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STUDY OF FLEXURAL BEHAVIOUR OF STEEL BEAM-COLUMN CONNECTION WITH GUSSET PLATE

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ABSTRACT

The aim of this research work is to study the flexural behaviour of steel beam-column connection with gusset plate under static loading condition. Connections are normally the focal points of receiving damage due to overload including earthquake. The main reason for the failure of connection is, their inability to deliver large rotation. Gusset plates are used for connecting two or more members together. While gusset plates are used as the connecting element of bracing to the beam-column joint, the load carrying capacity and stiffness of beam-column joints are possible to increase. To know the increasing capacity of beam-column connection with gusset plate are determined by conducting the experimental and analytical program. An experimental research demonstrates the actual behaviour of steel beam-column connection with gusset plate. There are four number of specimens are tested under static loading condition. Each specimen is fabricated by changing the connection parameter like gusset plate thickness, angle leg length. Finite element analysis was done using ABAQUS. Using the finite element model, a parametric study was conducted to determine the changes in the connection and initiation of damages. The contact element which is used as a surface to surface instead of node to node. Accurate results can be obtained by validating the results of experimental work with FEM analysis. The comparison is made for the deflection and strain occurred on the experimental program with the analytical results.

Keywords: Gusset plate; beam-column joint; stiffness; flexural behaviour.

1. INTRODUCTION

In steel structures, Connections are the structural element used for joining different members. Normally connections are the focal point of receiving damage due to overload or any disaster because of their inability to transfer the large rotation. The simple connections

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such as clip and seat angle connection, web angle connection, and flexible end plate connection can be adopted for beam-column connections [1].

In a frame of a steel building, a beam may be attached to another beam or a column. In such a cases, the design of connections under a system of loads depends on the elements and its behavior [2]. The beam to column connections expected to resist and transfer end reactions only are termed as shear connections or flexible connections. These permits free rotation of the beam end and do not have any moment restraint. Other types of connections which do not permit any relative rotation between the beam and column are expected to resist moments in addition to end reactions are termed as moment connections or rigid connections [3].

Simple connections of beams to column can be either seated or framed. In a seat connection, the beam is supported by an angle section connected to the column [1]. In this case, one leg of the angle is used to make a seat for the beam and another leg is connected to the column flange. Another angle called cleat angle or clip angle, is provided on the top flange of the beam. The web of the beam when connected to the column flange with angle sections, the connection is said to be a framed connection. Here experimentally investigate the flexural behaviour of steel beam-column connection with gusset plate under static load and validate with finite element simulation [4].

2. PRELIMINARY TEST

2.1 General

Structural steel has been classified by the Bureau of Indian Standards based on its yield strength [5]. For example, Fe-410 steel has a minimum tensile strength of 410 N/mm^2. The mechanical properties of steel depend on its atmospheric exposure, grain size, rolling methods, heat treatment and stress history.

2.2 Tension coupon test

Tension coupon test was carried out to obtain the stress-strain graph, tensile properties and hence, it has given the valuable information about the mechanical behaviour such as ultimate stress, yield stress, Young's modulus, load at breakage and the Engineering performance of the material.

In the tension coupon test, the flat bar is gradually pulled in UTM until it breaks. A flat steel specimen of 40 mm breadth and a thickness of 6 mm were used. Dimensions of the tension coupon specimen are taken as per IS: 1608 - 2005. Tension coupon test has been conducted on two numbers of specimens [6].

Gauge points are marked on the central portion of the specimen. The extension of the gauge length and the values of the corresponding loads are recorded at frequent intervals. A load vs. elongation curve was plotted by a digital recorder so that the tensile behaviour of the material can be obtained. The following Fig. 1 shows the schematic diagram of rectangular tension coupon specimen.

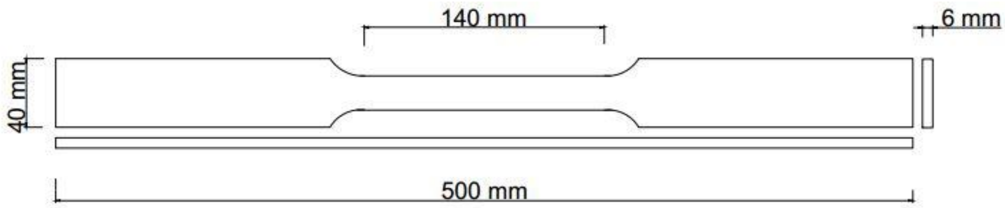


Figure 1. Schematic diagram of rectangular tension coupon specimen

The mechanical parameters can be found by studying on this curve as shown in Table 1. A typical Engineering stress- strain graph as shown in Fig. 2.

Table 1: Tension coupon test results

Specimen	Dimension (mm)	Young's modulus (10^6 N/mm^2)	Yield stress N/mm^2	Ultimate stress N/mm^2	% of elongation
1	40 × 6	193	353	508.25	33.57
2	40 × 6	197	341	495.08	31.26

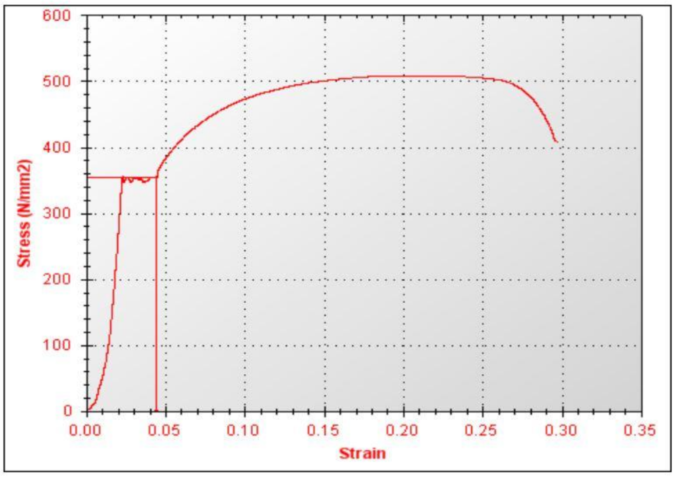


Figure 2. Stress strain graph for Tension coupon test

There being a general reduction in the area of cross section of the specimen. Local yielding begins, and a neck was formed at one point of the specimen. The stress at that point is called ultimate stress. Due to load, beyond that necking point, if the stress induced in the material, it starts decreasing, and the specimen breaks [7].

3. EXPERIMENTAL INVESTIGATION

3.1 General

This experimental program was conducted to study the behaviour of beam-column connection with gusset plate which is subjected to the static load. Initially, a pilot test was conducted for steel beam-column connection with seat and cleat angle under static load condition.

3.2 Beam-column specimen details

The following Table 2 gives the details of the specimen consider for experimental investigation.

Table 2: Details of the specimen used for experimental test

Specimen. No	Column section	Beam section	IS Angle in mm	Thickness of gusset plate in mm
1	ISMB 150	ISLB 100	50 × 50 × 6	6
2	ISMB 150	ISLB 100	65 × 65 × 6	6
3	ISMB 150	ISLB 100	50× 50 × 6	8
4	ISMB 150	ISLB 100	65 × 65 × 6	8

3.3 Pilot test on beam-column specimen

A pilot test was conducted for the beam-column specimen to assess the suitability of the test setup and loading frame. In a seat angle connection, the beam was supported by an angle section connected to the column. In this case, one leg of the angle was used to make a seat for the beam and another leg is connected to the column flange [2]. The another angle called cleat angle was provided on the top flange of the beam as shown in Fig. 3. The test setup for the pilot test as shown in Fig. 4.

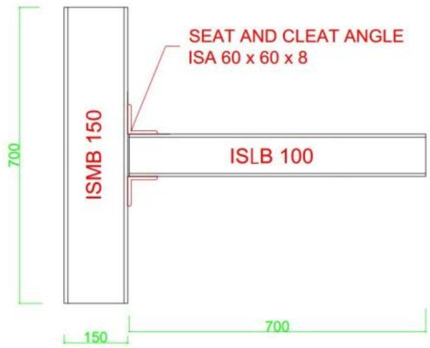


Figure 3. Beam-column connection with seat and cleat angle

Figure 4. Pilot test setup for beam-column specimen

3.4 Beam-column with gusset plate

The experimental program was initiated to investigate the flexural behaviour of welded beam-column connection with gusset plate under static loading condition. The angle was used to make the seat for the beam and another leg was connected to column flange. A gusset plate was connected to the column and beam joint region. The top gusset plate was very helpful in keeping the top flange of the beam from twisted out of place. Further, it provides lateral stability to the compression flange at the ends by restraining the beam against torsion.

3.5 Data acquisition

Data acquisition for the experimental was conducted using Linear variable differential transformer (LVDT), Dial gauge and Strain gauges.

3.6 Deflection measurement

Acquiring data about the flexural behaviour of connection and at the free end. The displacements were observed at the beam end and locality within the connection region. Generally, the deflection at the free end is more when compared to the connection. So that LVDT is placed at the free end and dial gauge was attached to the connection region.

3.7 Strain measurement

The linear strain gauges are used to determine the variation of strain through the connection region. While applying the load at the free end of the beam, the strain values are observed from the gusset plate and the angle.Electrical resistance strain gauge of type BKSA 10 was used for strain measurements.

The limitations of strain gauge are as follows,

i. Resistance factor - 120 ohms ± 0.02
ii. Gauge factor - 2.0 ± 0.2
iii. Gauge length - 10 mm

3.8 Static loading test setup

The beam-column specimen has been placed over the loading frame. The column part is fixed on the side of loading frame 16 mm diameter bolt with the plate of 200 mm×200 mm was used. Hydraulic load cell was placed at the end of beam for applying load and the proving ring was attached to the load cell to measure the load. LVDT was provided at the beam end and dial gauge was attached at the connection point to measure the deflection at the free end, at connection respectively.

The static load test setup for testing the beam-column with gusset plate is as shown in Fig. 5. The load was increased gradually about 1 kN up to the failure occurs on beam-column specimen. For every 1 kN increasing load, the rate of deformation is observed.

From the observation, the deflection is gradually increased from zero to the maximum deflection for the applied load. The maximum deflection and minimum defection was observed at the free end of the beam and at connection respectively.

Figure 5. Beam-column joint with gusset plate Assembly test setup.

4. ANALYTICAL WORK

4.1 General

The finite element analysis was done using ABAQUS software. Finite element simulations of beam-column connection with gusset plate are done [8]. From the analysis, Non-linear behaviour of connection has studied under static loading.

4.2 FEM model specification

The following Table 3 gives the details of the specimen consider for Finite Element Analysis.

4.3 Finite element model

A three-Dimensional finite element model consisting of solid elements was created as shown in Fig. 6. The finite element model of the connection is developed using ABAQUS. The size of the components used for FE analysis was based on the original member sizes listed in Table 3.

Table 3: Details of specimen used in FE analysis

S.No	Column section	Beam section	IS Angle in mm	Thickness of gusset plate in mm
1	ISMB 150	ISLB 100	50 × 50 × 6	6
2	ISMB 150	ISLB 100	50 × 50 × 6	8
3	ISMB 150	ISLB 100	65 × 65 × 6	6
4	ISMB 150	ISLB 100	65 × 65 × 6	8
5	ISMB 150	ISLC 100	40 × 40 × 6	6
6	ISMB 150	ISLC 100	50 × 50 × 4	6
7	ISMB 150	ISLB 100	50 × 50 × 4	4
8	ISMB 150	ISLB 100	40 × 40 × 4	4
9	ISMB 150	Double ISLC 100	50 × 50 × 6	6

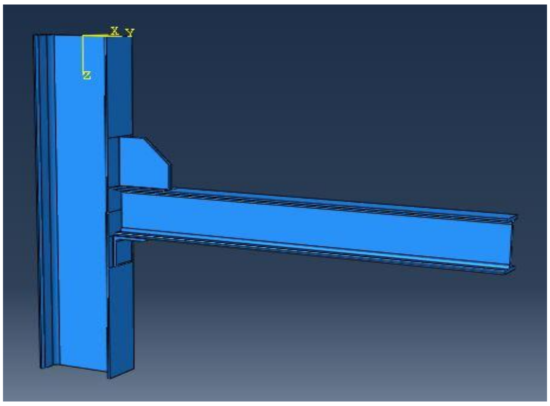


Figure 6. Finite element model

4.4 Material property

The properties of the materials are assigned as steel sections. The general property like mass density and elastic property such as Young's modulus, Poisson ratio has been given as input to the property module. The sections are solid category and homogeneous type. The same properties are assigned to the finite element model and assembled at the accurate position for loading. Static general loading types are taken for analysis of beam-column.

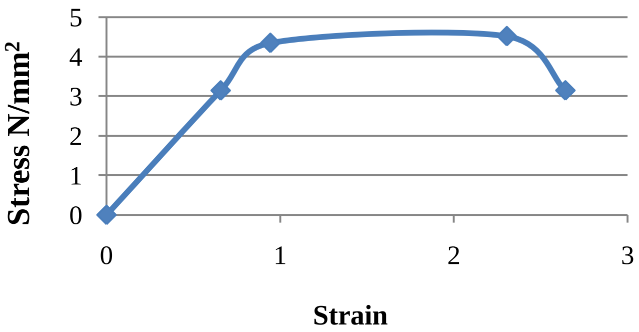


Figure 7. Stress-strain curve for material

4.5 Assembling and interaction

Finite element parts were created independently in its own coordinate system. Then all the parts are assembled for the interaction. Tie constraint is used for the interaction of part elements. The interaction between the angle, beam, column and gusset plate element is made by surface to surface contact for welded connection. Surface-to-surface contact elements are used to model contact between two surfaces, So it gave more stiffness to the connection.

4.6 Loading

The beam-column connection with gusset plate is subjected to a concentrated load. The static load was applied at the end of the beam element. Loads are able to apply on nodes only so it is important to create a set by selecting the number of nodes.

A set was created for applying load on the beam and named as loading point. The point load of 20 kN was applied at the set created for loading. The total loads applied are given to the node by the dividing number of node selected.

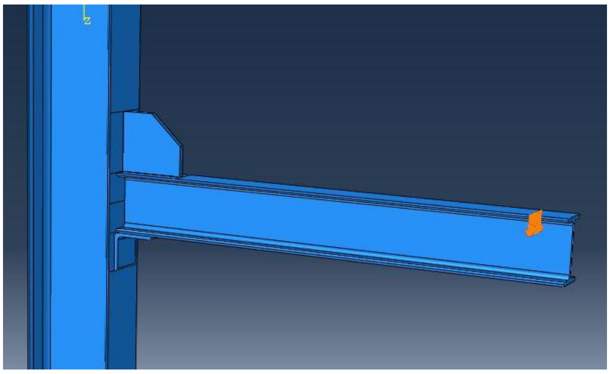


Figure 8. Point load at beam end

4.7 Joint configuration and boundary condition

In FEM, an interaction was created by means of surface to surface contact for welded connection. It is essential to create a boundary condition in a model. Boundary condition deals with the end conditions, loading details of the elements, displacement of the element, slope etc.

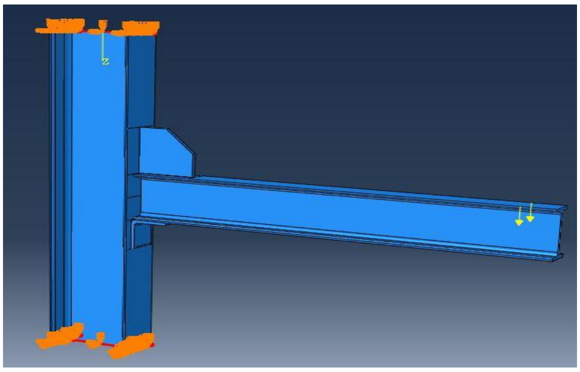


Figure 9. Boundary condition

In this model, the top and the bottom portion of the column is completely fixed, so that displacement and rotation will be zero. In ABAQUS, by use of ENCASTRE (U1=U2=U3=UR1=UR2=UR3=0); Fixed condition was achieved. Tie constraint was used as interaction.

4.8 Meshing

ABAQUS/CAE offers a variety of meshing techniques for different topologies. The free meshing technique is the most flexible meshing technique. The meshing type may consist of triangular or quadrilateral else tetrahedron or hexahedron. Based on suitability, assign the mesh type to the model.

The complex geometries can be difficult to mesh completely with hexahedrons. So tetrahedral mesh was used in this model as shown in Fig. 10. The elements were made with the aspect ratio of length to width to be as small as possible. In size control, the approximate global sizes of the element used as 4.

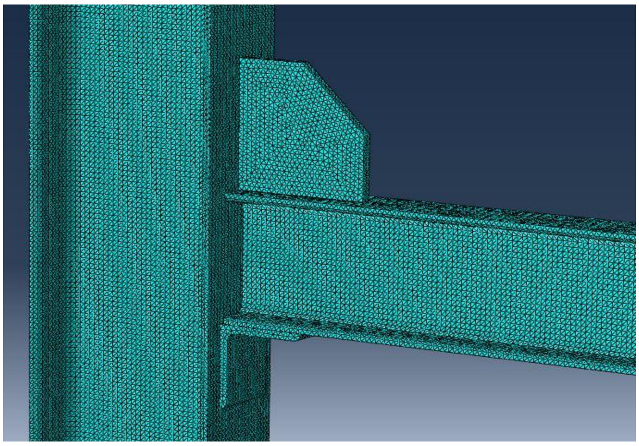


Figure 10. Mesh discretisation

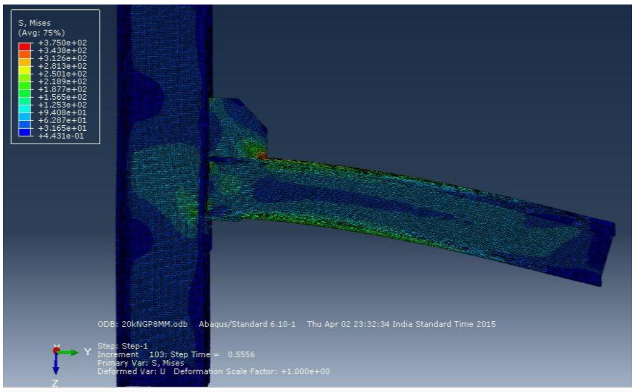


Figure 11. Deformed shape of the element

The Fig. 11 shows the deformed shape of the specimen after the concentrated load was applied on the free end of the beam. The stress distribution of the welded beam-column connection under the static loading was obtained by finite element analysis.

The above Fig. 12 shows the von-mises stresses. The contour scale is at its default setting which will take the maximum and minimum stress. The magnitude of stress variations is represented by blue, green, to red colour. Blue colour usually represents the lowest stress and it is gradually increased for the highest stress range is in red colour. The colour green was represents the average stress. When the material reaches the yield point the material can be considered as failed [11]. The stress observed on the gusset plate is more, it indicates the possible of failure at the connection.

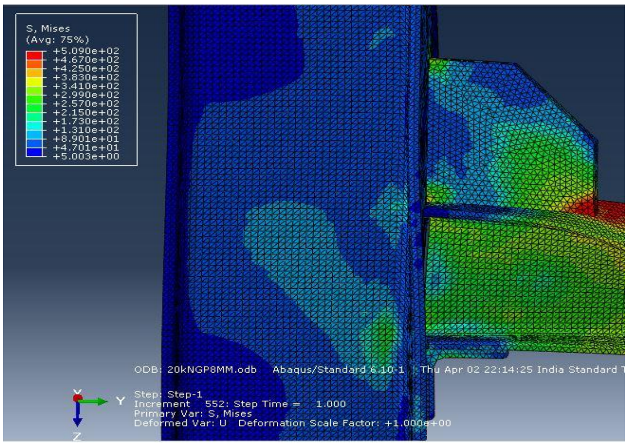


Figure 12. Stress distribution in connection

5. RESULTS AND DISCUSSION

5.1 General

The beam-column connection with gusset plate will be made and test the connection under static loading condition. Totally four number of specimens were made by changing the connection parameters like the thickness of gusset plate, the length of angle etc. The experimental result has been compared to the analytical results using Finite element analysis software.

5.2 Test results

The experimental test was conducted on beam-column connection with gusset plate. There are four number of specimens had consider for a static load test. For the applied load, deflection at beam end and at connection was observed. And then for the same load, the strain values also observed. The readings of LVDT and dial gauge are as shown in Table 4, 5, 6, and 7.

A graph in which increasing flexural loads on a beam-column was plotted along the vertical axis, and deflection resulting from these loads are plotted along the horizontal axis.

The strain energy produced due to the applied load was observed. When a beam bends due to concentrated load, layer on one side of the neutral axis are stretched and on the other side was compressed. The strain energy is observed on the connecting element of gusset plate and at the angle of the specimen. The graph is plotted for load versus strain. The same specimens which were used in the experimental test are analyzed with the finite element software and results are extracted from the finite element analysis. The results like deflection and strain are plotted in the graph.

5.3 Results of specimen 1

The following Table 4 shows the test observation of beam-column specimen 1.

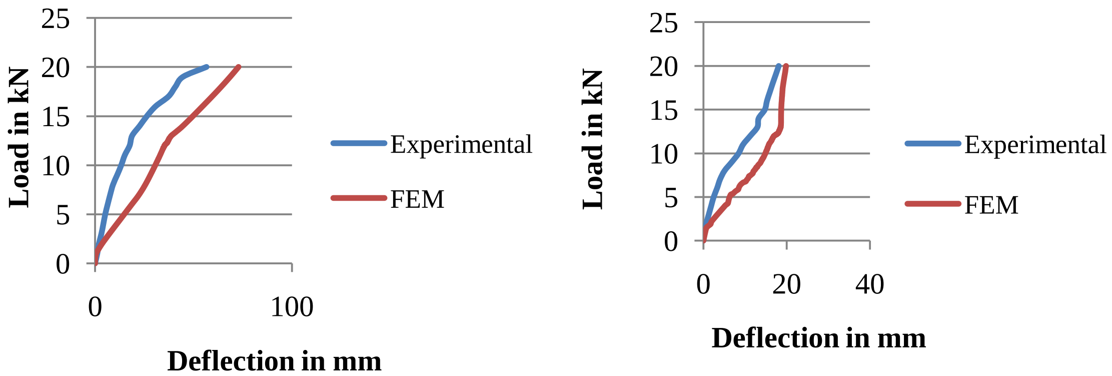
The ultimate load observed by the specimen 1 is 24 kN. The maximum deflection observed for the load of 20 kN is 56.60 mm at free the end and 18.07 mm at connection region.

5.3.1 Load vs Deflection graphs of specimen 1

The following Fig. 13 shows the deflection curve for the specimen 1.

Table 4: Experimental observation of specimen 1

Load in kN	Deflection in mm	
	At Beam end	At Connection
0	0	0
1	1.14	0.27
2	1.96	0.70
3	3.20	1.28
4	4.20	1.87
5	5.16	2.46
6	6.40	3.27
7	7.68	3.98
8	9.09	5.06
9	11.24	6.81
10	13.31	8.45
11	15.07	9.51
12	17.58	11.26
13	18.84	12.96
14	22.67	13.25
15	26.36	14.74
16	30.81	15.25
17	37.34	15.93
18	40.84	16.62
19	44.71	17.36
20	56.60	18.07

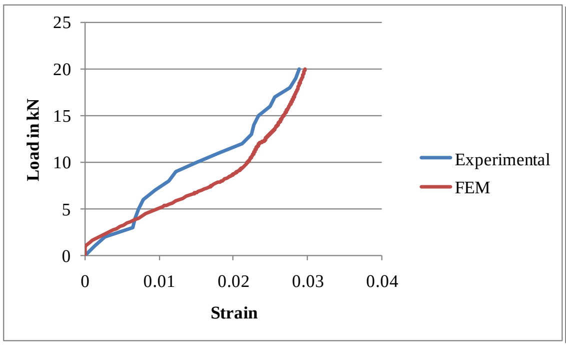


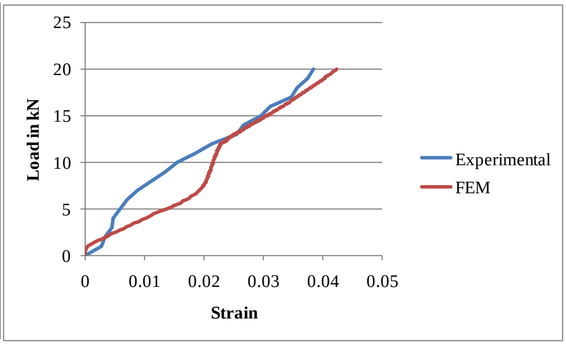
(a) At free end (b) At connection

Figure 13. Load vs. Deflection graph for specimen 1

5.3.2 Load vs Strain graphs of specimen 1

The following Fig. 14 shows the strain curve for the specimen 1.





(a) At angle (b) At gusset plate

Figure 14. Load vs. Strain graph for specimen 1

5.4 Results of specimen 2

The following Table 5 shows the test observation of beam-column specimen 2.

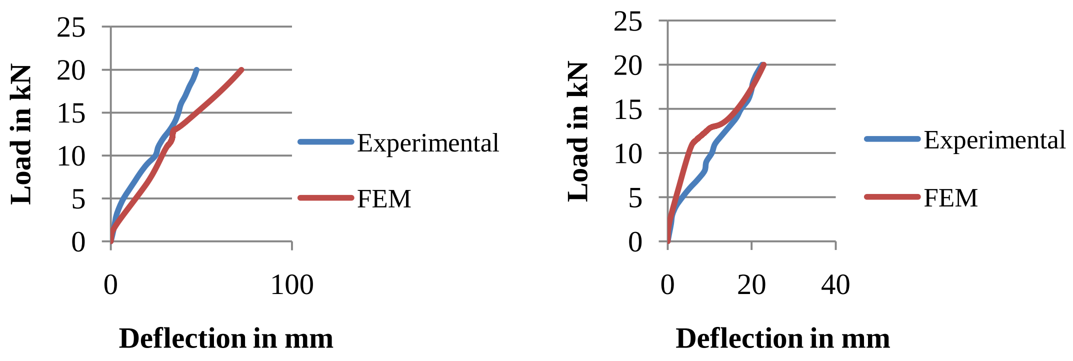
Table 5: Experimental observation of specimen 2

Load in kN	Deflection in mm	
	At Beam end	At Connection
0	0	0
1	1.14	0.40
2	2.12	0.80
3	3.03	1.10
4	4.75	2.00
5	7.01	3.50
6	10.01	5.20
7	13.22	7.17
8	16.36	8.80
9	20.01	9.20
10	24.64	10.51
11	26.19	11.24
12	28.95	12.90
13	32.62	14.68
14	35.51	16.37
15	37.35	17.50
16	38.74	19.12
17	41.24	19.89
18	43.30	20.30
19	45.72	21.20
20	47.41	22.50

The ultimate load obtained by the specimen 2 is 22 kN. The maximum deflection observed for the 20 kN load is 47.41 mm at the free end and 22.50 mm at connection region.

5.4.1 Load vs deflection graph of specimen 2

The following Fig. 15 shows the deflection curve for the specimen 2.

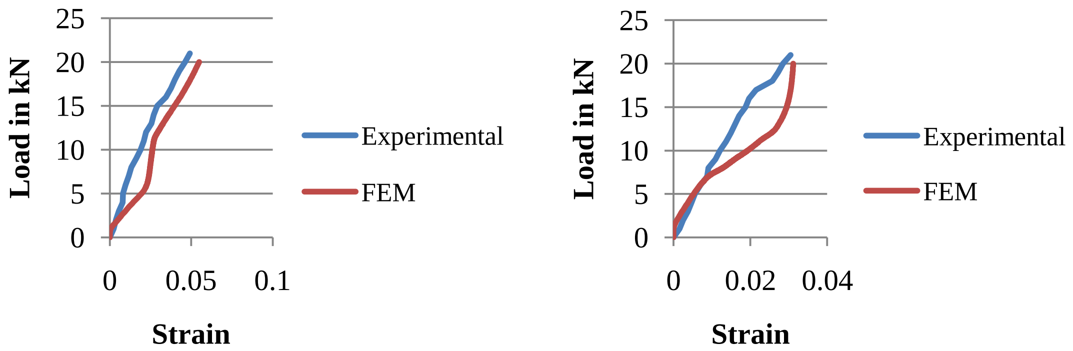


(a) At free end (b) At connection

Figure 15. Load vs. Deflection graph for specimen 2

5.4.2 Load vs Strain graph of specimen 2

The following Fig. 16 shows the strain curve for the specimen 2.



(a) At angle (b) At gusset plate

Figure 16. Load vs. Strain graph for specimen 2

5.5 Results of specimen 3

The following Table 6 shows the test observation of beam-column specimen 3.

Table 6: Experimental observation of specimen 3

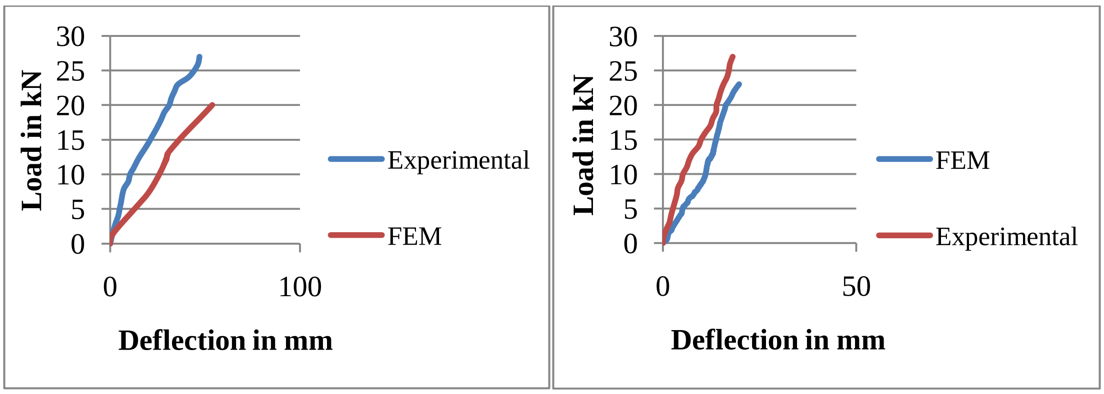
Load in kN	Deflection in mm	
	At Beam end	At Connection
0	0	0
1	0.85	0.20
2	1.83	0.90
3	2.91	1.70
4	4.24	2.10

5	4.96	2.60
6	5.74	3.12
7	6.35	3.60
8	7.36	3.90
9	9.58	4.80
10	10.47	5.20
11	12.51	6.20
12	14.33	6.80
13	16.53	7.70
14	18.95	9.20
15	21.08	9.90
16	23.16	11.00
17	25.17	12.30
18	26.97	12.90
19	28.57	13.80
20	31.11	13.90
21	32.22	14.50
22	33.87	15.00
23	35.71	15.70
24	41.15	16.60
25	44.28	17.10
26	46.34	17.40
27	47.05	18.10

The ultimate load obtained by the specimen 3 is 28 kN. The maximum deflection observed for the load of 27 kN is 47.05 mm at free the end and 18.10 mm at connection region.

5.5.1 Load vs deflection of specimen 3

The following Fig. 17 shows the deflection curve for specimen 3.

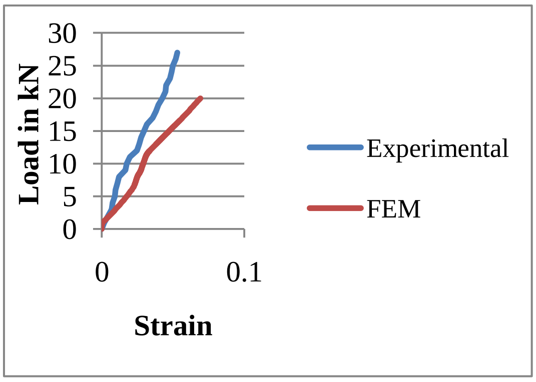


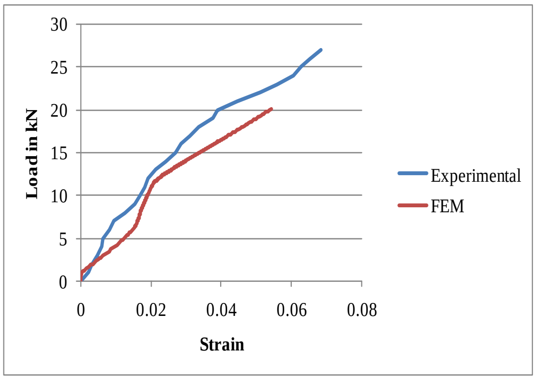
(a) At free end (b) At connection

Figure 17. Load vs. Deflection graph for specimen 3

5.5.2 Load vs Strain graph for specimen 3

The following Fig. 18 shows the strain curve for specimen 3.





(a) At angle (b) At gusset plate

Figure 18. Load vs. Strain graph for specimen 3

5.6 Results of specimen 4

The following Table 7 shows the test observation of beam-column specimen 4

Table 7: Experimental observation of specimen 4

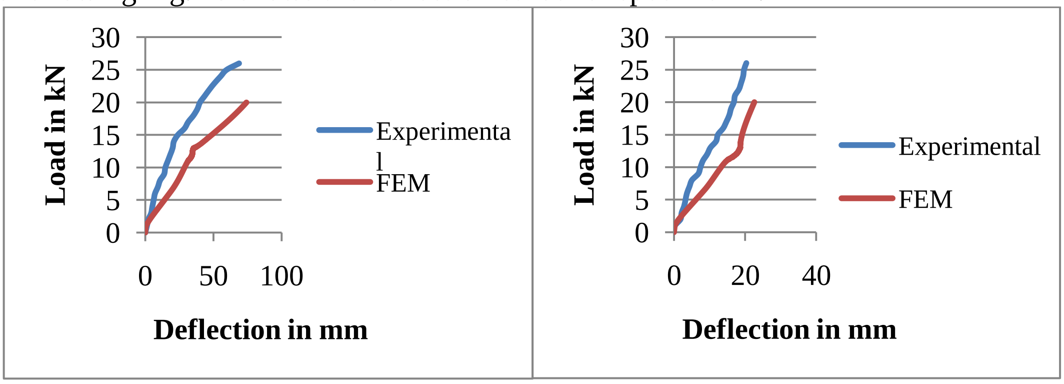
Load in kN	Deflection in mm	
	At Beam end	At Connection
0	0	0
1	1.19	0.3
2	2.22	1.9
3	4.31	2.2
4	5.17	2.9
5	6.15	3.3
6	7.11	3.7
7	8.21	4.4
8	9.81	5.1
9	10.86	6.90
10	12.71	7.50
11	14.54	8.20
12	16.37	9.40
13	18.08	10.30
14	19.97	11.90
15	21.87	12.40
16	24.77	13.90
17	27.53	14.80
18	29.37	15.60
19	31.26	16.10
20	33.13	16.90

21	35.63	17.20
22	40.14	18.34
23	44.95	18.95
24	51.29	19.50
25	56.61	19.75
26	68.83	20.40

The ultimate load obtained by the specimen 4 is 27 kN. The maximum deflection observed for the 26 kN load is 68.83 mm at the free end and 20.40 mm at connection region.

5.6.1 Load vs deflection of specimen 4

The following Fig. 19 shows the deflection curve for specimen 4.

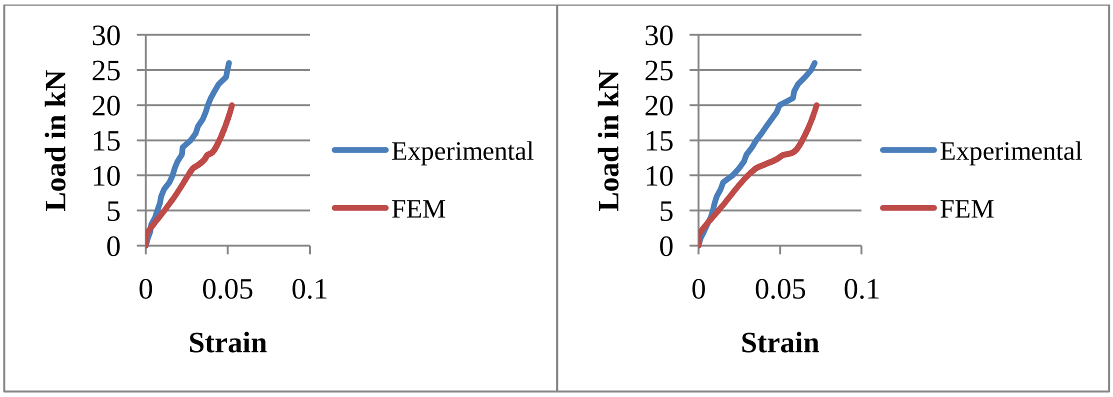


(a) At free end (b) At connection

Figure 19. Load vs. Deflection graph for specimen 4

5.6.2 Load vs Strain of specimen 4

The following Fig. 20 shows the strain curve for specimen 4.



(a) At angle (b) At gusset plate

Figure 20. Load vs. Strain graph for specimen 4

The above graphs demonstrate the beam-column connection behaviour under static load.

The deflection in the connection is less and the deflection at the free end of the beam is more which is indicated in the graph. From this experiment, it is clear that the load is first transferred to the beam part and then it fails the connection.

The connecting elements such as seat angle and gusset plate gives strength to the beam-column connection. In addition to that, an interaction between the angle, beam, and column element is made by surface to surface contact for welded connection. So it has given more load carrying capacity to the connection. The deflection is gradually increased while increasing load. The load versus deflection graph was linear up to the capacity of the element. When the specimen reaches its maximum capacity, the specimen unable to take load and leads to failure. So the curve is gradually increasing and suddenly failed at maximum load.

5.7 Comparison between experimental and FEM results

The following Table 8 and 9 shows the comparison of experimental and FEM results.

Table 8: Comparison of deflection

Specimen No	Deflection at free end in mm		Deflection at connection in mm	
	Experimental	FEM	Experimental	FEM
1	56.60	72.92	18.07	19.90
2	47.41	72.10	22.50	22.88
3	47.05	53.76	18.10	19.70
4	68.83	74.35	20.40	22.62

Both experimental and FEM results show that the deflection at free end is larger than at connection for all the specimens. The reason for larger deflection in the free end is, the load was given as concentrated load in that region. The load transferred to connection is less compared to the free end. The deflection observed from experimental is less compared to the deflection calculated from FEM.

Table 9: Comparison of Strain

Specimen No	Strain at Gusset plate		Strain at Angle	
	Experimental	FEM	Experimental	FEM
1	0.0384	0.0423	0.0289	0.0297
2	0.0491	0.0548	0.0309	0.0312
3	0.0684	0.0691	0.0529	0.0543
4	0.0713	0.0724	0.0511	0.0526

In the experimental test, the strain observed at gusset plate is more than strain at the angle. The reason is, while applied concentrated load at free end, tension forces acted at top of the beam and gusset plate joint and then compression forces acted in bottom seat angle. Due to elongation of the gusset plate, the strain energy observed was more than any other part. So failure happened at the tension region of gusset plate. The following Fig. 21 shows the force acting region.

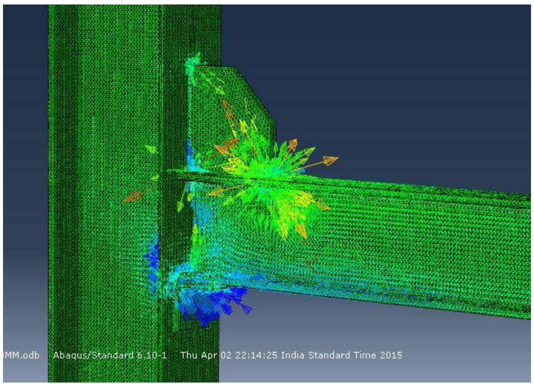


Figure 21. Region of compression and tension force acting zone

5.8 Stiffness of beam-column

The following Table 10 and 11 shows the stiffness for the connection region and at the free end. The stiffness value for the corresponding load of 10 kN at the angle and free end are 1923.08 N/mm and 956.94 N/mm respectively. This is the maximum stiffness observed in the specimen.

Table 10: Stiffness of the specimen from experimental test

Specimen No	Stiffness in N/mm	
	At Angle	At Free End
1	1183.43	751.31
2	951.47	405.84
3	1923.08	956.94
4	1333.33	1923.08

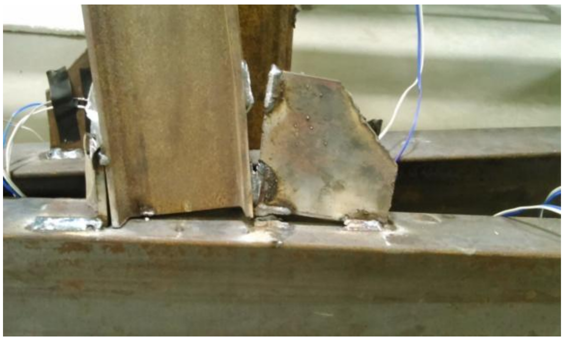
Table 11: Stiffness of the specimen from FE analysis

Specimen No	Stiffness in N/mm	
	At Angle	At Free End
1	671.50	326.36
2	1988.77	353.56
3	907.93	387.28
4	754.39	346.85

The stiffness of specimen observed from the experimental work is 1.5 times more than FE Analysis. From this, it is clear that the specimen is safe in the experimental test.

5.9 Failures in specimens

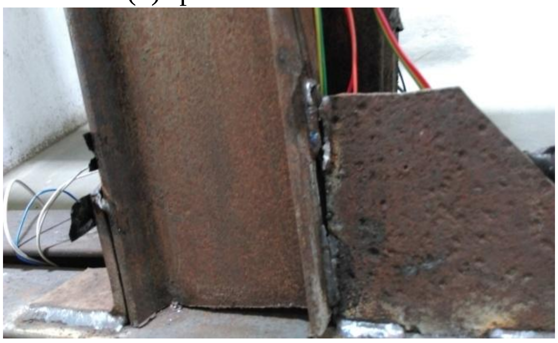
The following Fig. 22 shows the failure on specimens



(a) specimen 1

(b) specimen 2

(a) specimen 3



(b) specimen 4

Figure 22. Failure on specimens

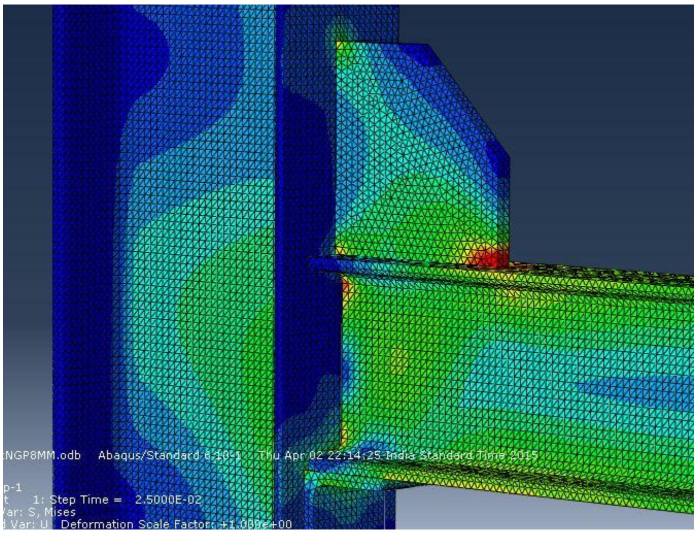


Figure 23. Failure on specimen by FEM

The connection between the gusset plate and beam was failed .due to increased stress in that position. It is showing clearly that, failure happens in the maximum stress induced portion. Fig. 22 shows the failure happened in experimental analysis. Fig. 23 shows the failure in FEM analysis. The region of failure in gusset plate, in experimental as well as FEM analysis are same. The failure observed at the front end of the gusset plate.

6. CONCLUSION

i. The connection was made by seat and gusset plate, due to interaction in beam-column by means of the weld, the connection strength was calculated as 30 kN.
ii. The strain taken from the position of gusset plate is 0.0713 which is more than the strain taken from the position of angle section 0.0511.This variation indicates that the load acting on gusset plate is more than angle portion. The strain at gusset plate is 1.37 times greater than the strain at the angle portion.
iii. The maximum deflection at the free end is 68.83 mm by experimental and 74.36 mm by FEM. By comparing the experimental and FEM results at the free end, the deflection in FEM is 1.26 times higher than experimental values. Similarly at the connection, deflection by FEM is 1.08 times higher than experimental.
iv. Over all, it was observed that failure happened between the gusset plate and beam. There was a bending observed in the angle section too.
v. The stiffness of the specimen observed from the experimental work is 1.5 times more than FE Analysis. So the connection is safe.

From the comparison of experimental results with finite element simulation, the results obtained from the experimental work are 10 % less than the results FE Analysis. So the specimen is safe in the strength point of view. The capacity of connection is larger in experimental work compare to FEM Analysis.

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