ANALYTICAL AND EXPERIMENTAL INVESTIGATION OF STAINLESS STEEL BUILT UP BEAMS

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Abstract: *This paper deals with the numerical, analytical and experimental investigation of stainless steel sections. Sigma back to back and face to face sections are studied. Austenitic stainless steel is used due to its high corrosive resistant nature. Tensile coupon test is carried out to determine the material properties of the stainless steel sections. The analytical investigation is based on finite element modelling with ABAQUS software followed by experimental validation using four-point bending tests for the determination of the flexural strengths of the stainless steel specimens. The numerical investigations are to be carried out using the Direct Strength Method(DSM) with reference to the corresponding American code. The results will be presented as a comparative study of the numerical, analytical and experimental results obtained.*

Key Words: **Stainless Steel, DSM, CUFSM, ABAQUS and Two Point Loading**

1. INTRODUCTION

Cold forming eliminates the residual stress in steel sections due to temperature variations and also increases yield point. The stainless steel used in this study is manufactured by cold forming. The stainless steel sheets of Grade 304 is cut by hydraulic shearing machine to get straight edges of high precision and are subsequently bent to shape using press braking technique. The elastic buckling moments required for the direct strength method are determined by the finite strip software CUFSM [1]. ABAQUS [2] is used for finite element analysis since it is more accurate than ANSYS and capable of performing non linear analysis. Stainless steel particularly austenitic exhibits high corrosive resistant proprerty which finds its structural application in coastal areas. Though stainless steel is much costlier than mild steel, the maintenance cost during its service period decreases the life span cost. The DSM method followed in this study is validated for closed builtup beams in local buckling [3]. The finite element modelling for the built up section is validated against the flexural investigation on hollow beams done by Huang[4].

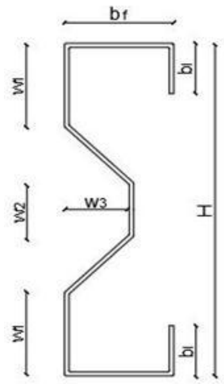
The DSM (Direct Strength Method) is used to check the accuracy and reliability of the built up sections. The residual stresses of the sections are not included in this study.

Despite numerous research work done on stainless steel hollow sections, built up section beams have not been adequately studied. This paper presents a comparative study of the numerical, analytical and experimental results obtained for such sections.

2. Sectional Properties

2.1 Section details

The specimens are made by the cutting and bending of 1.2 mm stainless steel sheets. A corner radius of 0.5 mm is provided at the corner portions. Geometric imperfections were identified in the specimen which is measured and used for the FE analysis.



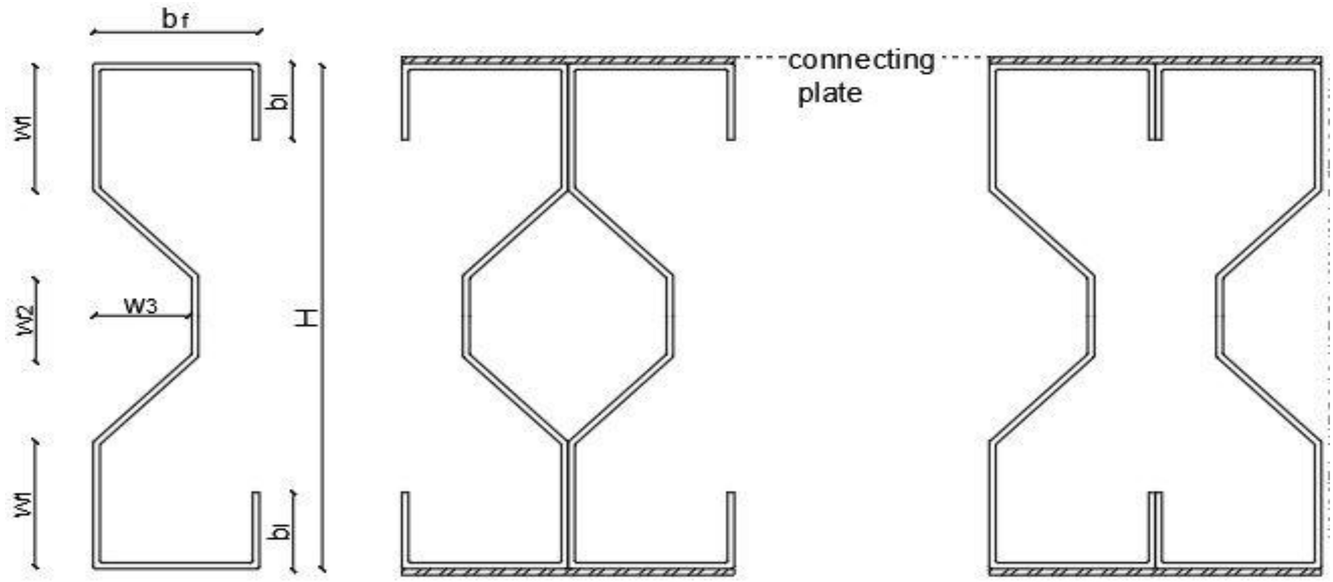


Fig1

Two sigma sections are connected back to back and another two sections face to face with connecting plates as shown in figure. The connection between the specimen and the plates are made through self-drilling screws. 4.6 grade screws are used of diameter 8 mm. A screw spacing of 150 mm is maintained for both the sections. The sectional properties of the built up sigma sections are shown in table 1.

Section	Details (mm)
H	100.2
w1	25
w2	15
w3	17.5
bf	30.1
bl	15
thickness	1.2
length	1200

Table 1

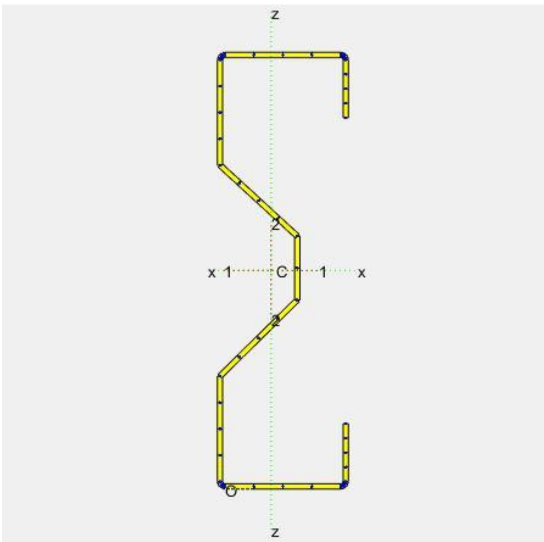


Fig 2

The geometric properties of the sigma section obtained from CUFSM is shown in table2.

Area(mm^2)	238.14
I_{xx}(mm^4)	326499.77
I_{zz}(mm^4)	25810.32
X_{cg}(mm)	11.7
Z_{cg}(mm)	50

Table 2

3. Material Properties:

Tensile coupon tests are carried out to determine the material properties of the SS specimen. The properties include yield strength, ultimate strength, % elongation and modulus of elasticity of specimen. The flat and the corner properties of the specimens obtained from the coupon tests are shown in table 3.

Section	E (N/mm²)	$\sigma_{0.2}$ (N/mm2)	σ_y (N/mm2)	Elongation %
Sigma section	21000	637	639	52.75

Table 3

4. Numerical Investigation:

The Bending capacity of the built up sections are determined by using the DSM formulae specified in AISI S100-2012[5].The following formulae are used in calculating the flexural strength.

M_{DSM} = Min. of (M_{nl}&M_{nd})

$$M_{\mathrm{DSM}} = \min(M_{\mathrm{nl}}, M_{\mathrm{nd}})$$

$$M_{nl} = \begin{cases} M_y + (1 - 1/C_{yl}^2)(M_p - M_y) & \text{for } \lambda_l \le 0.776 \\ \left[1 - 0.15\left(\frac{M_{crl}}{M_y}\right)^{0.4}\right]\left(\frac{M_{crl}}{M_y}\right)^{0.4} M_y & \text{for } \lambda_l > 0.776 \end{cases}$$

$$M_{nd} = \begin{cases} M_y + (1 - 1/C_{yd}^2)(M_p - M_y) & \text{for } \lambda_l \le 0.673 \\ \left[1 - 0.22\left(\frac{M_{crd}}{M_y}\right)^{0.5}\right]\left(\frac{M_{crd}}{M_y}\right)^{0.5} M_y & \text{for } \lambda_l > 0.673 \end{cases}$$

Where $\lambda_l = M_y/M_{crl}$, $C_{yl} = (0.776/\lambda_l)^{0.5} < 3$

$M_p = Z_f f_y$, $M_y = S_f f_y$

$\lambda_d = M_y/M_{crd}$, $C_{yd} = (0.673/\lambda_d)^{0.5} < 3$

S_f =gross section modulus at the extreme fibre during first yield,

Z_f = plastic section modulus,

f_y = yield stress,

M_{crl} =critical elastic local buckling moment,

M_{crd} =critical elastic distortional buckling moment.

The first minima in the signature curve represents the local buckling, second minima the distortional buckling and the third minima represents the global or lateral torsional buckling. In this curve, X-Axis represents the load factor ($\frac{M_{cr}}{M_y}$) and the Y-Axis represents the half-wavelength of the sinusoidal wave in log scale.

Specimen	λ_l	λ_d	M_{nl} (kNm)	M_{nd} (kNm)	M_{DSM} (kNm)
Face to Face	1.69	1.62	5.43	4.89	4.89
Back to Back	1.925	1.644	4.95	4.84	4.84

Table 4

The DSM strength values for both the sections are almost similar. Finite Element Analysis is carried out to verify the better section in flexure.

The overlapping parts of the sections are modelled as shown in figure3.

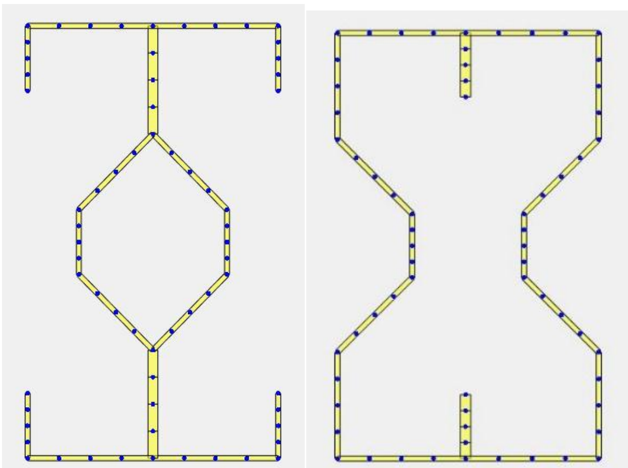


Figure 3 Modelling of back to back and face to face sections in CUFSM

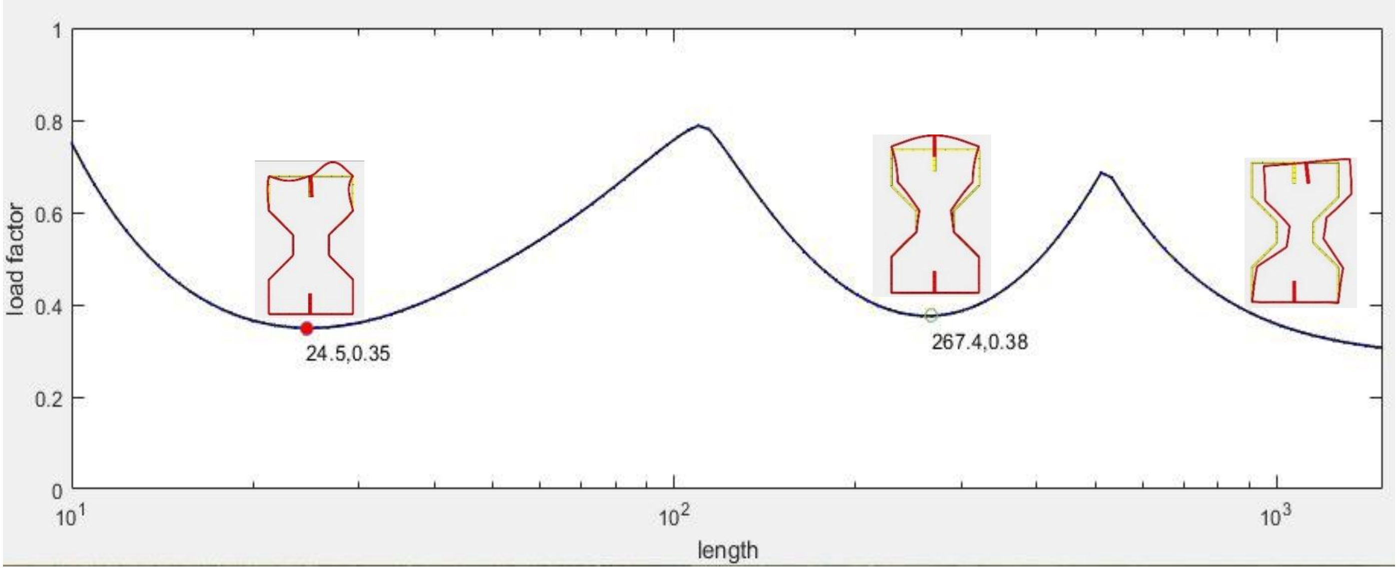


Figure 4

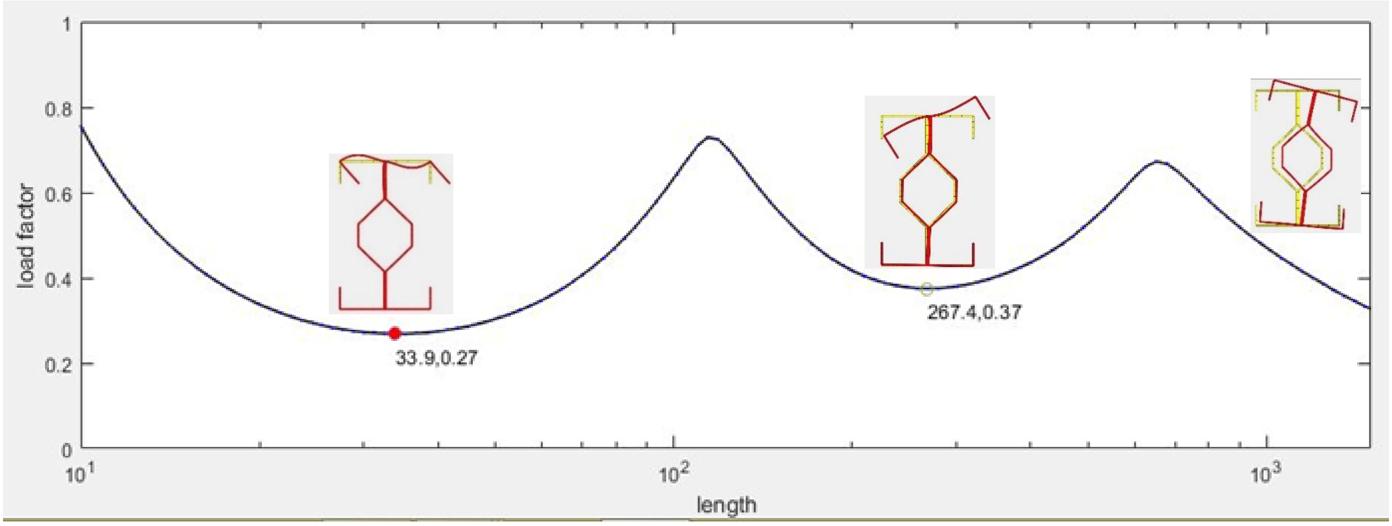


Figure 5

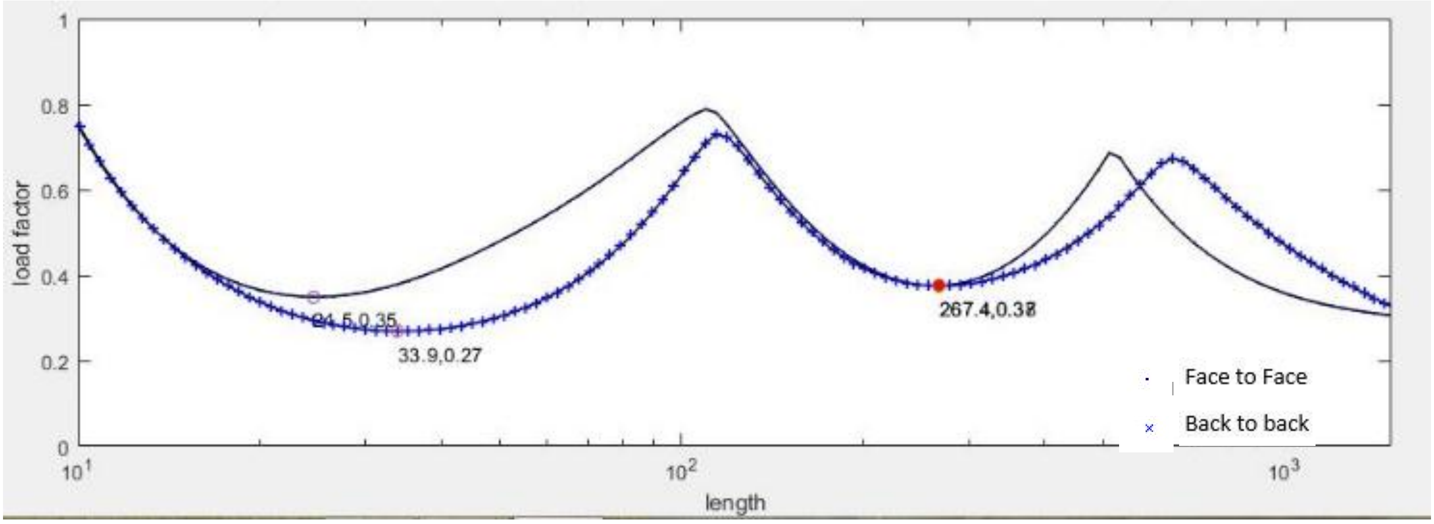


Figure 6

Fig.4 and 5 represents the local buckling (first minima), distortional buckling (second minima) and global buckling (third minima) of face to face and back to back sections respectively. Figure 6 represents a comparison of the signature curve between back to back and face to face sections.

5. FINITE ELEMENT ANALYSIS:

The FE analysis is carried out with the help of finite element software ABAQUS 6.13. Several beams shown by HUANG [4] are modelled and validated for the failure modes and results in terms of flexural capacity and deflection.

5.1 Material Property:

The material property is obtained from the tensile coupon test conducted experimentally. Both the corner and the flat elements are assumed to have the same properties (yield strength, modulus of elasticity of steel, etc.,)

5.2 Finite element type and mesh:

A 4 noded doubly curved shell element with reduced integration (S4R element in the ABAQUS library) has been used for the built up sections[6]. In this element, each node has six degrees of freedom (three displacements and three translations. A mesh size of 5mmx5mm is used in this study to obtain accurate results in the flat portions. A finer mesh (3 elements) is used for the corner elements.Fig.7 shows the meshing done in ABAQUS software. [7]

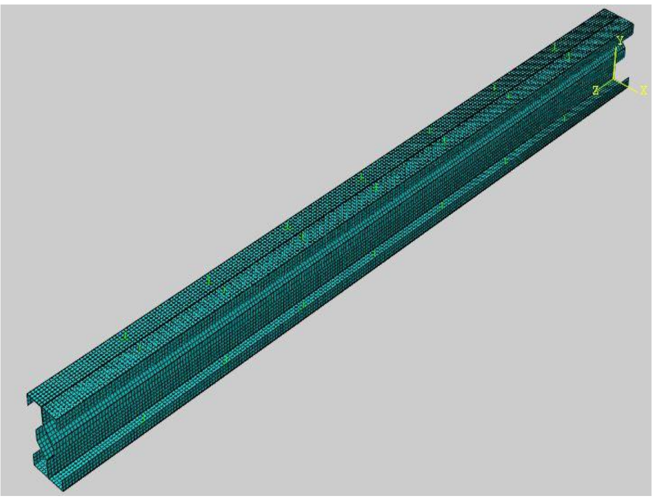


Figure 7

5.3 Load and Boundary Conditions:

All the cross section nodes at the beam end sections are coupled to the corresponding reference points created at the centroid of the cross section as shown in figure 8. The support conditions are applied through the reference points at the centeroid. The roller support is simulated by restricting the translation along the X and Y directions(U1,U2) and the rotation along the Z direction(UR3).The hinged support is simulated by restricting the translation along the X,Y and Z directions(U1,U2 and U3). Two point loading is applied as line loads to simulate the spreader beam loading carried out experimentally. The moment span is kept as 350 mm for both the beams. Displacement control method is used in the analysis of built up beams.

5.4 Non Linear Analysis:

In order to include local imperfection, the built up beams are first analysed in linear analysis. The resulting buckling mode of the specimen is incorporated as imperfection in the non linear analysis(*IMPERFECTION). The imperfection factor is assumed as 0.35t as suggested by Schafer and Pekoz[8]. The yield strength of the specimen from coupon test is included in the non linear analysis. The Static RIKS step from the ABABQUS library is used.

5.5 Contact Modelling:

The contact existing between the web portions of the built up sections are given as small sliding formulation with hard contact in normal behaviour. It is also assumed to be a frictionless contact in tangential behaviour. The same contact properties are given between the connecting plates and the built up sections.

5.6 Connection between sections:

The connectors category is given as complex and the complex type is given as beam. The influence radius is given as 10 mm and the layer of interaction is taken as 1.The fasteners provided at the top and bottom portion of the built up section as shown in figure 8.

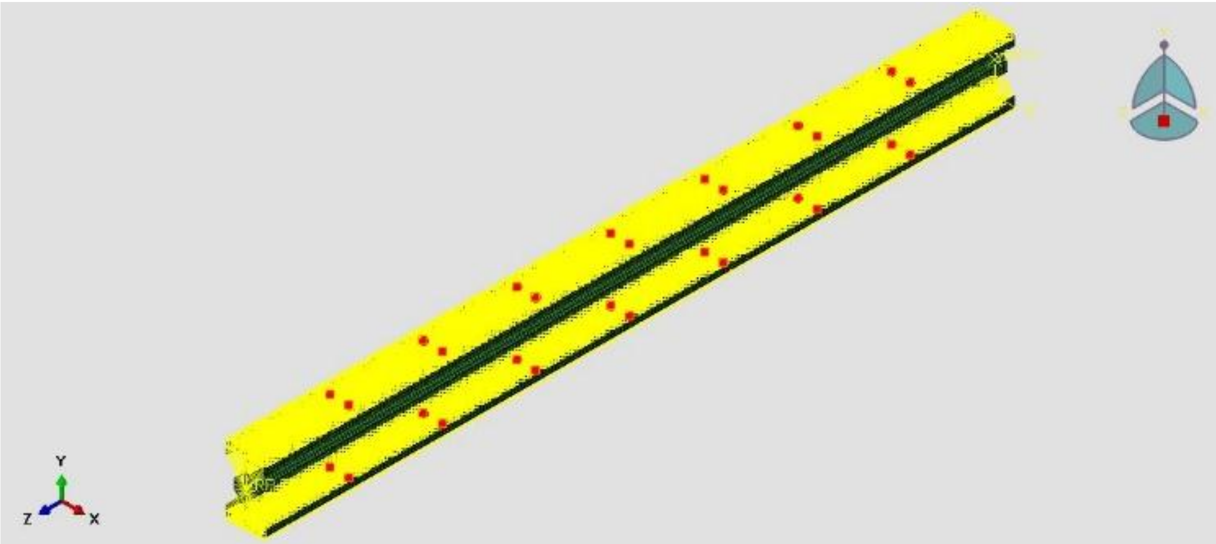


Figure 8

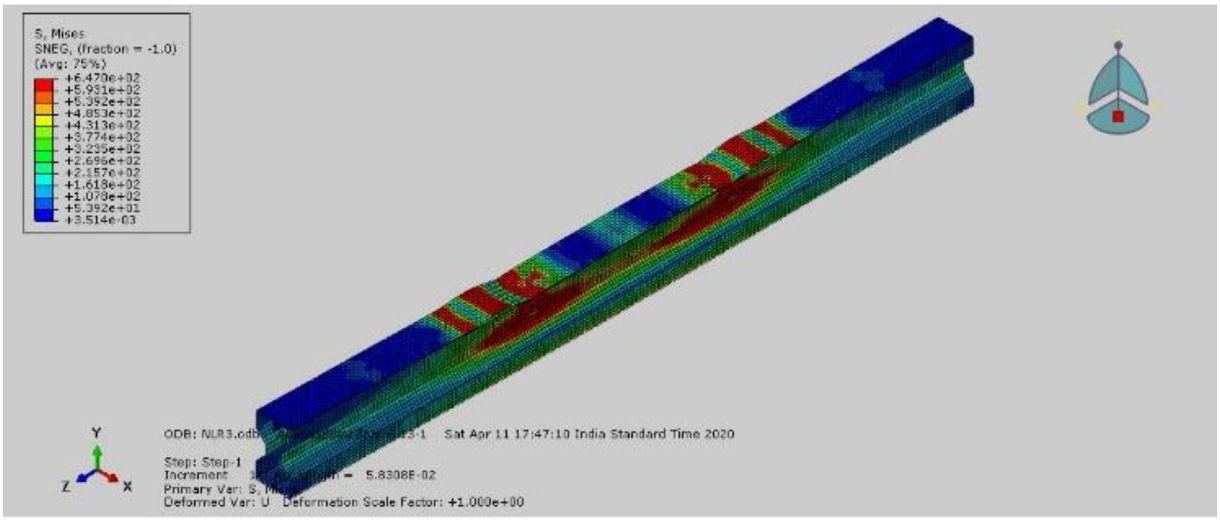


Figure 9

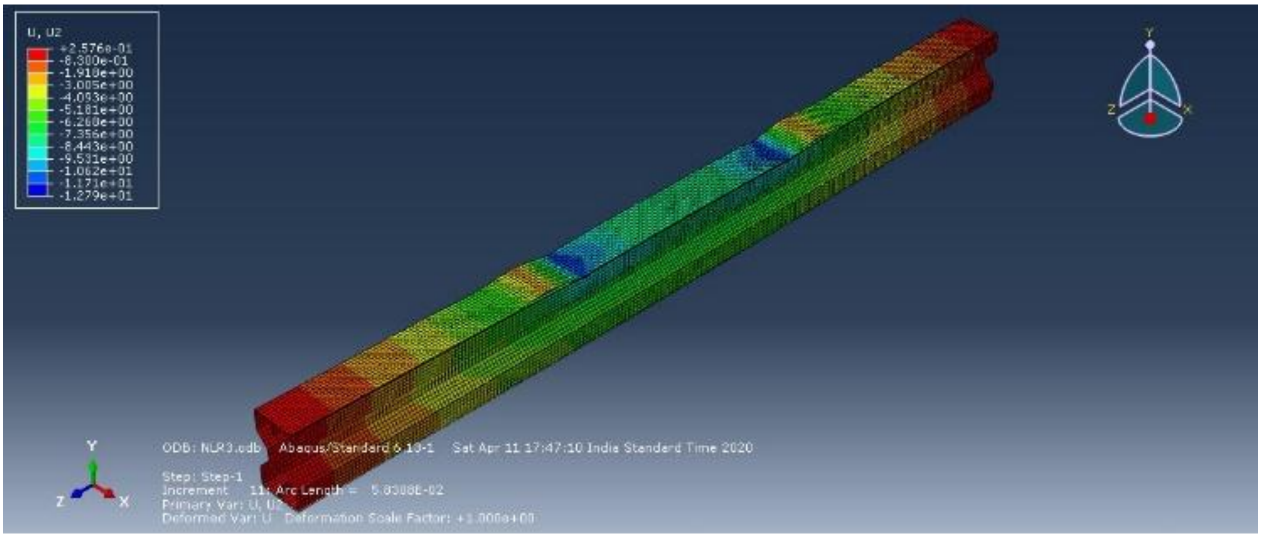


Figure 10

Figure 9 shows the Von Mises stress values of the face to face section. The stress values are higher at the loading points and lower near supports.

Figure 10 shows the deformation of the beam at failure. Upward deflection takes place at supports, while at the center, downward deflection takes place.

6. Experimental Investigation:

The experimental test was carried out by using a 250kN loading frame as shown in figure 11.A proving ring of 100 kN is used for the determination of the applied load. The loading is applied through a spreader beam to the specimen.

Figure 11

The moment span and the shear span is kept as 350mm for both the specimens. The hinged support is simulated by a welded roller restricting the translation along the beam length. The roller support is simulated by a free roller which can translate in Z direction. A bearing length of 75mm is used in the study. Five dial gauges are used in order to determine the deflection at the particular locations(two inverted dial gauges at the support, two at the loading points and one at the mid span location).

The face to face section failed by local buckling as shown in figure 12.The specimen failed at an ultimate load of 16.47 kN with a bending capacity of 5.76 kNm.

Figure 12

The back to back section failed by lateral torsional buckling as shown in figure 13.The section has an ultimate load carrying capacity of 11.74 kN with a bending capacity of 4.2 kNm.

Figure 13

7. Comparison of analytical and experimental results:

The experimental and the analytical results are compared to check the accuracy of the work. The failure mode of the face to face section from analytical and experimental work is shown in fig.14.

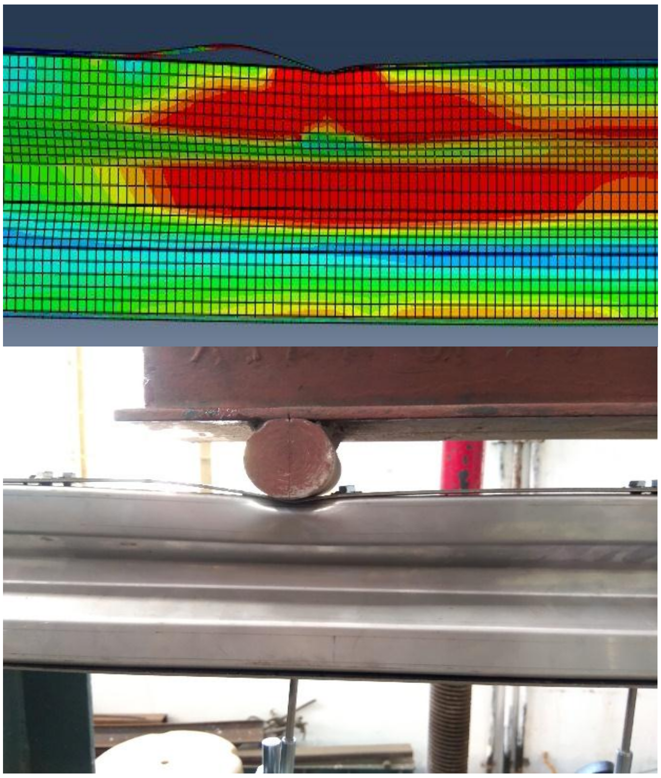


Figure 14

The load vs deflection curve for the face to face section is shown in figure 15.

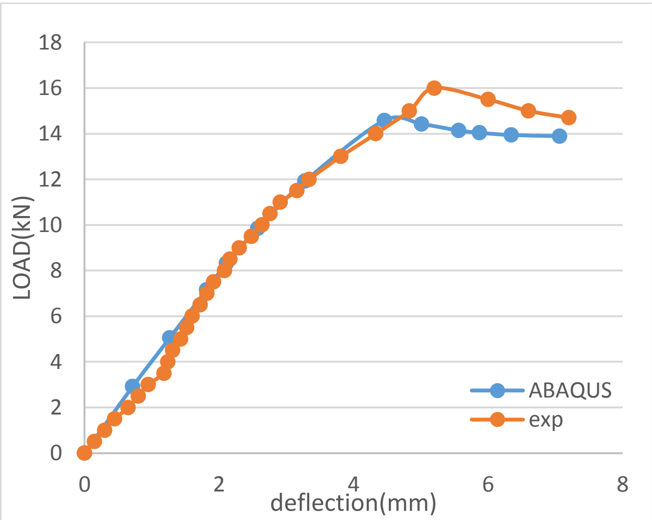


Figure 15

Section	MDSM (kNm)	MFEA (kNm)	MEXP (kNm)	MFEA/MEXP
Back to Back	4.84	4.46	4.2	0.92
Face to Face	4.89	5.075	5.6	0.91

Table 5

8. Conclusions:

- The back to back section failed by local buckling whereas the face to face section failed by lateral torsional buckling.The face to face built up section has a greater bending capacity (16 kN) than the back to back section(11.2 kN).The ultimate deflection was found to be 4.9 mm and 5.5 mm in face to face and in back to back sections respectively. Therefore,face to face section is better in flexure than the back to back section.

- This work is carried out with w3/bf ratio as 0.6.The work could further be extended with w3/bf ratio as 0.2, 0.4, 0.8 etc., for more accurate comparison between the two built up sections.

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