problems in physical world. The solution of these problems requires solution to boundary value problem for partial differential equations. To solve the problem, it subdivides a large system into smaller, simpler parts that are called finite elements. The simple equations that model these finite elements are then assembled into a larger system of equations that models the entire problem. Choice of Element Type Element type S4 is a fully integrated, general-purpose, finite-membrane-strain shell element available in ABAQUS/Standard. The element's membrane response is treated with an assumed strain formulation that gives this study. All the Elements are tested under simply supported boundary condition. For the load to apply on the element, the restrain is released in the direction of load. This is achieved by providing Multiple Point Constraint (MPC) into the reference point where the boundary condition/load is to apply. The load is applied on the surface of the beam element whose boundary conditions are already defined. The applied pressure load is uniformly distributed throughout the cross section. It is necessary to perform the mesh convergence study to arrive at a mesh size that would yield an accurate result with the minimum computation time. The mesh convergence study is done and a suitable mesh size is arrived (5mm).

Table 4.1 Dimension details of column

SERIES	NOMENCLATURE	DIMENSION(mm)									LENGTH (mm)	LOAD (MPa)
		L	bf	tf	bw	tw	D	h-dia	h- edge	Spacing		
A												
A1	ISMB300	2000	100	15	270	15	300				2000	1
A2	ISMB300	2000	100	15	270	15	300				2000	2
A3	ISMB300	2000	100	15	270	15	300				2000	3
A4	ISMB300	2000	100	15	270	15	300				2000	4
A5	ISMB300	2000	100	15	270	15	300				2000	5
B	ISMB 300 WITH 1 CENTRE CIRCULAR HOLE	2000	100	15	270	15	300	50			2000	5
C	ISMB 300 WITH 5 CIRCULAR HOLE	2000	100	15	270	15	300	50		450	2000	5
D	ISMB 300 WITH 1 CENTRE HEXAGONAL HOLE	2000	100	15	270	15	300		100		2000	5
E	ISMB300 WITH 5 HEXAGONAL HOLE	2000	100	15	270	15	300		100	403	2000	5

Table 4.2 Material Properties of steel section

Grade of steel	ISMB300
Analysis Method	Nonlinear ,General- Elastic
Poisson’s ratio	0.3
Load Type	Pressure
Magnitude of Load	1,2,3,4,5 MPa
Element Type	8 Noded
Time Period	1,6
Young’s Modulus	209GPa
Increment	0.1
Mesh sizes	5mm,20mm,50mm

Modeling:-

CASE 1

I- Beam Parametric :- The model of the Reference Steel I-beam Element considered in this study is mentioned below. This model is the base model and to compared the General, Elastic Convergence Study different load parameters.
Elastic Study :- Load is applied as uniformly distributed load as 1MPa under simply supported condition.

Fig 4.1 shows that as ISMB 300 which is simply supported left end is hinged and right end is roller is used. In hinged condition Ux=0,Uy=0,Uz=0 all other displacement degrees are restrained .In roller Support Ux=0,Uy=0, .so that only translational degrees of freedom is allowed in z- direction ,all other degrees of freedoms are restrained and along that 1MPa load is applied on the surface of beam. Applying a value of 209.E3 for Young's modulus and a value of 0.3 for Poisson's ratio in the material data fields. The value of 0.1 for the initial increment size. U1, U2, and U3, since only the translational degrees of freedom need to be constrained. The magnitude of 0.5 for the load and the default Amplitude selection (Ramp) and the default Distribution (Uniform).

Use the Mesh module to generate the finite element mesh. To choose the meshing technique that ABAQUS/CAE will use to create the mesh, the element shape, and the element type. ABAQUS/CAE uses a number of different meshing techniques. The default meshing technique assigned to the model is indicated by the color of the model when you enter the Mesh module; if ABAQUS/CAE displays the model in orange, it cannot be meshed without assistance from the user. Reference I-beam is modeled using hexahedron 5mm size mesh.

Fig 4.3 shows that to create the element part as 8 nodded 3Dimensional reduced integration for the analysis. The element type is used here is solid. Element size used for meshing is 5mm. In the Job Manager to start the Job Manager. From the buttons on the right edge of the Job Manager, click Submit to submit the job for analysis. The status field will show Running. When the job completes successfully, the status field will change to Completed, ready to view the results of the analysis in the Visualization module. Results in the Job module's Job Manager to enter the Visualization module.ABAQUS/CAE opens the output database created by the job (Deform.odb) and displays a fast plot of the model.

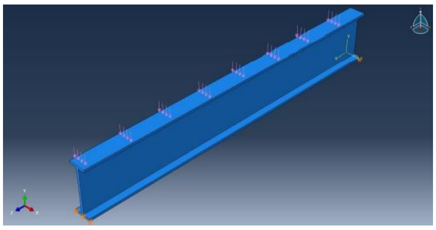


Fig.4.1 Loading of the base model.

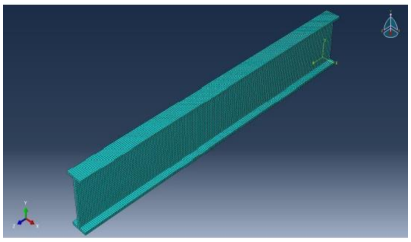


Fig.4.2 meshing of the base model.

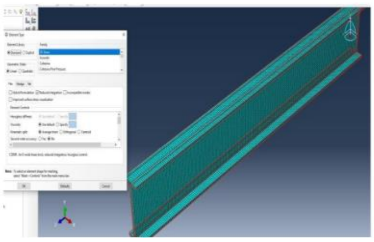


Fig.4.3 Element type of the base model.

Analysis:-

Figure 4.4 and 4.5 shows the stress strain deformation of reference I-section with 1MPa loading under simply supported condition .The stress is maximum at the point of support and the strain is maximum at the support of the section .Figure 4.6 is showing the deflection of the section under 1MPa is maximum at the x-coordinate.

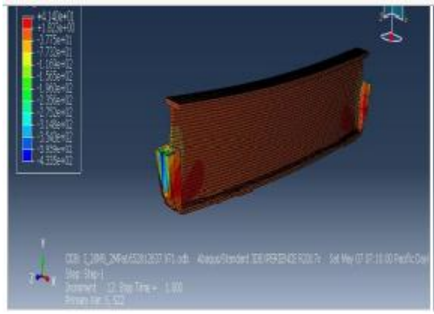
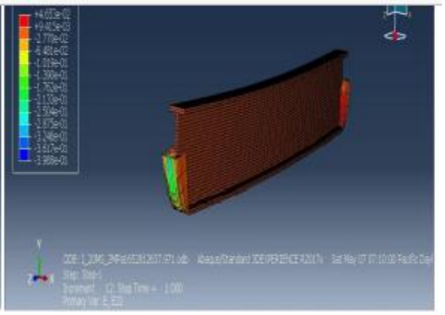



Fig.4.4 Stress Deformation of the base model. Fig.4.5 Strain Deformation of the base model.

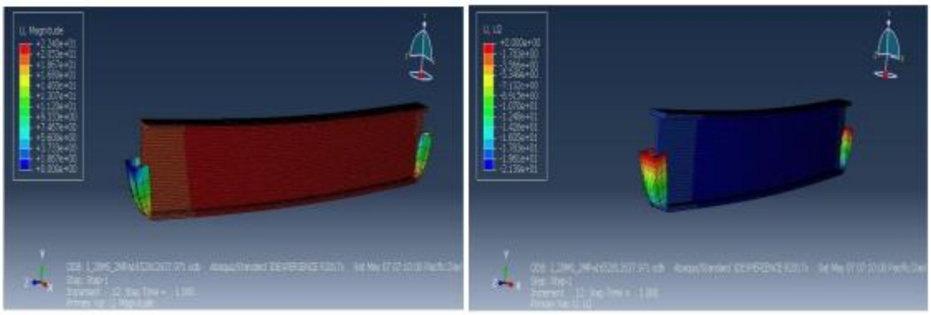


Fig.4.6 Total Deflection of Steel I-Beam

The result obtained from the nonlinear static structural analysis of Steel I-Beam with different loads of 1MPa, 2MPa, 3MPa, 4MPa, 5MPa shown below.

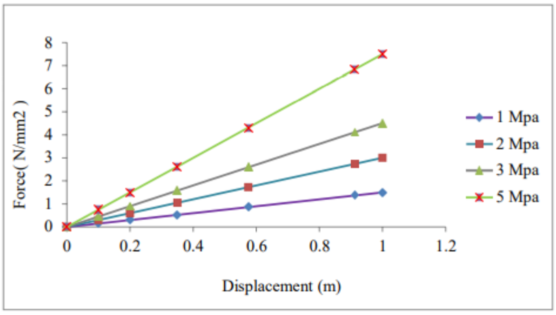


Fig.4.7 Force –Displacement Graph

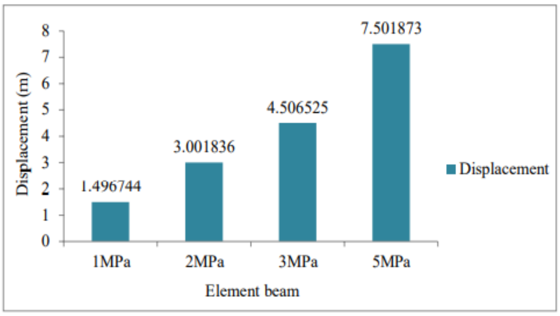


Fig.4.7 Force –Displacement Graph

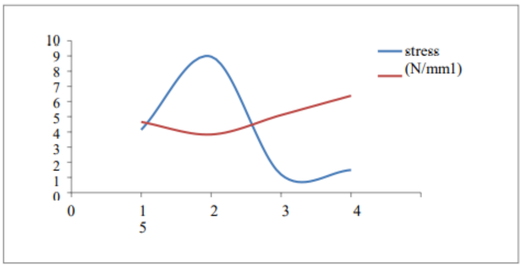


Fig:4.8 (a) Stress , Strain curve

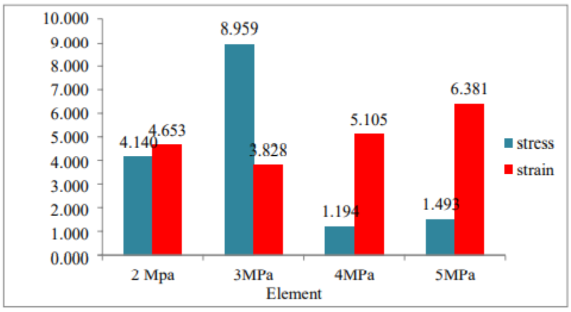


Fig.4.8(b) Comparison of Stress/Strain

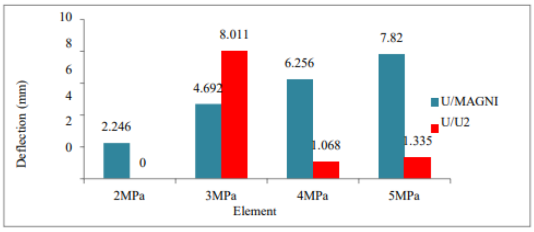


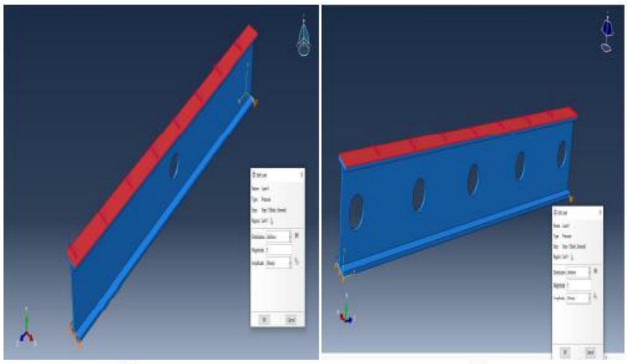
Fig.4.9 Comparison of Deflection

In this elastic studies found displacement of beam with Element of load 2, 3, 4 MPa is increased 1.5 rd. times each and 3times of 3 Element load of 5MPa.Principal stress is maximum at Element load of 2MPa and strain is minimum at Element load of 4MPa.Principal strain is maximum at Element load of 5MPa and minimum at Element load of 2Mpa. Maximum deflection attained in the Element of load 3MPa.Normal stress is maximum at Element load of 3MPa and strain is at Element load of 5MPa.From the above mentioned table and corresponding graph we can conclude that the maximum load that the Reference Beam element can carry without any defects is 3MPa under the deformation of 8.011mm.

V. CASE 2

The Reference I-Beam with Centre 1circular hole were modeled in ABAQUS software with Constant length and thickness under load 5MPa . First model was having a 1Centre circular hole of diameter 50mm, flange 100mm,web300mm,15mm thickness ,length 2000mm and second beam having 5 circular holes of constant parameters with spacing 400mm.. Beam Element is modeled using hexahedron mesh.

Analysis is carried out to study the general elastic of beam with different parameters. Nonlinear static structural analysis is carried out in ABAQUS software. Deformation and load carrying capacity is studied and compared.



(a) (b)

Fig 5.1 Modeling of ISMB(300X100X15), by constant length and load (a) Element ISMB300 (300X100X15) with 1 Centre circular hole (b) Element ISMB(300X100X15) with 5 circular holes.

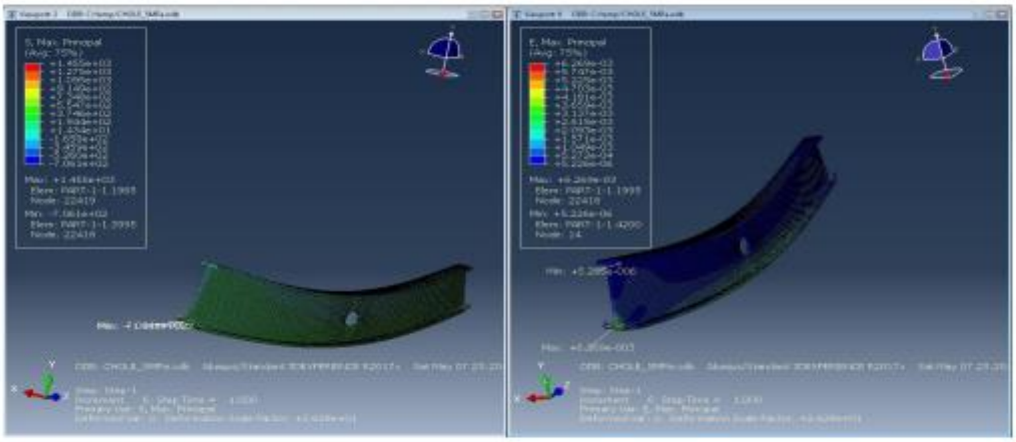


Fig 5.3 Stress /Strain Deformation of Element

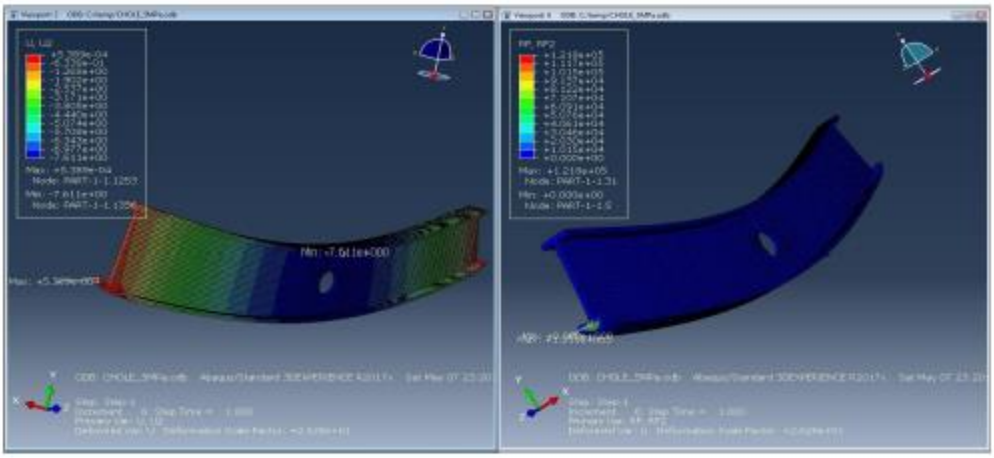


Fig 5.4 Deflection Deformation of Element

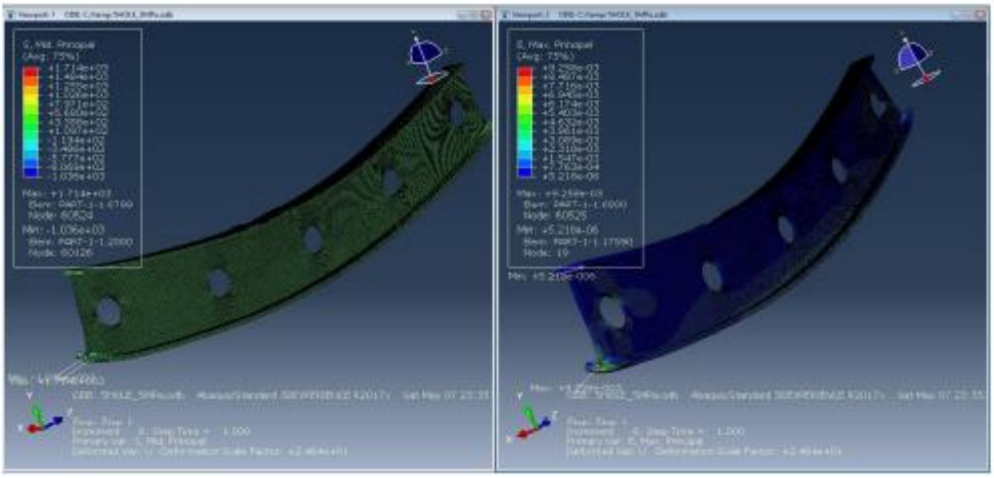


Fig 5.5 Stress /Strain Deformation of Element

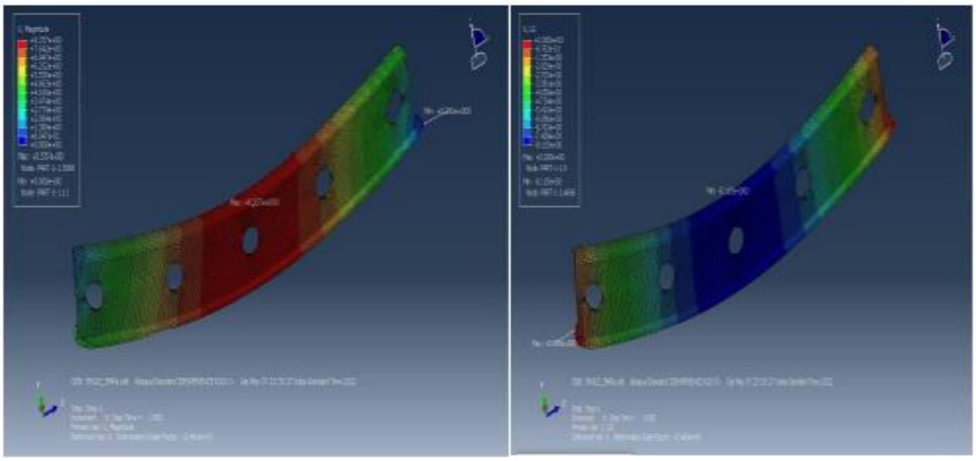


Fig 5.6 Deflection Deformation of Element

The maximum load that the Reference Beam with 5 circular holes element can carry without any defects under 5MPa load at the deformation of 0 mm.

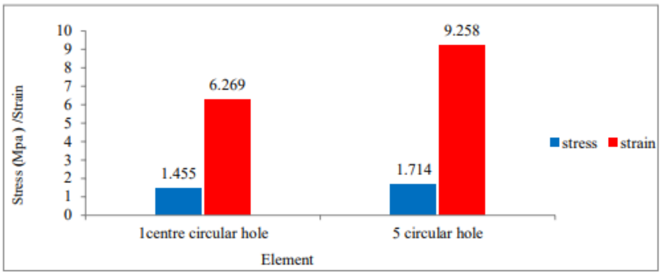


Fig.5.7 Comparison of Stress/Strain

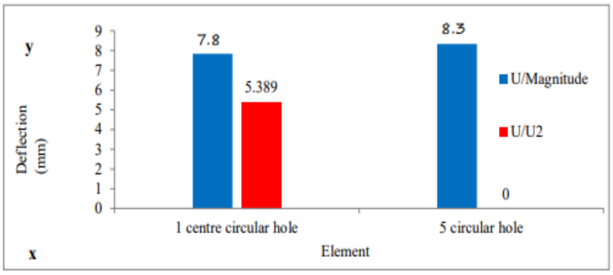


Fig.5.8 Comparison of Deflection

VI. CASE 3

The Reference I-Beam with Centre 1centre circular hole were modeled in ABAQUS software with Constant length and thickness under load 5 MPa . First model was having a 1Centre circular hole of diameter 50mm, flange 100mm,web 300mm,15mm thickness ,length 2000mm and second beam having 1 Centre hexagonal hole of constant parameters.

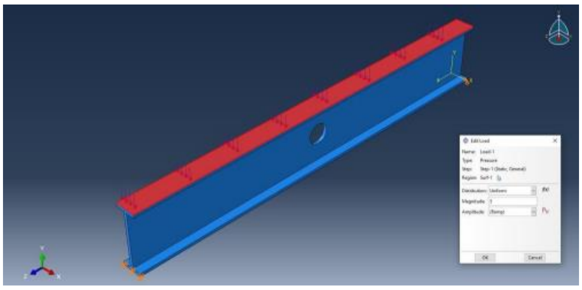


Fig: 6.1 Element of ISMB300 with 1 Centre circular hole

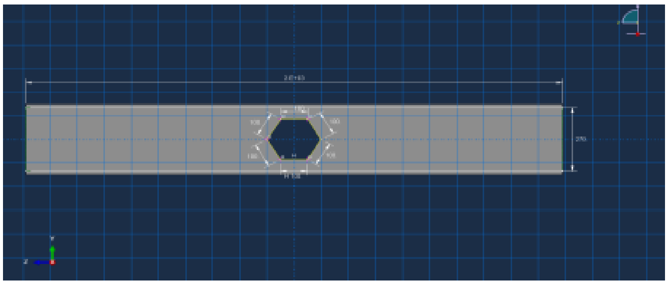


Fig: 6.2 Element ISMB with 1 Centre Hexagonal holes.

Analysis is carried out to study the general elastic of beam with different parameters. Nonlinear static structural analysis is carried out in ABAQUS software. Deformation and load carrying capacity is studied and compared .

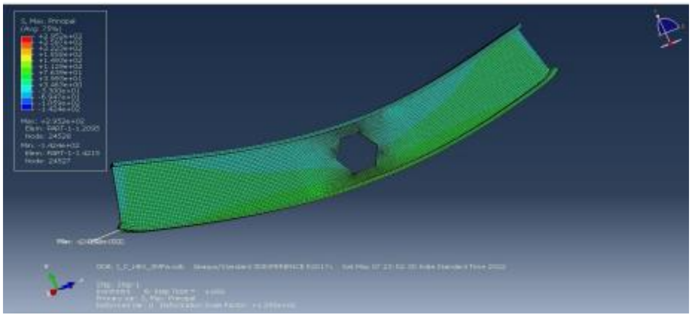


Fig 6.3 Stress Deformation of Element

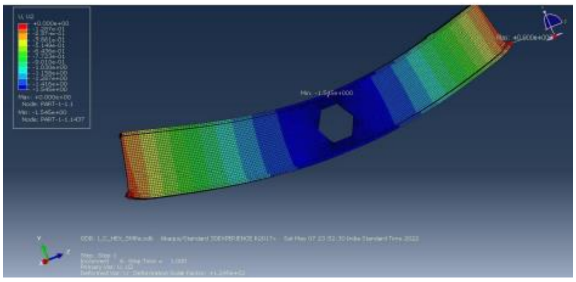


Fig 6.4 Deflection Deformation of Element

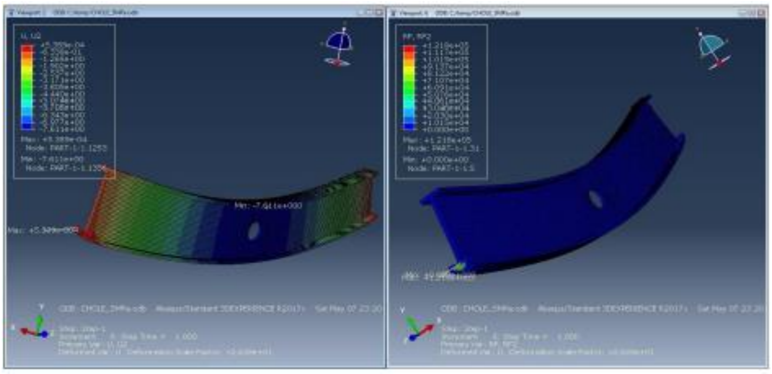


Fig 6.5 Deflection Deformation of Element Fig 6.3 shows the Stress deformation of beam under 5MPa load. Fig 6.4 and Fig 6.5 shows the deflection degree of freedom at X,Y ,Z Coordinates

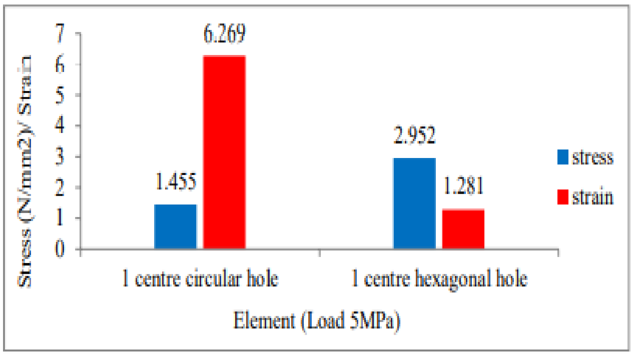


Fig 6.6 Stress/Strain Comparison Graph

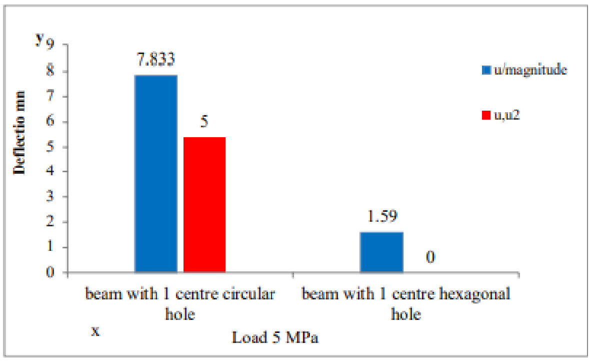


Fig 6.7 Deflection Comparison Graph

From the above mentioned table and corresponding graph the Maximum stress is acting on the sharp edge of Reference beam with 1 hexagonal hole than smooth curved shape of opening and maximum load that the Reference Beam with 1 Centre circular holes element can carry without any defects under 5MPa load at the deformation of 5.389 mm. From this we can conclude that the section with 1 circular hole is more feasible.

VII. CASE 4

The Reference I-Beam with Centre 1centre hexagonal hole were modeled in ABAQUS software with Constant length and thickness under load 5 MPa . First model was having a 1Centre hexagonal hole of edge 100mm, flange 100mm, web 300mm,15mm thickness ,length 2000mm and second beam having 5 hexagonal hole of constant parameters.

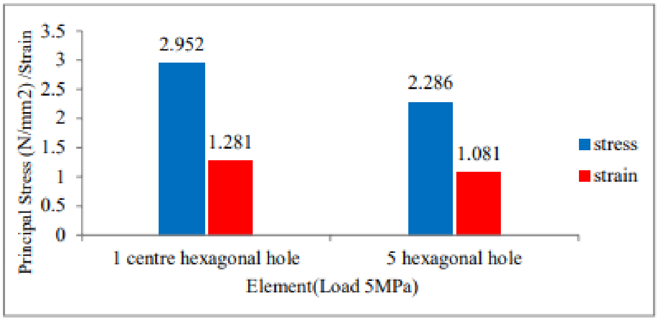


Fig 7.1 Stress/Strain Comparison Graph

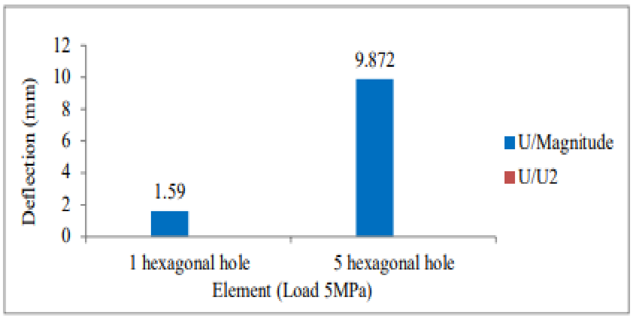


Fig 7.2 Deflection Comparison Graph

The Maximum stress acting on the sharp corner of Reference beam with 1 hexagonal hole and maximum load that the Reference Beam with 5 hexagonal holes element can carry without any defects under 5MPa load at the deformation of 9.872 mm. From this we can conclude that the section with 5 hexagonal holes is more feasible.

VIII. CASE 5

The Reference I-Beam with web hole were modeled in ABAQUS software with Constant length and thickness under load 5 MPa . First model was having a 5circular hole, flange 100mm, web 300mm,15mm thickness ,length 2000mm and second beam having 5 hexagonal hole of edge 100mm ,flange 100mm, web 300mm,15mm thickness ,length 2000mm parameters..

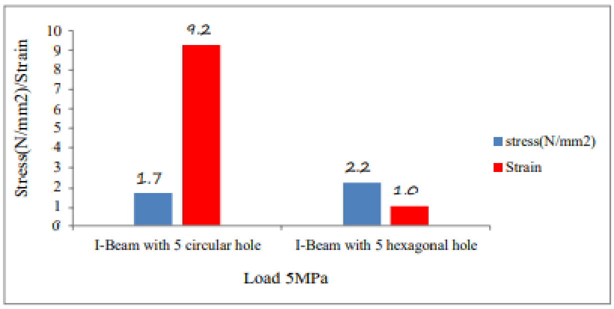


Fig: 8.1 Stress/Strain comparison graph

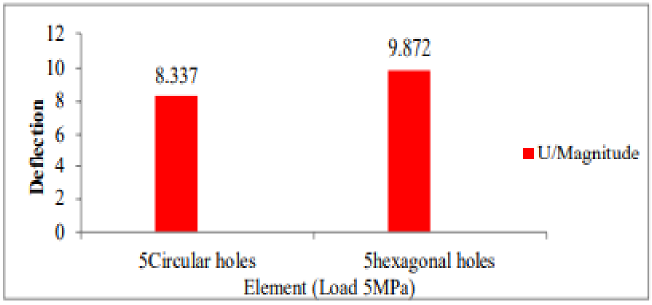


Fig: 8.2 Deflection comparison graph

The Maximum stress acting on the sharp corner of Reference beam with 5 hexagonal hole than the smoothened curve and maximum load that the Reference Beam with 5 hexagonal holes element can carry without any defects under 5MPa load at the deformation of 9.872 mm. From this we can conclude that the section with 5 circular hole is more feasible.

IX. CASE 6

The Reference I-Beam and beam with web hole were modeled in ABAQUS software with Constant length and thickness under load 5 MPa . First model was having a 1 Centre circular hole, flange 100mm, web 300mm,15mm thickness ,length 2000mm and second beam having 1 Centre hexagonal hole of edge 100mm ,flange 100mm, web 300mm,15mm thickness ,length 2000mm parameters.

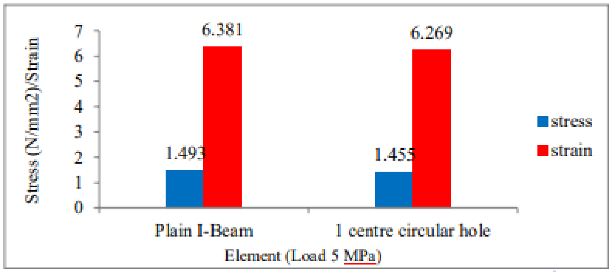


Fig: 9.1 Stress/Strain comparison graph

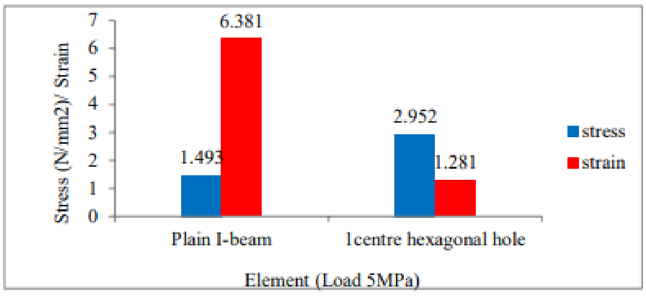


Fig: 9.2 Stress/Strain comparison graph

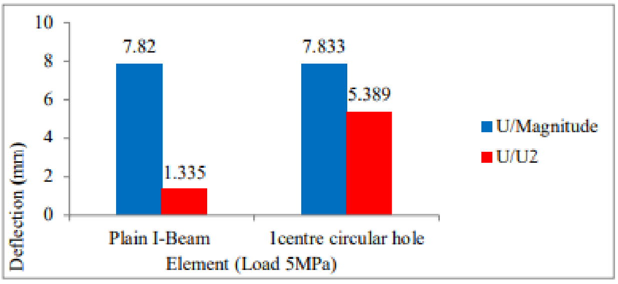


Fig: 9.3 Deflection comparison graph

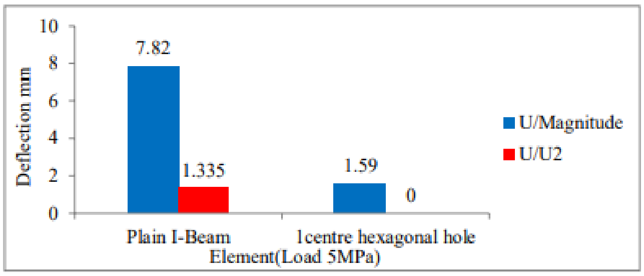
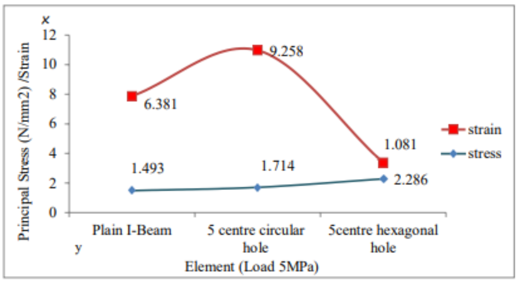


Fig: 9.4 Deflection comparison graph

The Maximum stress acting on the sharp corner of Reference beam with 1 Centre hexagonal hole than the smoothened curve and maximum load that the Reference Beam with 1 Centre circular holes element can carry without any defects under 5MPa load at the deformation of 5.389 mm. From this we can conclude that the section with 1 Centre circular hole is more feasible.

X. CASE 7

The Reference I-Beam and beam with web hole were modeled in ABAQUS software with Constant length and thickness under load 5 MPa . First model was having 5 circular hole, flange 100mm, web 300mm, 15mm thickness, length 2000mm and second beam having 5 hexagonal hole of edge 100mm ,flange 100mm, web 300mm,15mm thickness ,length 2000mm parameters.



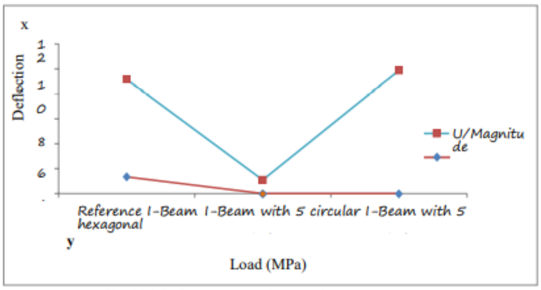


Fig: 10.1 Stress/Strain comparison graph Fig: 10.2 Deflection comparison graph

The Maximum stress acting on the sharp corner of Reference beam with5 hexagonal hole than the smoothened curve and maximum load that the Reference Beam with 5 circular holes element can carry without any defects under 5MPa load at the deformation of 0.00 mm. From this we can conclude that the section with 5 circular holes is more feasible.

XI. BUCKLING ANALYSIS OF CASTELLATED I-BEAM

Eigenvalue buckling is generally used to estimate the critical buckling loads of stiff structures (classical eigenvalue buckling). Stiff structures carry their design loads primarily by axial or membrane action, rather than by bending action. Their response usually involves very little deformation prior to buckling. A simple example of a stiff structure is the Euler column, which responds very stiffly to a compressive axial load until a critical load is reached, when it bends suddenly and exhibits a much lower stiffness. However, even when the response of a structure is nonlinear before collapse, a general eigenvalue buckling analysis can provide useful estimates of collapse mode shapes. Eigenvalue buckling analysis:

- is generally used to estimate the critical (bifurcation) load of "stiff" structures;
- is a linear perturbation procedure;
- can be the first step in an analysis of an unloaded structure, or it can be performed after the structure has been preloaded—if the structure has been preloaded, the buckling load from the preloaded state is calculated;
- can be used in the investigation of the imperfection sensitivity of a structure;
- works only with symmetric matrices (hence, asymmetric stiffness contributions such as the load stiffness associated with follower loads are symmetrized); and cannot be used in a model containing substructures.

Abaqus /cae offer the Lanczos and the subspace iteration eigenvalue extraction methods. The Lanczos method is generally faster when a large number of Eigen modes is required for a system with many degrees of freedom. The subspace iteration method may be faster when only a few (less than 20) Eigen modes are needed. By default, the subspace iteration Eigen solver is employed. Subspace iteration and the Lanczos solver can be used for different steps in the same analysis; there is no requirement that the same Eigen solver be used for all appropriate steps. For each step in the analysis the "Step Manager" also indicates whether Abaqus will account for nonlinear effects from large displacements and deformations. If the displacements in a model due to loading are relatively small during a step, the effects may be small enough to be ignored. However, in cases where the loads on a model result in large displacements, nonlinear geometric effects can become important. The Nlgeom setting for a step determines whether Abaqus will account for geometric nonlinearity in that step

REFERENCE I-BEAM WITH 5 HEXAGONAL HOLE.

Table No.11.1 Mode and Eigen Values

MODE NO	EIGEN VALUE
1	-1.4583
2	1.4669
3	1.6523
4	2.4189
5	3.9421
6	-4.1905
7	4.5882
8	-5.0605
9	5.9393
10	7.9424

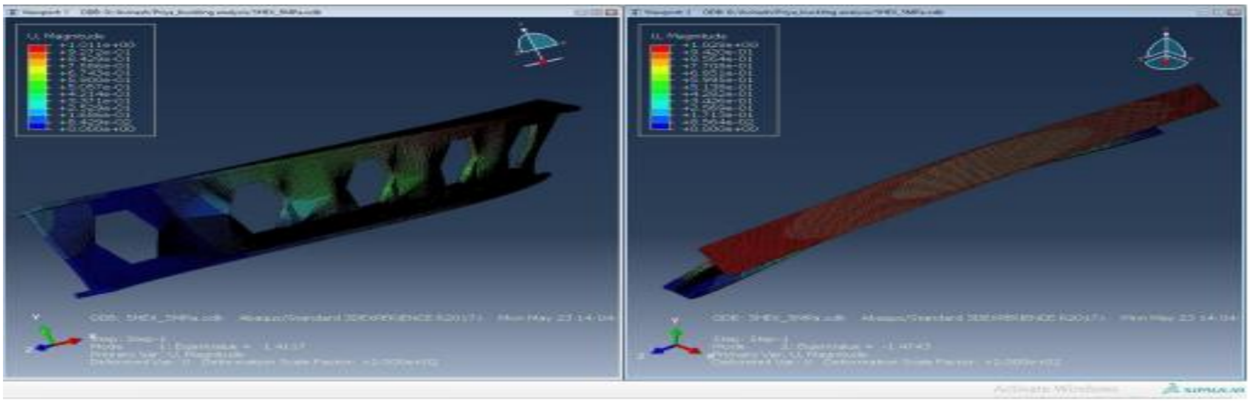


Fig 11.1 : Buckling Of Reference Beam with 5 hexagonal web hole (Mode 1 and 2)

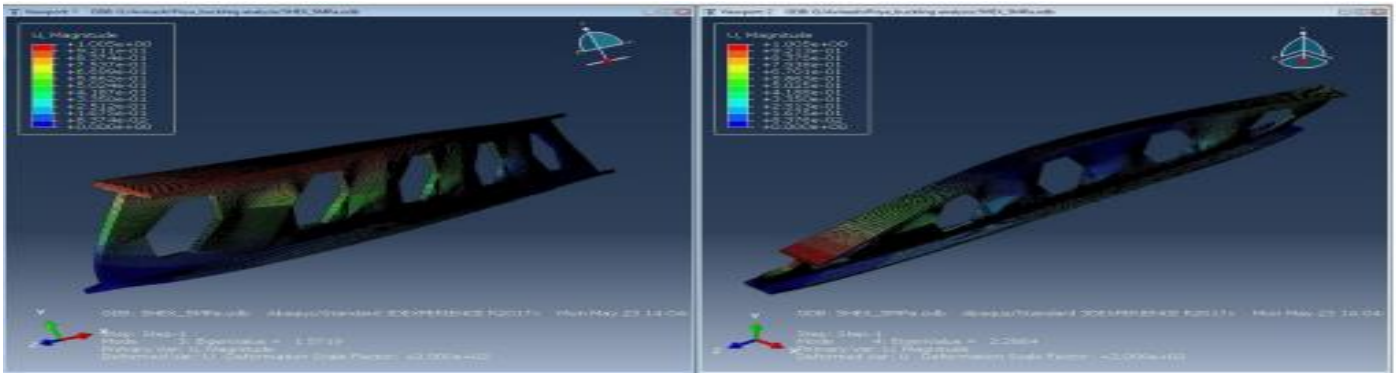


Fig 11.2 : Buckling Of Reference Beam with 5 hexagonal web hole (Mode 3 and 4)

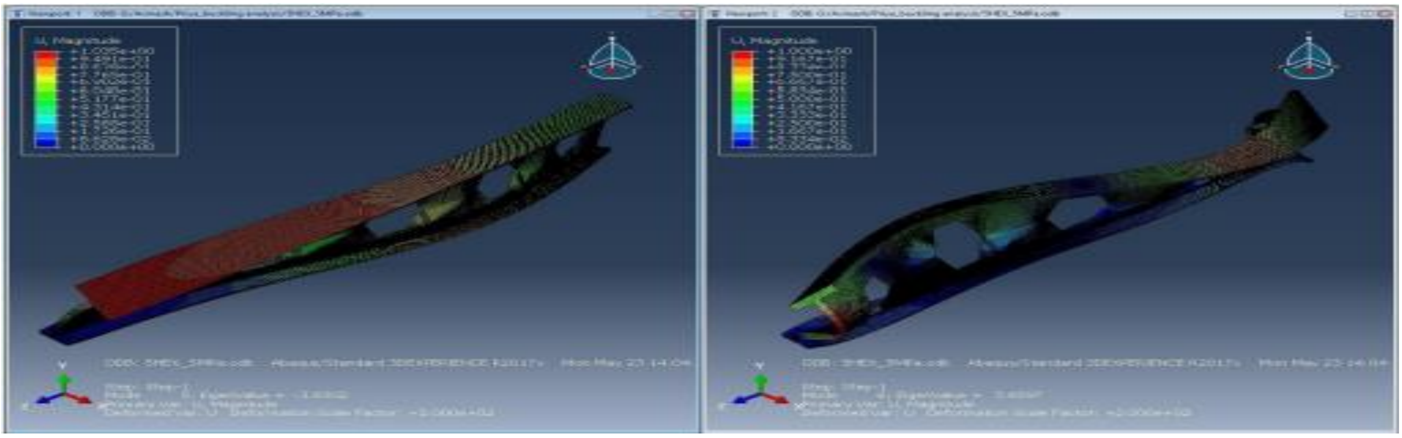


Fig 11.3 : Buckling Of Reference Beam with 5 hexagonal web hole (Mode 5 and 6)

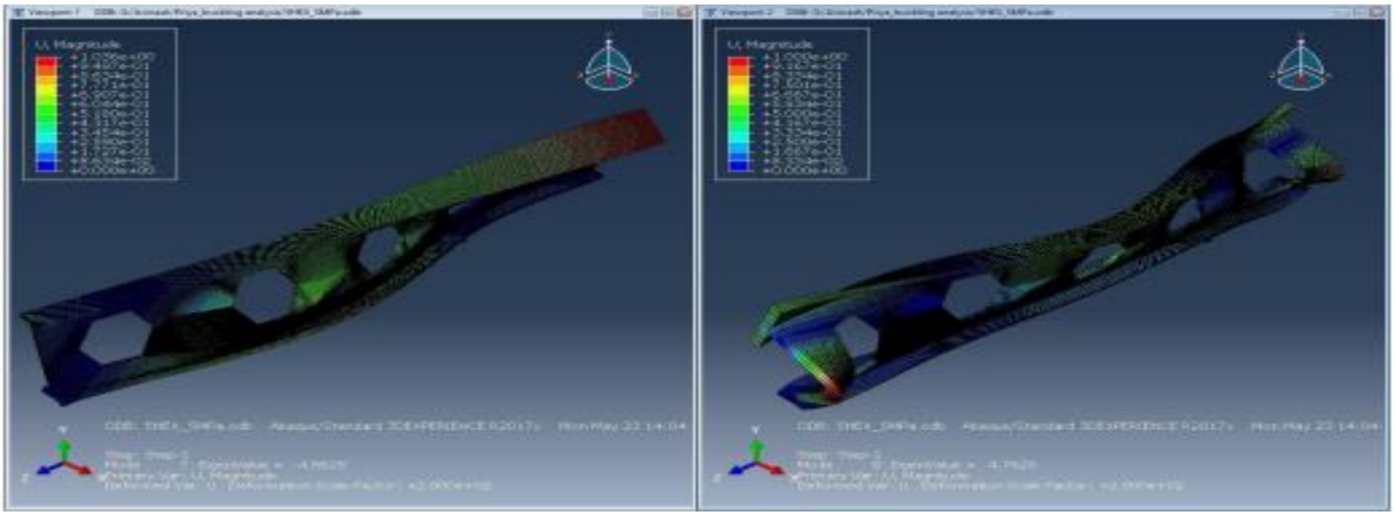


Fig 11.4 : Buckling Of Reference Beam with 5 hexagonal web hole (Mode 7 and 8)

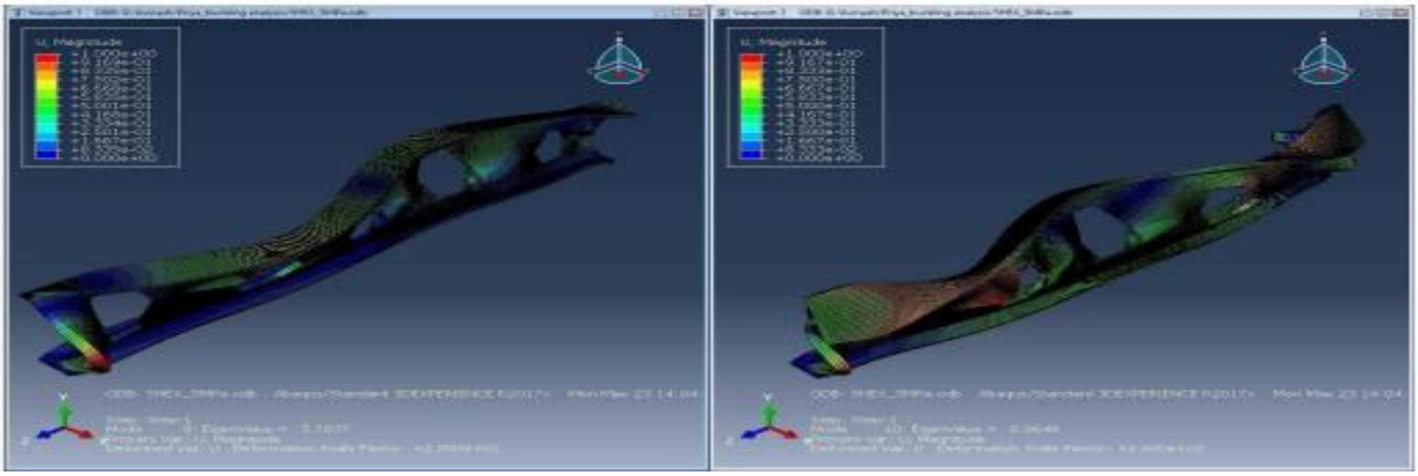


Fig 11.5 : Buckling Of Reference Beam with 5 hexagonal web hole (Mode 9and 10)

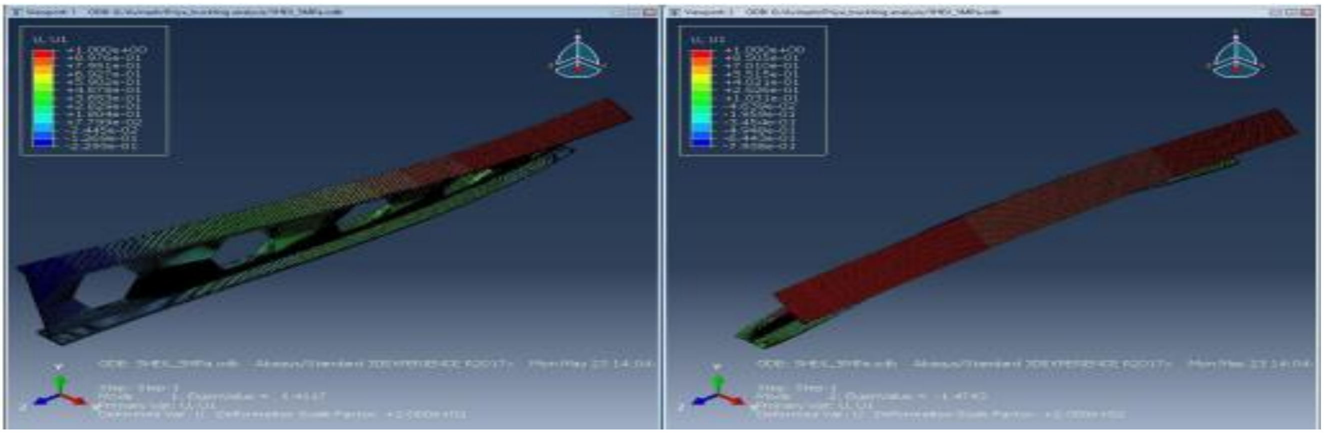


Fig 11.6 : Buckling Of Reference Beam with 5 hexagonal web hole (Mode 1and 2)

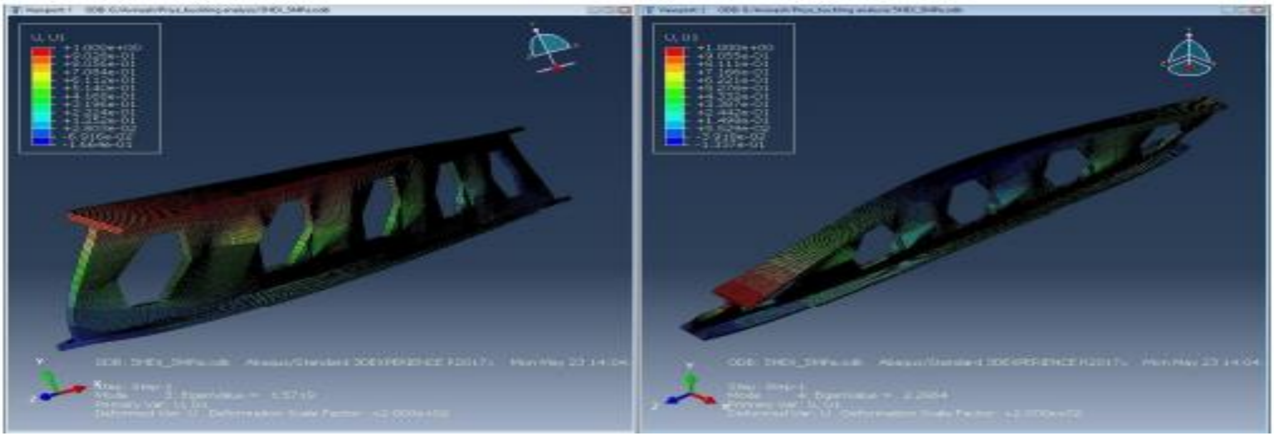


Fig 11.7 : Buckling Of Reference Beam with 5 hexagonal web hole (Mode 3and 4)

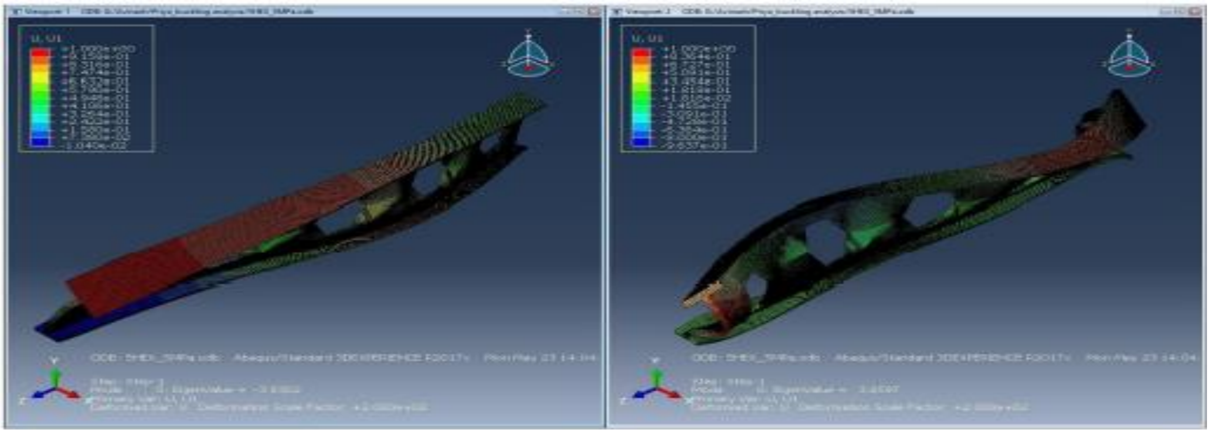


Fig 11.8 : Buckling Of Reference Beam with 5 hexagonal web hole (Mode 5and 6)

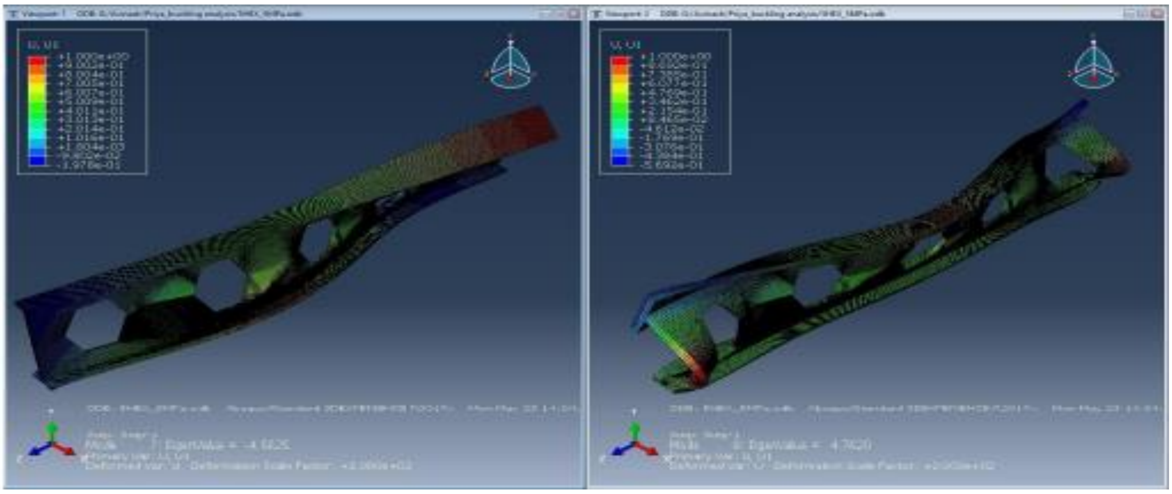


Fig 11.9 : Buckling Of Reference Beam with 5 hexagonal web hole (Mode 7and 8)

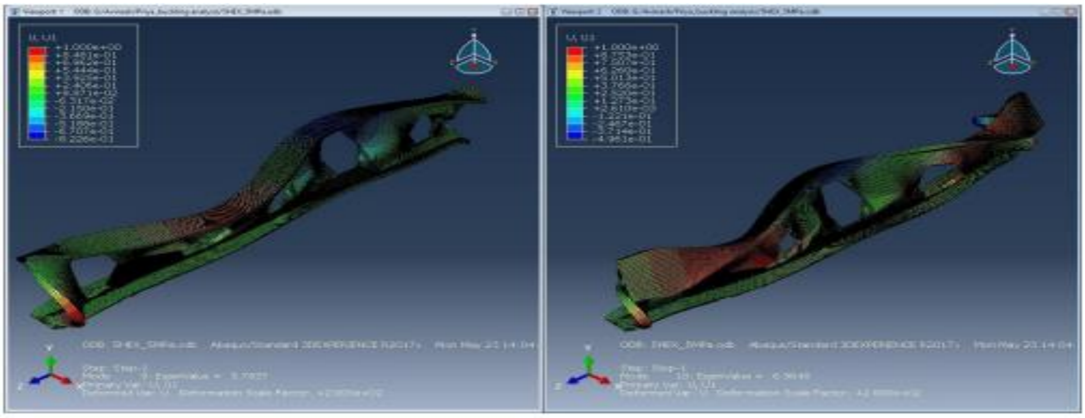


Fig 11.10 : Buckling Of Reference Beam with 5 hexagonal web hole (Mode 9and 10)

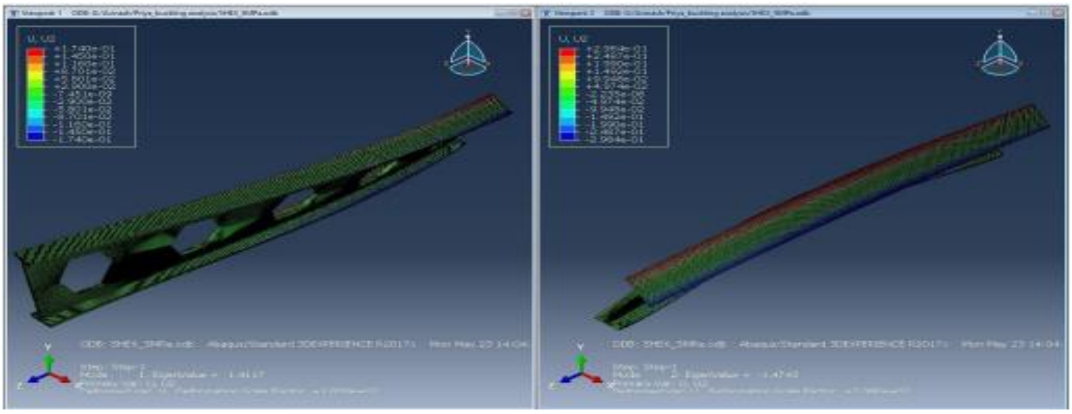


Fig 11.11 : Buckling Of Reference Beam with 5 hexagonal web hole (Mode 1and 2)

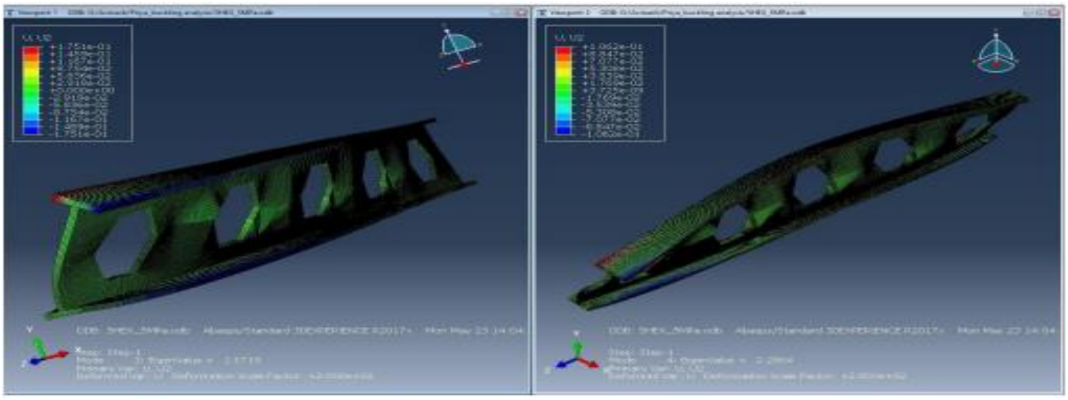


Fig 11.12 : Buckling Of Reference Beam with 5 hexagonal web hole (Mode 3and 4)

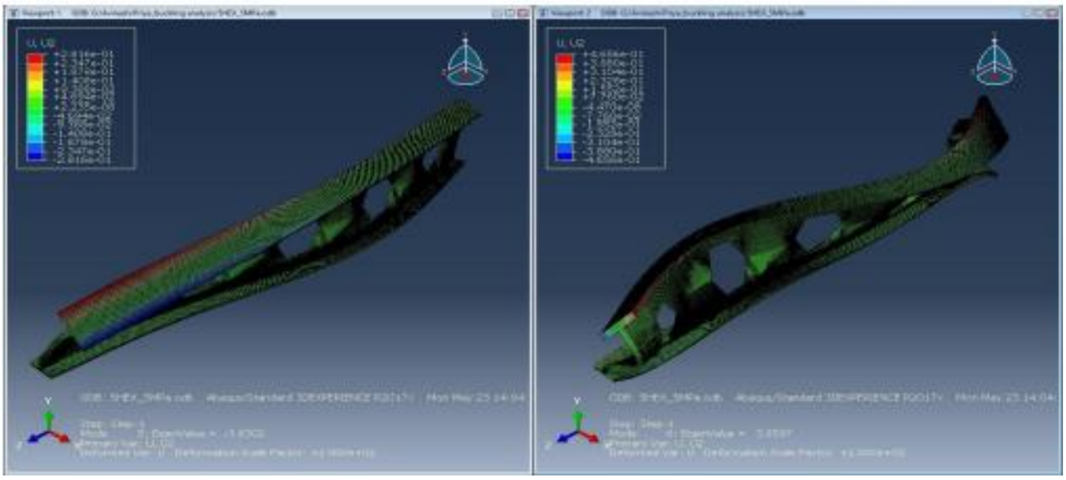


Fig 11.13 : Buckling Of Reference Beam with 5 hexagonal web hole (Mode 5and 6)

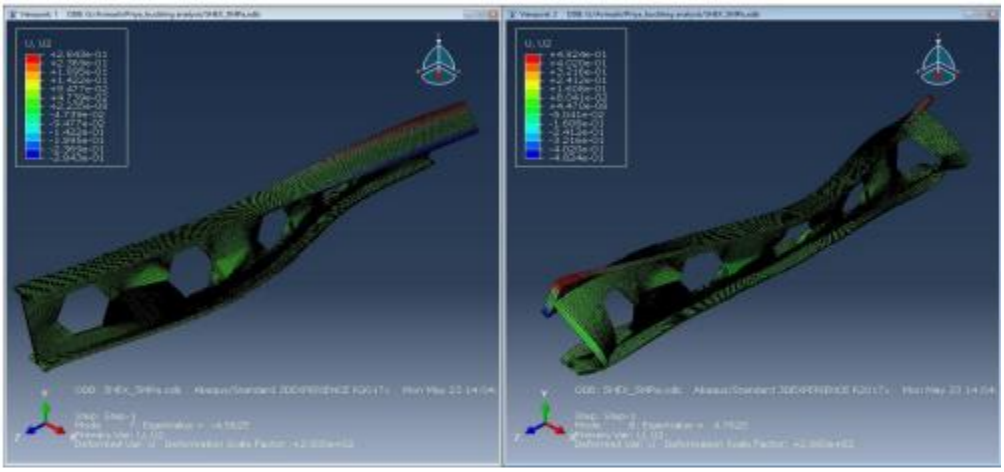


Fig 11.14 : Buckling Of Reference Beam with 5 hexagonal web hole (Mode 7and 8)

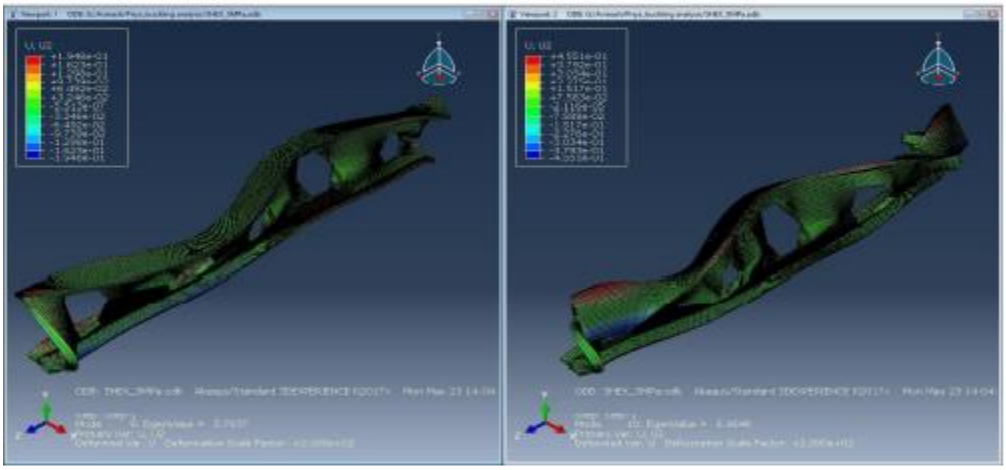


Fig 11.15 : Buckling Of Reference Beam with 5 hexagonal web hole (Mode 9and 10)

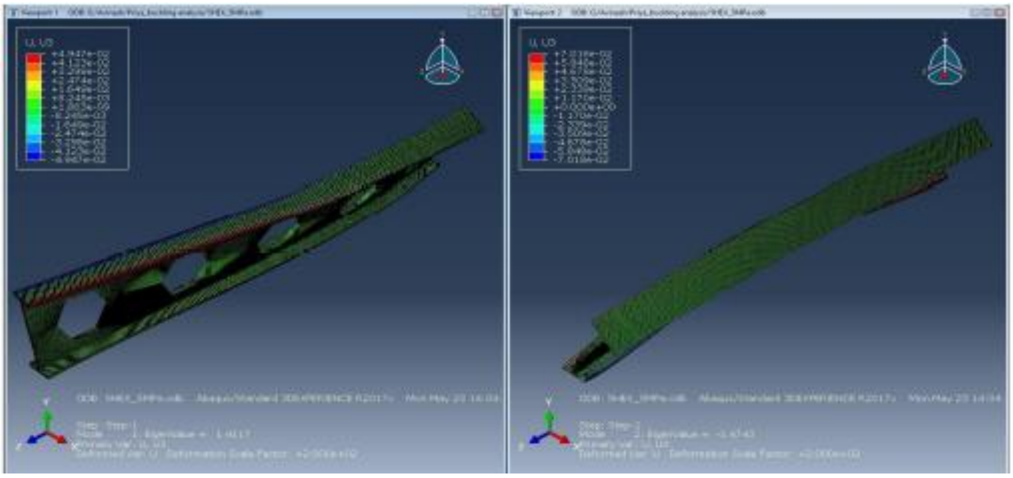


Fig 11.16: Buckling Of Reference Beam with 5 hexagonal web hole (Mode 1and 2)

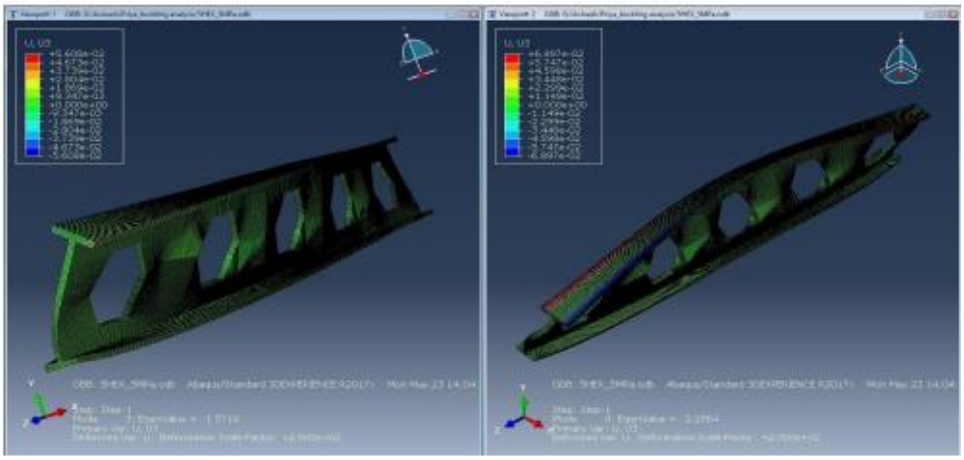


Fig 11.17 : Buckling Of Reference Beam with 5 hexagonal web hole (Mode 3and 4)

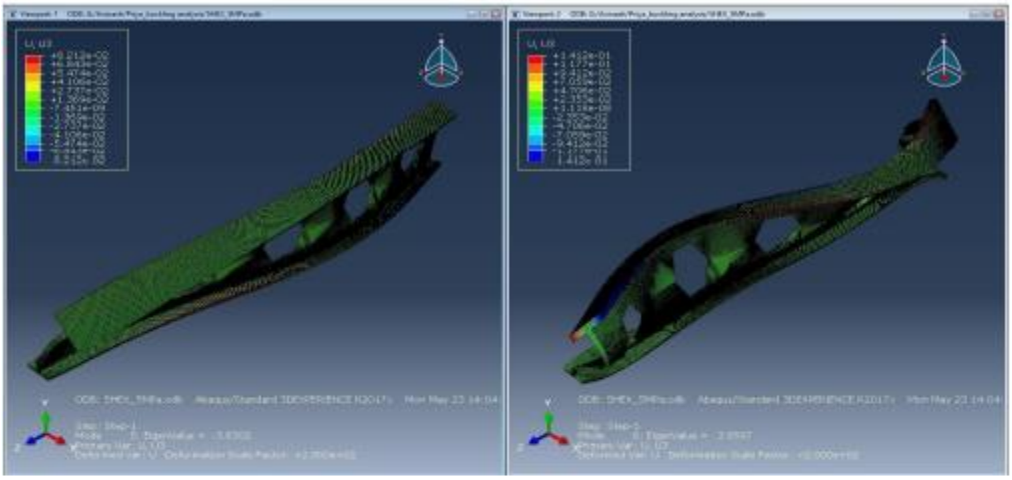


Fig 11.18 : Buckling Of Reference Beam with 5 hexagonal web hole (Mode 5and 6)

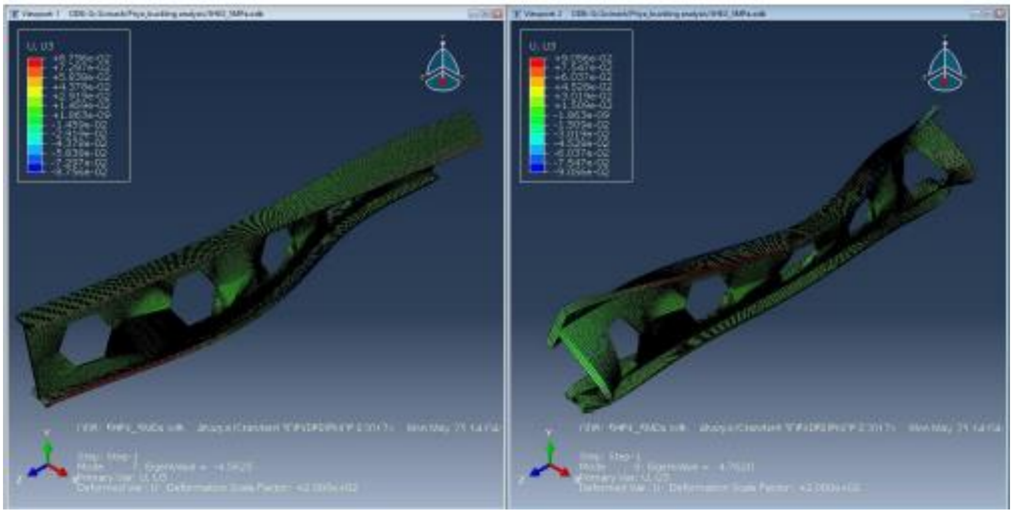


Fig 11.19 : Buckling Of Reference Beam with 5 hexagonal web hole (Mode 7and 8)

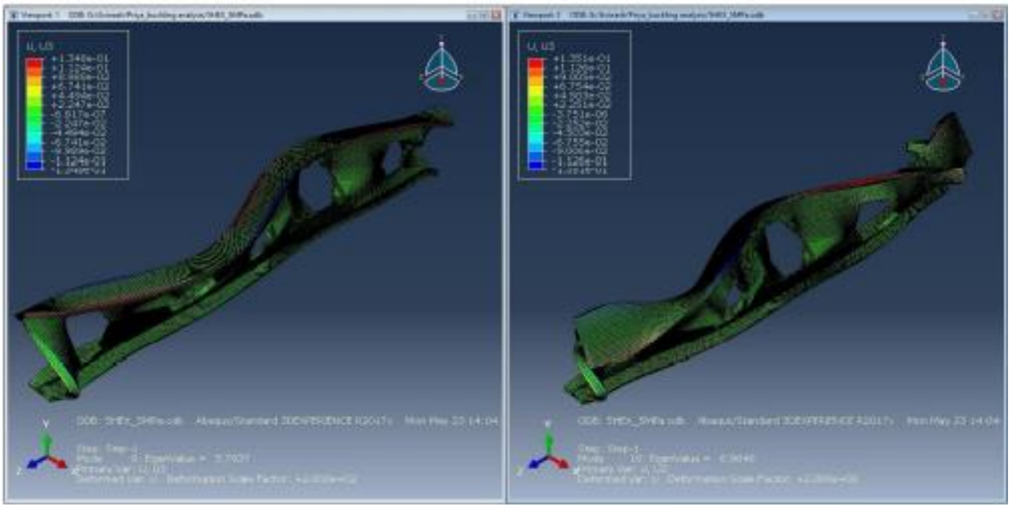


Fig 11.20: Buckling Of Reference Beam with 5 hexagonal web hole (Mode 9and 10)

In the buckling analysis compared to Reference I-Beam ,I-Beam with 5circular holes and I-Beam with 5 hexagonal holes of constant load 5MPa, I-Beam with 5 circular and I-Beam with 5 hexagonal holes Elements gives almost same resultant.

XII. CONCLUSION

Elastic convergence studies carried out I-section with constant parameters having varying loads. Elastic convergence studies shown that in castellated beam sections, Stress is maximum at the point of sharp edges and minimum at the smoothened curved .The section with circular web openings is the maximum load withstand without any deformation. From this found that the Section with Circular web opening is the most feasible structure. This study has been carried out to investigate the behavior of simply support and pinned-Roller castellated beams subjected to uniformly distributed load using analytical and numerical solution. Comparison has been made between the results of the linear analysis and the geometrical and material nonlinear analysis by using finite element method.
The main conclusions can be summarized as follows:

- The critical load of lateral-torsional buckling of castellated beams is influenced by the beam size, web openings, boundary conditions, and material properties of the beam.
- The value of torsional constant should be calculated by using the average torsional constant of the full and reduced section properties.
- The longer the beam, the closer the critical load obtained from the linear lateral-torsional buckling analysis to the failure load obtained from of the full nonlinear analysis.
- When the serviceability is also considered, the deflection limit seems to be the dominant criterion in controlling the load in most of the beam length regions ,It is evident that the stiffness of the specimen is decreasing with the increase in length.
- The longer the beam, the less importance of the nonlinearity need to be considered.

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