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Study on Steel Beam with Folded Web Plates

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Abstract -*Steel beam with folded web plate is a steel structure similar to steel ring web beam. In steel ring web beams top and bottom flanges are connected using steel ring pipes as web. In steel beam with folded web plates, top and bottom flanges are connected using folded plates. Amount of welding and cutting of steel can be reduced and the load carrying capacity can be increased with reduced cost of construction and time. The model was studied under static loading, with varying shapes in the folded web plates and with stiffeners of different thickness and depth at different positions. The best model was subjected to impact loading.*

Key Words: Steel Beam- Folded web plate –varying web plate shape-varying stiffeners-Finite Element Analysis-Four-point loading test–Impact loading test.

1. INTRODUCTION

Steel Beam with Folded Web Plates is an improved version of Steel Ring Web Beam which was introduced in 2019 in the bridge designing field. Steel Ring-Web Beam is similar in appearance with castellated steel beams, which can be used as pedestrian bridges, landscape galleries, etc.[1]

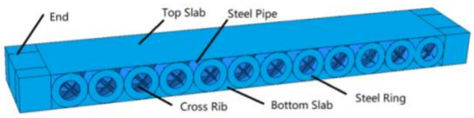

Fig -1: Steel Ring Web Beam model [1]

Both Steel Ring Web Beam and Steel Beam with Folded Web Plates have three main components. Top and bottom slabs are common for both the steel structures in which the stiffeners are attached by weld joint. Only difference is that Steel Ring Web Beam has a Circular Pipe attached to the top and bottom slabs[1] whereas Steel Beams with Folded Web Plates have folded steel plates with weld joints. In Steel Ring Web Beam, two circular steel rings with cross ribs are welded on two ends of a steel pipe. Two columns of steel pipes with steel rings and cross ribs that lie on two sides of bottom slab are arranged along longitudinal direction. Two ends, setting the reinforcing ribs are hollow structures, which are welded on the top and bottom slabs [1]. In Steel Beam with Folded Web Plates steel rings and cross stiffeners are excluded to reduce steel consumption and welding.

Steel ring web beam had a span of 4824mm. The beam was made up of steel with yield strength of 300 MPa, Poisson's ratio of 0.3 and ultimate strength of 385 MPa. So steel beam with folded web plate models were also modeled with same length, width, depth and material properties. Steel ring web beam has a load carrying capacity of 402 kN and ultimate deflection of 15.76 mm [1]

Advantages of Steel Beam with Folded Web Plates are lightweight, convenience in manufacturing and better global stability. Compared to Steel Beam with Folded Web Plates and Steel Ring Web Beam, Castellated steel beam has poor resistance to transverse torsional deformation. Shortcomings of castellated steel beams, such as poor torsion resistance and poor shear capacity, were overcome. Furthermore, Steel Beam with Folded Web Plates were investigated with different shaped folded web plates and with stiffeners along the length of plates with varying parameters such as number of stiffeners, position of stiffener, thickness and depth of stiffeners under static loading conditions and best model was subjected to dynamic loading.

2. FINITE ELEMENT MODELLING

2.1 General

To investigate structural performance of steel beam with folded web plate, modeling of structure was done using SOLID186 element of ANSYS 16.1

2.2 Scope

Scope of the work is limited to find the load carrying capacity of steel beam with folded web plate under different configurations of folds in plates and stiffeners and to compare with the performance of steel ring web beam, using nonlinear finite element approach.

2.3 Objectives

To study the behavior of Steel Beam with Folded Web Plates of different shapes and find the optimum shape. To provide the model increased number of folds and different types of stiffeners by varying number of stiffeners, position of stiffeners, thickness and depth of stiffeners. Find the best and economic model under static loading and subject it to dynamic loading.

2.4 Geometry and Material properties

Steel beam with folded web plate system had a span of 4824mm, depth 361mm and width of 800mm. The beam was made up of steel with yield strength of 300MPa, Poisson's ratio of 0.3 and ultimate strength of 385MPa. Varying factors in geometry are number of folded plates, shape of folded plates, number of stiffeners, positioning of stiffeners, thickness and depth of stiffeners. Web plates of circular, elliptical and hexagon were also modelled with stiffener thickness of 4.5 mm, 13.5 mm and depth of 15 mm, 22.5 mm, 45 mm were used. Bilinear isotropic hardening was adopted to reproduce the plastic behavior of materials.

In total there were 12 models ,1 circular, 1 elliptical, 1 hexagonal,1 hexagonal with increased number of folds, which are models without stiffeners and There were 5 models with one stiffener, 2 models with two stiffeners and 1 model with three stiffeners. Shapes of web were obtained by placing two folded plates of the same shape symmetrically against each other. Circular and Hexagonal plates were fitted into a diameter of 352 mm. Elliptical plate had 352mm long and 264mm short diameters. Number of folded plates of hexagonal shaped models were increased by shortening diameter along horizontal axis to176mm.

Table -1: Material properties of steel beam models

Properties	Description
Density (kg/m^3)	7850
Young's modulus (MPa)	210000
Poisson's ratio	0.3

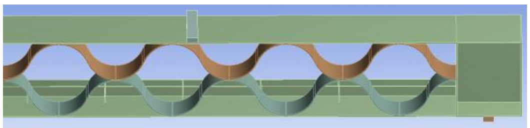

Fig -2: Beam model with Circular folded web plate

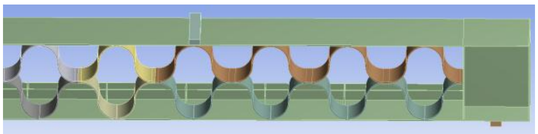

Fig -3: Beam model with Elliptical folded web plate

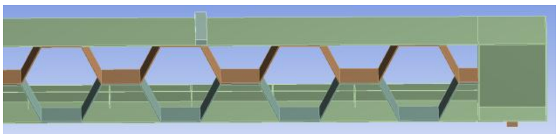

Fig -4: Beam model with Hexagonal folded web plate

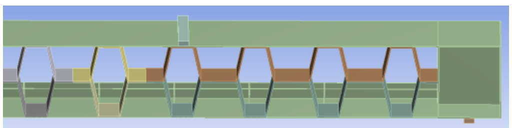

Fig -5: Beam model with Hexagonal folded web plate without stiffener

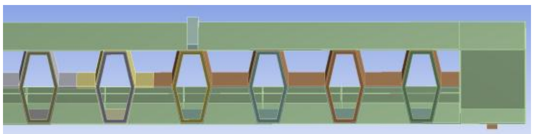

Fig -6: Beam model with Hexagonal folded web plate of one exterior stiffener

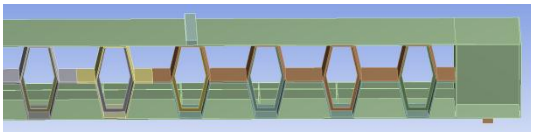

Fig -7: Beam model with Hexagonal folded web plate of one central stiffener

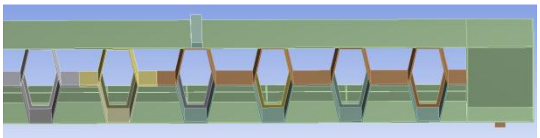

Fig -8: Beam model with Hexagonal folded web plate of one interior stiffener

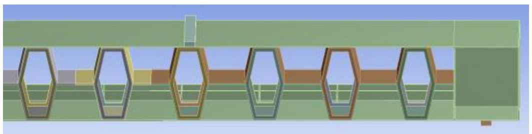

Fig -9: Beam model with Hexagonal folded web plate of two stiffeners one interior and one exterior

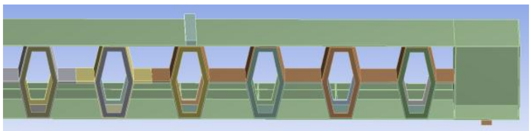

Fig -10: Beam model with Hexagonal folded web plate of two stiffeners one interior and one exterior of depth 22.5mm

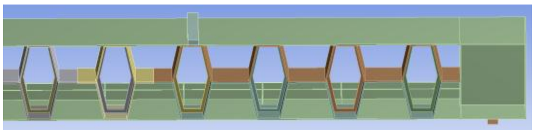

Fig -11: Beam model with Hexagonal folded web plate of one central stiffener of thickness 13.5mm

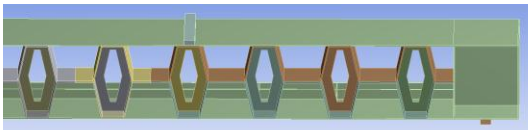

Fig -12: Beam model with Hexagonal folded web plate of one central stiffener of depth 45mm

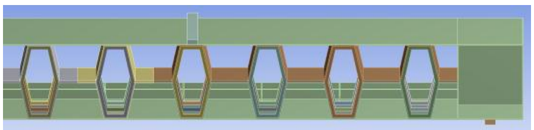

Fig -13: Beam model with Hexagonal folded web plate of three stiffeners, one exterior, one interior and one central stiffener

2.5 Meshing

To understand structural behavior properly solid models were subjected to meshing. Meshing divided whole model into finite elements. After meshing solid models were converted into finite element models.

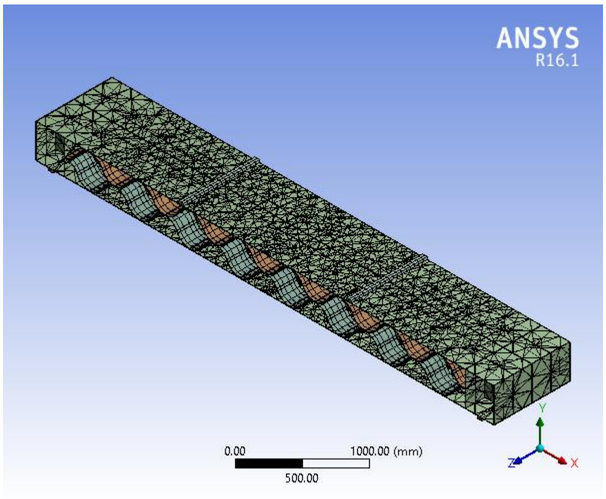

Fig -14: Meshing of 3D model in ANSYS 16.1

2.6 Loading and Boundary conditions

To stimulate real conditions, steel beam with folded web plates were analyzed with a simply supported system at both ends and load was applied as four-point loading in one direction. The load was placed at a distance of 1532mm from both the ends and impact loading on the best model is analyzed with a simply supported system with load acting at centre span. The bilinear isotropic hardening rule was used for finite element analysis.

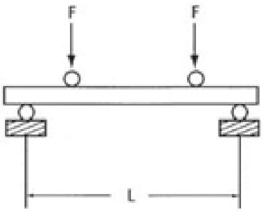

Fig -15: Four-point loading

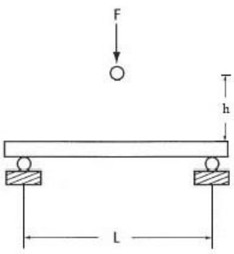

Fig -16: Impact loading

3. RESULTS AND DISCUSSIONS

3.1 Four-point loading test

Steel beam with folded plate web models were subjected to four-point loading. The models were simply supported at a distance of 150mm from both the ends and loads were applied at a distance of 1532mm from both ends of the model. From the load deflection graph, maximum load carrying capacity and total deflection of model was obtained and compared with the load and deflection value of the Steel ring web beam model.

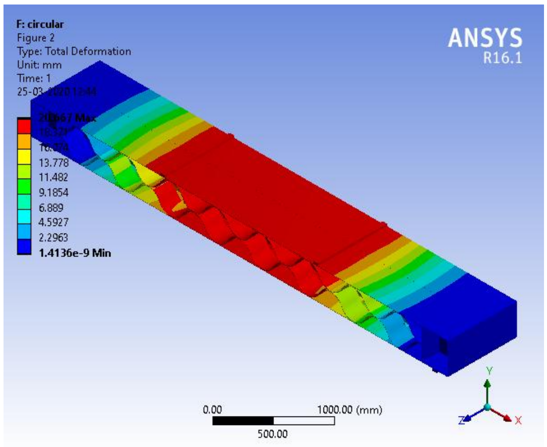

Fig -17: Total deformation of Beam model with Circular folded web plate

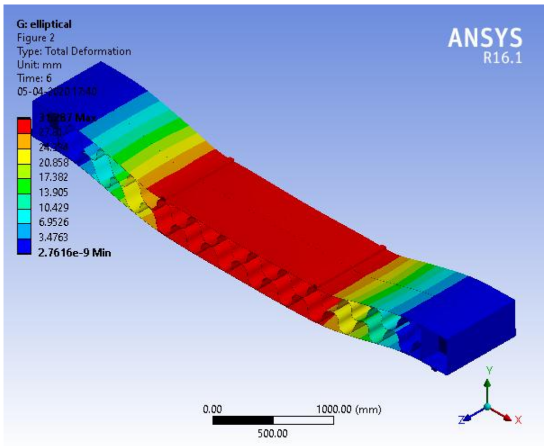

Fig -18: Total deformation of Beam model with Elliptical folded web plate

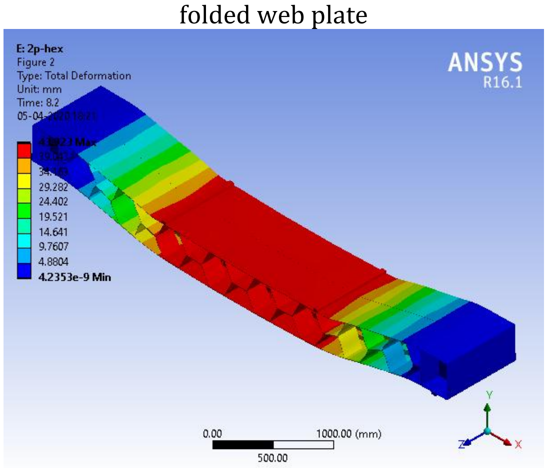

Fig -19: Total deformation of Beam model with Hexagonal folded web plate

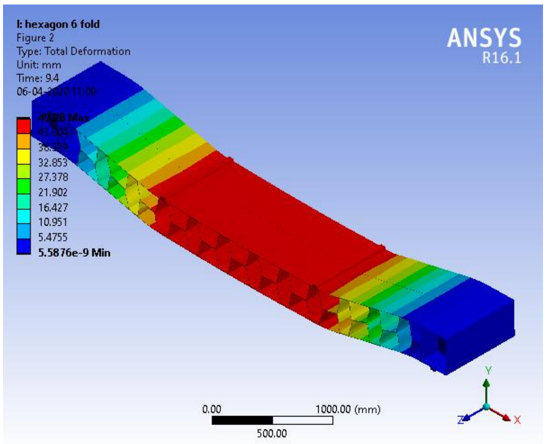

Fig -20: Total deformation of Beam model with Hexagonal folded web plate without stiffener

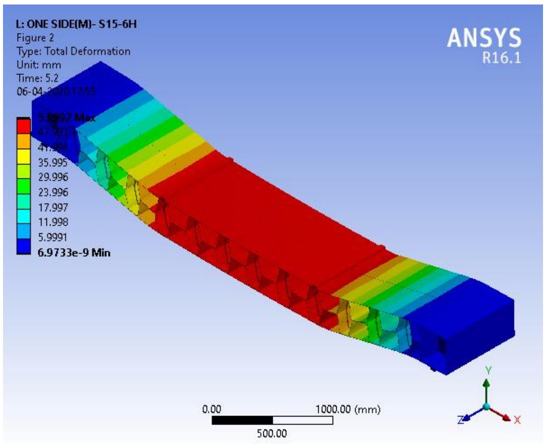

Fig -24: Total deformation of Beam model with Hexagonal folded web plate of one central stiffener

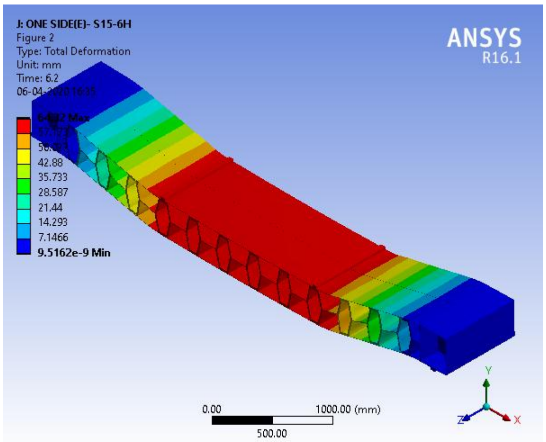

Fig -21: Total deformation of Beam model with Hexagonal folded web plate of one exterior stiffener

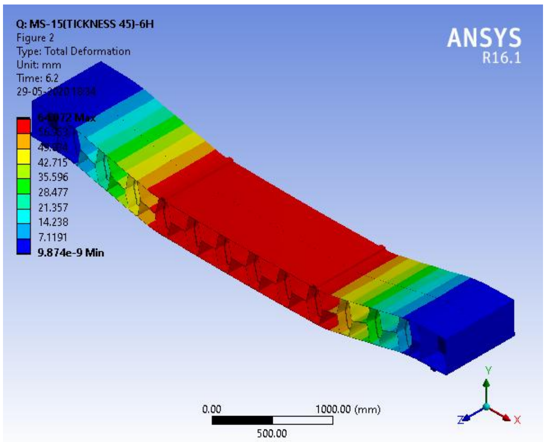

Fig -25: Total deformation of Beam model with Hexagonal folded web plate of one central stiffener of thickness 13.5mm

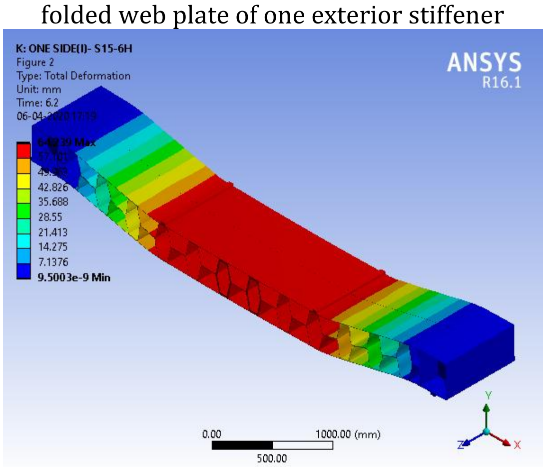

Fig -22: Total deformation of Beam model with Hexagonal folded web plate of one interior stiffener

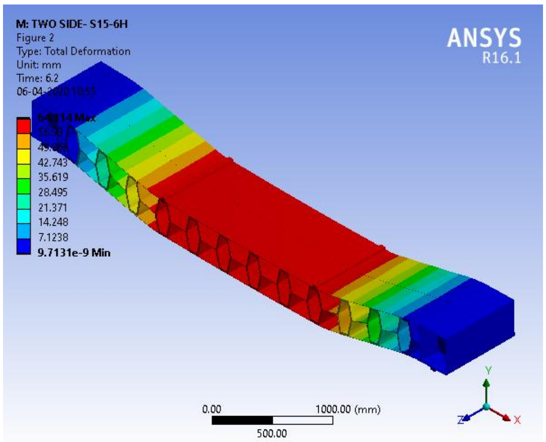

Fig -26: Total deformation of Beam model with Hexagonal folded web plate of two stiffeners one interior and one exterior

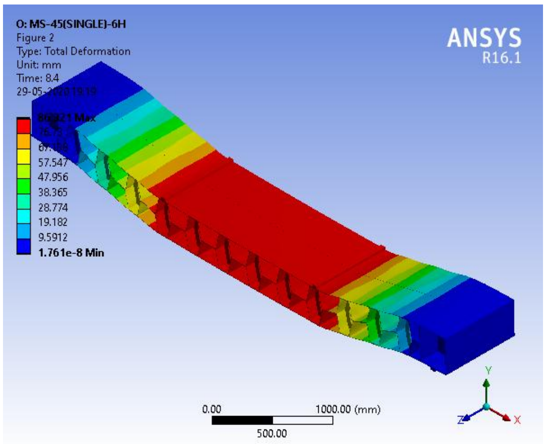

Fig -27: Total deformation of Beam model with Hexagonal folded web plate of one central stiffener of depth 45mm

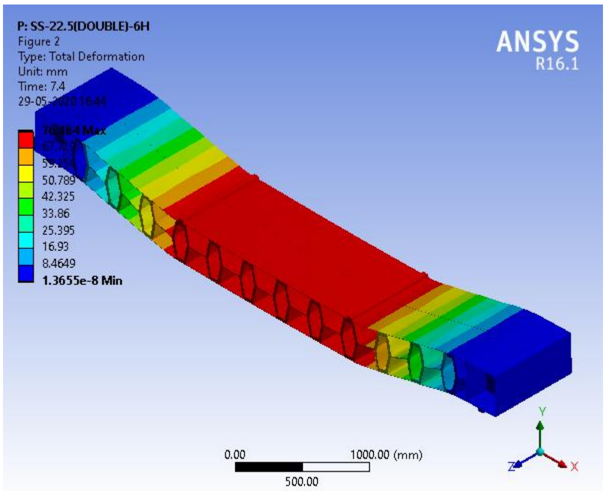

Fig -28: Total deformation of Beam model with Hexagonal folded web plate of two stiffeners one interior and one exterior of depth 22.5mm

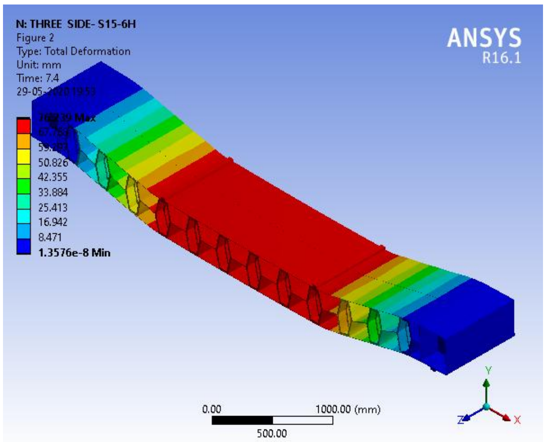

Fig -29: Total deformation of Beam model with Hexagonal folded web plate of three stiffeners, one exterior, one interior and one central stiffener

Table -2: Ultimate load and Total deformation Steel ring web beam model [1]

	Ultimate load (kN)	Total deformation (mm)
Steel Ring Web Beam	44.87	14.52

Table -3: Ultimate load and Total deformation of models based on shape of web plate

No.	Shape of folded plate	Ultimate load (kN)	Total deformation (mm)
1	Circular	44.87	14.52
2	Elliptical	212.96	31.28
3	Hexagonal	405.6	43.92

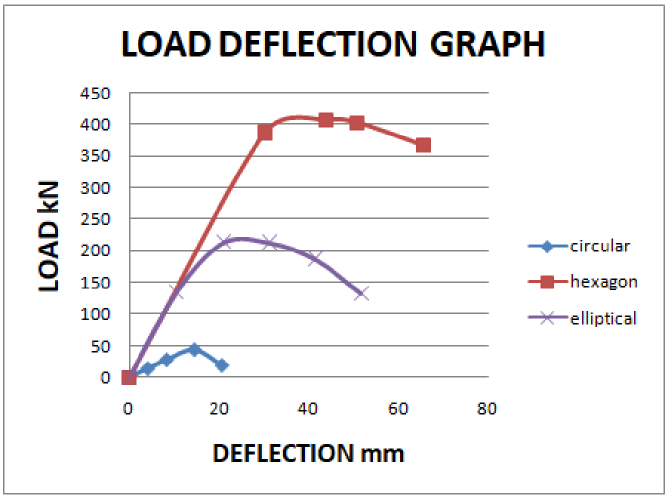

Chart -1: Load deflection graph of models based on shape of web plate.

Table -4: Ultimate load and Total deformation of models based on difference in stiffeners

No.	Type of Stiffeners		Ultimate load (kN)	Total deformation (mm)
1	Without stiffener	0 S	457.64	49.28
2	1Stiffener-External	1S-E	540.28	64.32
3	1Stiffener-Interior	1S-I	526.12	64.23
4	1Stiffener-Central	1S-C	495.36	53.99
5	1Stiffener-Central-Thickness-13.5mm	1S-C-t13.5	565.56	64.114
6	1Stiffener-Central-Depth-45mm	1S-C-d45	689.32	75.985
7	2Stiffeners-Exterior & Interior	2S-E&I	592.70	64.377
8	2Stiffeners-Exterior & Interior-Depth-	2S-E&I-d22.5	887.8	86.668

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	22.5mm			
9	3Stiffeners- Interior, Exterior & Central	3S-I,E&C	596.4	76.009

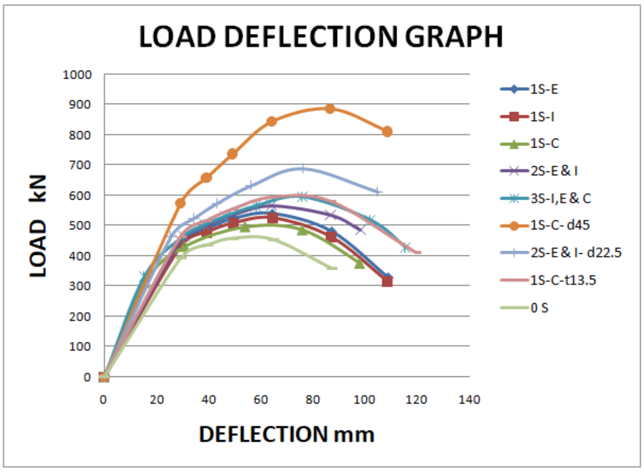

Chart -1: Load deflection graph of models based on difference in stiffeners

From the data obtained it is clear that steel beams with folded web plate models are having more load carrying capacity than steel ring web beam model. By comparing shape of folded plates, it was found that hexagonal shape showed better load carrying capacity than models with elliptical and circular shaped plates. It was also found that the strength can be increased by increasing the number of folds.

Best shape with a greater number of folds was provided with stiffeners of varying parameters and was again tested. It was found that position of stiffeners can influence load carrying capacity, and with increasing number of stiffeners strength is increased. By increasing depth and thickness also load carrying capacity was increased, From the 12 models it was identified that model with hexagonal folded web plate of one central stiffener of depth 45mm as the best model.

3.1 Impact loading test

Steel beam with hexagonal folded web plate model of one central stiffener of depth 45mm was subjected to impact loading. A load of 150 kg with density 12500kg/m³ was applied from a height of 3m height at a velocity of 7.668m/s. Energy absorbed by beam, plastic energy unrecovered force acting on beam and total deflection was found and impact resistance of best model was found.

Table -5: Impact Test results of model with 1 central stiffener of depth 45mm (1S-C-d45).

Model	1S-C-d45
Energy absorbed by beam (mJ)	984500
Plastic Energy (mJ)	210400
Force (kN)	209
Total deflection (mm)	14.2

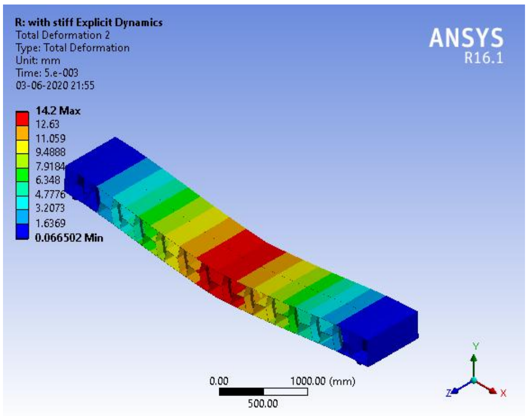

Fig -30: Total deformation of model with 1 central stiffener of depth 45mm (1S-C-d45).

From the values obtained, steel beam with hexagonal folded plate of one central stiffener of depth 45mm(1S-C-d45) has a deflection value of 14.2 and impact energy of 984500 mJ and plastic energy unrecovered 210400 mJ and the model has a ultimate load value of 209kN.

4. CONCLUSIONS

From the study, following conclusions were arrived at

- Hexagonal folded web plates have more strength than elliptical and circular folded web plate models
- Hexagonal folded web plates have more strength than Steel ring web beam model.
- Increase in number of folds can increase load carrying capacity of model. It is found that hexagonal 12 folded web plate model has a greater load carrying capacity than 8 folded web plate model
- Providing stiffeners can improve load carrying capacity of the model. Beam model with 3 stiffeners is better than a model with2 stiffeners and 1 stiffener.
- Position of stiffener can influence strength of beam. It is found that providing 1external stiffener is better than providing 1 central stiffener and 1 central stiffener is better than providing 1 internal stiffener
- Increasing thickness can increase load carrying capacity of model. In model with 2, when the depth of stiffeners was increased from 15mm to22.5mm, strength also increased
- Increasing depth can increase load carrying capacity of model. It was found that model with a central stiffener of 13.5mm thickness has more

strength than model with 1 central stiffener of 4.5mm thickness

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