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COMPARATIVE STUDIES ON THEORETICAL AND ANALYTICAL MODELLING OF CONFINED STEEL CONCRETE COMPOSITE BEAMS USING ABAQUS

A. SRAVANI

Assistant Professor Department of Civil Engineering,
St. Martins Engineering College, Secunderabad-500100, Telangana State, India.

E-mail: alurisravani1991@gmail.com

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ABSTRACT
This paper concerned with the study on the theoretical and the analytical investigation of the behaviour and the ultimate strength of the confined steel concrete composite beam subjected to combined bending and the torsion. The theoretical equations for the ultimate strength of the beam were derived based on the three modes of the failure and their results were comparatively validated by means of 3D finite element model simulated by means of ABAQUS demonstrated that the numerical approach followed is a valid tool in predicting the performance of the behaviour accurately.

KEYWORDS: Composite beam, Cold formed steel sheet, Finite element, Shear connector, ABAQUS.

I. INTRODUCTION

The present day demand in the economic structure with the strength, reliability and the performance leads to the development of the new type of the composite beam known as confined steel concrete composite beam whichis madeup of the concrete beam shuttered with the cold formed steel sheet and mechanical interlocked by means of the welded stud T shaped shear connector on three sides of the beam provided with the bracing on the top of the beam in the pure bending region. The minimum reinforcement is provided at the soffit of the beam to take care of the negative bending moment, shrinkage stresses and the temperature stresses. The shuttered cold formed sheet passives and confines the concrete and acts as a permanent formwork by preventing the lateral bulging of the concrete. The ductile shear connector transfer the horizontal shear through its large deformation to prevent the horizontal slip and the vertical uplift of the cold formed steel sheet from the concrete and thus incorporate adequate bond in between them. The braces does not influence any increase in strength it holds good for the confinement. Probably there is no structure subjected to pure bending or torsion or shear especially these loads are inseparable in the modern structural configurations .Among these various combinations of the loads the combined effects of bending and torsion is an important practical problem which causes sudden failure of the structure without giving any warning. Due to the lack of sufficient availability of the equipment's for the tests and also in order to reduce the significant time in conducting the full scale experiments the present investigation focuses on the derivation of the theoretical equations for the ultimate strength of the beam based on the three modes of the failure and their results were numerically validated by the 3D finite element model simulated by the software ABAQUS.

II. LITERATURE REVIEW

The combined effects of bending and torsion of steel concrete composite beams are yet not addressed in the international standards on composite steel–concrete construction such as the Euro code 4 [2] or the American Institute of Steel Construction or in the Australian Standards AS 2327[1]. Yam and Chapman [4] investigated the inelastic behaviour of steel concrete composite beam and produced predictor corrector method However, the several assumptions were needed such as linear stress strain curve of steel in both the compression and tension region and also the there is a perfect bond between steel and concrete without separation. Steel concrete composite beam were modeled by [4, 5] using 2D truss element for the shear connector, shell elements for concrete slab and steel in ABAQUS. Thevendran et al. [6] predicted the behaviour of steel concrete composite beam curved in plan using the 3D finite element model developed using shell elements, rigid beam element for concrete slab and steel beam and for shear connector respectively. But the behaviour of beams straight in plan was not considered in this study. N.E., Ghanshyam Kumar and Thevendran [7] used welded stud shear connector to

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transfer the horizontal shear in between steel plate and concrete core of composite deck slab and the model were simulated using ABAQUS but yet now the model for confined steel concrete composite beam simulated using ABAQUS were not proposed. E.L Tan and B.Y Uy [9] analyzed the non linear behaviour of composite beam subjected to combined bending and torsion using the 3D finite element model simulated using ABAQUS and concluded that the torsional strength. D vijayalakshmi and D Tensing [12] studied experimentally and theoretically the behaviour of confined steel concrete composite beam subjected to combined bending and torsion and using a pair of 16 beams shuttered with the 1.2mm and 1.5 mm thickness cold formed steel sheet and with the variation in the spacing of the bracings provided at the top of the beam.

III. GEOMETRIC DETAILS OF BEAM

In order to investigate the effect of this proposed method in improving the ultimate strength, four composite members with different spacing of welded stud shear connector were used in this study.

Table -1: Specimen Categorization

S.no	Specimen	Spacing of shear connector
1	A	75 mm
2	B	100 mm
3	C	125 mm
4	D	150 mm

Fig -1: Longitudinal Section of CSCC Beams

Fig -2: Beams Cross Section of CSCC Beams

Table -2: Specimen Categorization Properties Of Materials

S.No.	Properties	Values (n/mm2)
1	Bond stress between concrete and connector fBCC	1.4 [10]
2	Bond stress between concrete and sheet fBCS	0.187 [11]
3	Actual stress in cold formed sheet fs	158

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4	Actual stress in the reinforcement fY	184
5	Compressive strength of concrete Fck	25
6	Modulus of elasticity of steel Es	2.1 X 105
7	Modulus of elasticity of sheet Esy	1.8 X 105
8	Modulus of concrete Ec	33.7 X103

Table -3: Characteristics of beam

S.No	Parameters	Dimensions
1	Length of beam	2300mm
2	Cross section of the beam	150mm X 230mm
3	Support conditions	Simply supported
4	Loading condition	Combined bending and torsion
5	Type of shear connector	Welded T Shaped stud shear connector
6	Diameter of shear connector	6mm
7	Length of shear connector	80mm
8	Number of shear connector	Vary
9	Thickness of the cold formed steel sheet	1.2 mm
10	Grade of reinforcement bars	Fe 415
11	Diameter of steel	8mm
12	Number of tensile reinforcement	2
13	Grade of concrete	M35

IV. THEORETICAL ANALYSIS OF ULTIMATE STRENGTH

As per earlier literature, [9] for a rectangular beam subjected to the pure torsion, failure is identified by the developmentof the spiral cracks inclined at a constant angle to the longitudinal beam axis. For the rectangularbeam subjectedto the pure bending the failure is defined by the development of cracks perpendicular to the longitudinal axis of the beam. For the beam subjected to the bending and the torsion simultaneously , the modes of the failure is explained by the skew bending theory which explains that the flexural moment and the torsional moment combine to generate a resultant moment inclined to the axis of the beam resultingin the warping failure.

4.1 Assumptions[12]

- The failure cracks defining the failure plane occur after the separation of the cold formed steel sheet from the concrete.
- The failure plane is bounded by the spiral cracks on the three sides of the beam and ends up with the rectangular compression zone in the fourth side.
- The spiral cracks are assumed to be straightinclined at constant angle not less than 45 degree to the longitudinal axis of the beam.
- No local loads were present along the length of the failure plane.
- The bond stress developed for the half the length of the beam.
- The reinforcement near the face of the beam on which compression zone located is ignored.
- All the reinforcement crossing the failure plane yields at the failure.

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4.2 Modes Of Failure [12]

The modes of the failure are identified based on their relative magnitudes of bending moment and torsional moment.

Table -3: Modes Of Failures

Cases	Modes Of Failures	Description
MODE 1	Modified Bending Failure	M > T
MODE 2	Lateral Bending Failure	M and T comparable
MODE 3	Negative Bending Failure	M < T

4.3 Nomenclature

- b = beam width
- C = length of warped failure plane projected on the longitudinal axis of the beam corresponding to each mode of failure.
- Z = Lever arm depth corresponding to each mode of failure.
- Ast = area of the longitudinal reinforcement at the bottom face.
- Mt = ultimate theoretical twisting moment of the beam.
- Mb = ultimate theoretical bending moment of the beam.
- q = ratio of force in shear connectors and force in bottom reinforcement.
- r = ratio of bond force and force in bottom reinforcement.
- p = ratio of force in the cold formed steel sheet to force in bottom reinforcement.
- l,m,n are the constants
- Fyt = yield stress of the reinforcement.

Cm = the maximum value that C1can have Modified Bending Failure(Mode1)

As per earlier research, this mode of failure occurs when the effect of bending is larger than torsion. The warped failure plane is considered on the top face of the beam which is defined by the spiral cracks on the bottom and vertical faces and the ends of the spiral cracks are joined by the compression zone at the top of thebeam.

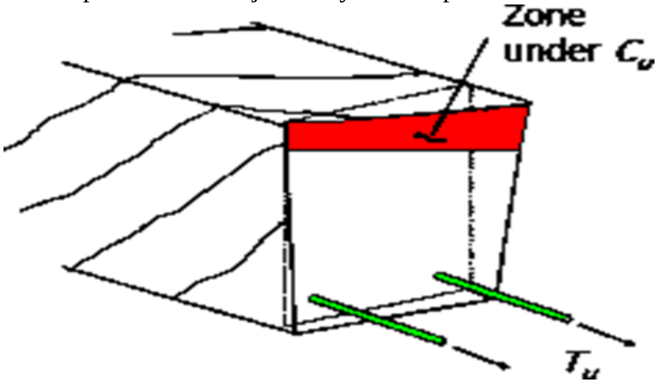

Fig -3: Idealized pattern for Mode 1 Failure

$$M_{t1}\left(\frac{c_1}{b}\right) + M_{b1} = A_{st1} \times f_{yt1}\left(z_1 + c_1^2 p_1 l_1 + c_1^2 r_1 n_1 + q_1 c_1 m_1\right)$$

Modified Bending Failure(Mode2)

As per earlier research, this mode of failure occurs when the effect of bending and torsion are comparable. The warped failure plane is considered on one of the sides of the beam.

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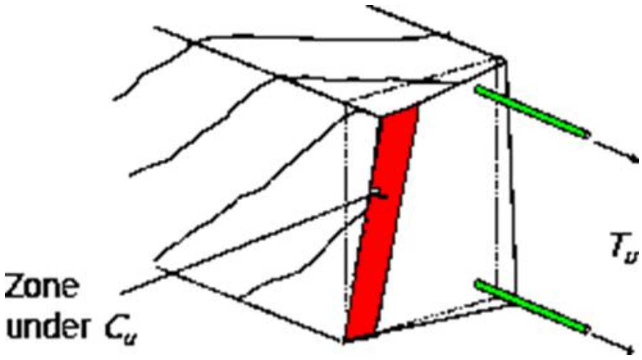

Fig -4: Idealized pattern for Mode 2 Failure

$$M_{t2}\left(\frac{c_2}{b}\right) + V = A_{St2} \times f_{yt2}\left(z_2 + p_2 l_2 c_2^2 + r_2 n_2 c_2^2 + q_2 m_2 c_2\right)$$

Modified Bending Failure(Mode3)

As per earlier research, this mode of failure occurs when the effect of torsion is larger than bending. The warped failure plane is considered at the bottom of the beam

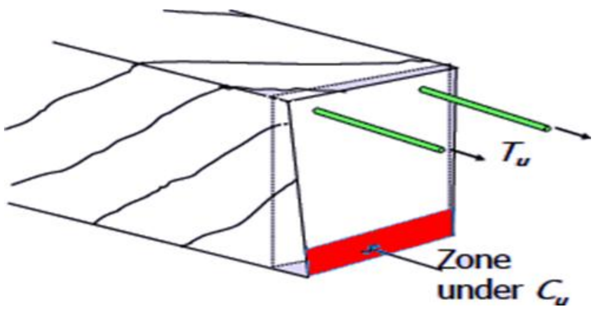

Fig -4: Idealized pattern for Mode 3 Failure

$$M_{t3}\left(\frac{c_3}{b}\right) + M_{b3} = A_{st3} \times f_{y3}\left(c_3^2 p_3 l_3 + c_3^2 r_3 n_3 + q_3 m_3 c_3\right)$$

V. FINITE ELEMENT ANALYSIS

The finite element method is the most powerful numerical method to study the behaviour of the composite beams. This section describes the development of the 3D finite element model capable of simulating the behaviour of the confined steel concrete composite beam subjected to the combined bending and torsion using the software ABAQUS

5.1 Material Model For Concrete

The concrete is purely non-linear material because it has different behaviour in compression and tension. In compression, the stress-strain curve of concrete is linearly elastic up to about 30% of the maximum compressive strength. Above this point, the stress increases gradually up to the maximum compressive strength, and then descends into a softening region, and eventually crushing failure occurs at an ultimate strain εcu. In tension, the stress-strain curve for concrete is approximately linearly elastic up to the maximum tensile strength. After this point, the concrete cracks and the strength decreases gradually to zero.

5.2 Material Model For Steel

The Fe415 grade steel is used for the development of FEM model is assumed to be an elastic-perfectly plastic material and identical in tension and compression with Poisson's ratio of 0.3

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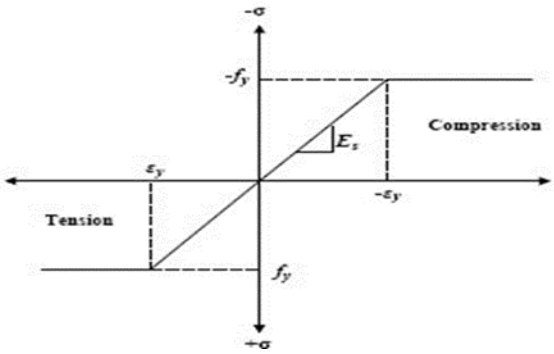

Fig -5: Stress strain curve for steel [12]

5.3 Modelling Procedure Using ABAQUS

The modelling procedure of the confined steel concrete composite beam using ABAQUS are as follows as steps in the following figures. There is always a slip between steel and concrete interface however, a perfect bond is assumed here. By using merge option the coinciding nodes of cold formed steel sheet and concrete are shared and thus composite action is achieved.

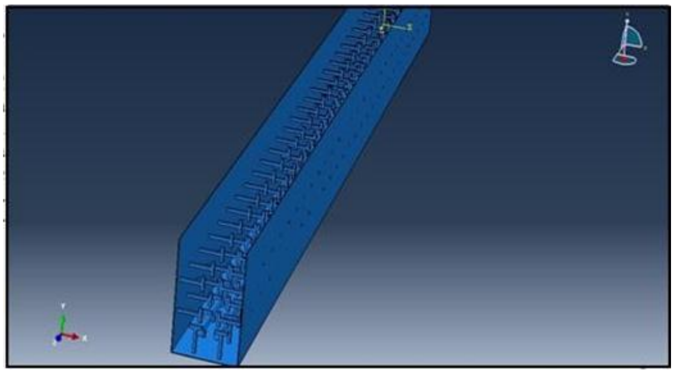

Fig -5: Geometry of composite beam model

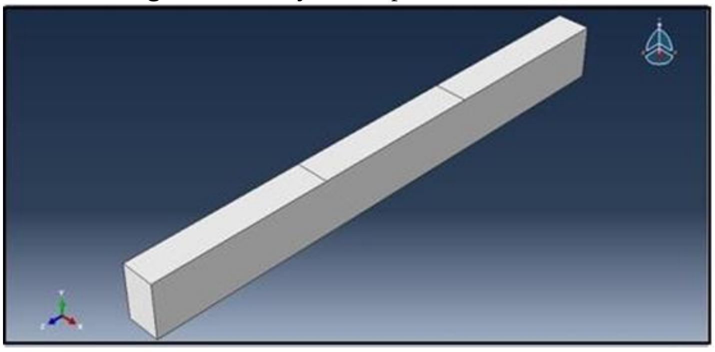

Fig-6: Assigning the material property

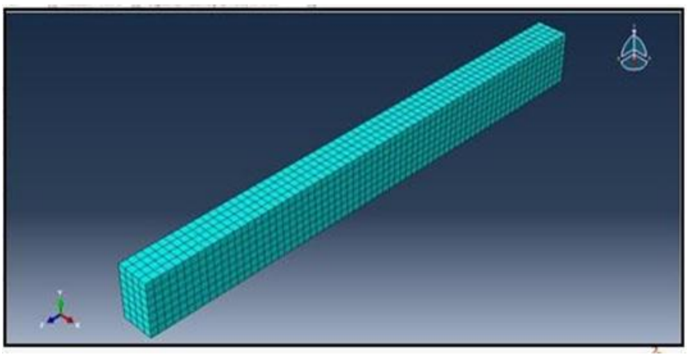

Fig-7: Meshing

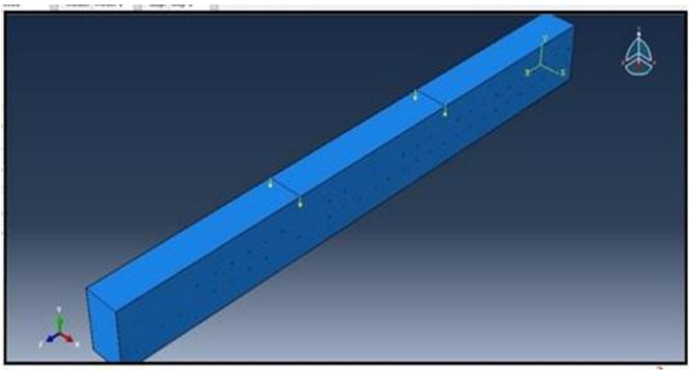

Fig-8: Application of the load

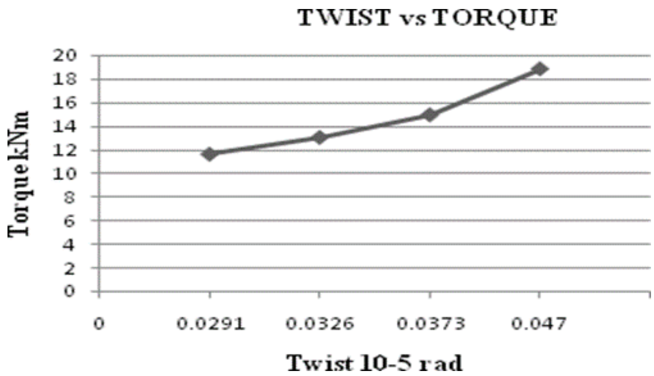

Fig-10: Twists vs. Torque

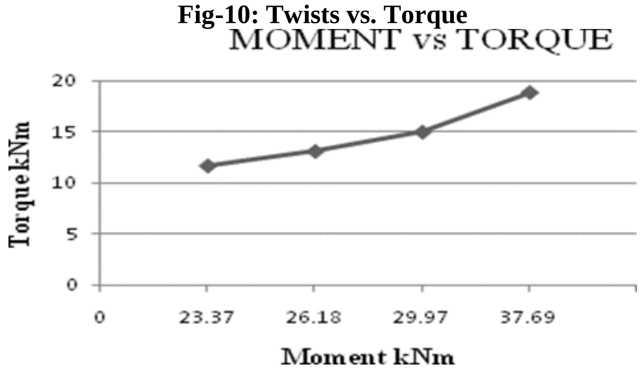

Fig-11: Moment vs. Torque

Table5: Comparison Of Ultimate Strength Of Beams

Specimen	Theoretical analysis value (KNm)	FEM analysis value (KNm)
1	115.59	121.25
2	91.91	97.66
3	80.30	81.00
4	71.70	76.12

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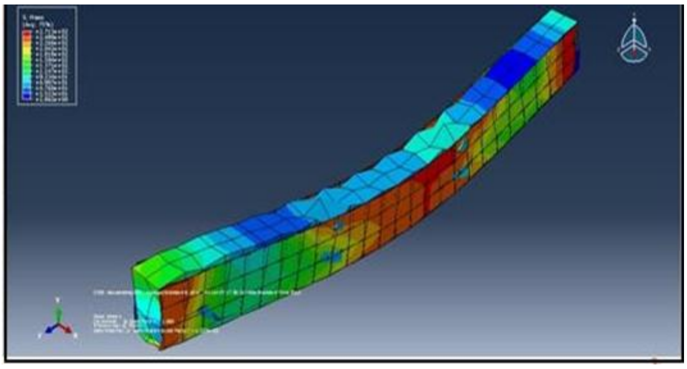

Fig-9: Deformation Results

VI. RESULTS

The behaviour of the confined steel concrete composite beam subjected to 30% ultimate torque and bending could be identified from the following figures. The closely spaced shear connector and longitudinal bars contributed more resistance to twist. This is owing to the reason that the shear connector and reinforced bar act as a ties carrying tension which restrict the torsional deformation and enhances the torsion carrying capacity of the beam.

VII. CONCLUSION

A comparative study on the behaviour and the ultimate strength of the confined steel concrete composite bam which has been carried out analytically and theoretically revealed that the,

- Ultimate strength increases with the decrease in the spacing of the welded stud shear connector.
- The theoretical and analytical results prove to be good in agreement.

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