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A Numerical, Experimental and Analytical Study on Confined Steel Concrete Composite Beam

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Abstract: This project deals with the Ultimate strength and Behavior of a new type of composite beam called Confined Steel Concrete Composite Beam subjected to bending. A concrete beam with a small amount of reinforcement is shuttered with cold formed steel sheet confines the concrete on three sides of the beam and acts as a formwork during construction. Shear connectors in the form of headed studs are provided to have bond between the concrete and the sheet. In addition, the beam is welded with braces in bending region at top face of the beam to avoid the separation of sheet from concrete during loading. This type of beam is referred as Confined Steel Concrete Composite Beam (CSCC BEAM).This paper presents the behavior of cold formed steel sheet with shear connectors. The numerical and experimental analysis has been done using the finite element software ANSYS. This CSCC beams reduce the construction time due to the elimination of form work and more number of reinforced steel is reduced.

Keywords: **cold formed steel sheet, bending, shear connector, confined composite beam,form work.**

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I. INTRODUCTION

A. *GENERAL*

In the construction of modern structures, the continuing performance of civil engineering infrastructure ranging from industrial building to power station and bridges. For the satisfactory performance of the existing structural system, the need for strengthening improvement is essential. The commonly encountered engineering problems such as increase in service loads, changes in use of the structure, design and constructional errors, degradation problems, changes in design code regulation and seismic retrofitting are some of the causes that lead to the need for new technology to upgrade the performance of the structures.

B. *COMPOSITE CONSTRUCTION*

A structural member consists of two or more dissimilar materials joined together to act as a combined unit is referred as composite structure. Joining two dissimilar materials to form a composite member does not only combine the collective strengths of the two materials, forming a junction between relevant materials actually enhances their physical characteristics and makes the composite stronger than the addition of their strengths. An example in civil engineering structures is the steel-concrete composite beam in which a steel wide-flange shape (I or W shape) is attached to a concrete floor slab. There are many other kinds of composite beams include steel-wood, wood-concrete and plastic-concrete or advanced composite materials–concrete.

C. *STEEL CONCRETE COMPOSITE CONSTRUCTION*

In order to design the structural steel member with maximum efficiency and minimum cost, steel-concrete composite construction is adopted. It is a powerful construction concept in which compressive strength of concrete and the tensile strength of steel are almost effectively used. Steel and the concrete have almost same thermal expansion apart from an ideal combination of strength. Hence, these essential different materials are completely useful and complementary to each other. Steel-concrete composite beams are now widely used for bridges and industrial buildings.

In large scale construction, steel and concrete are most regularly used combination for composite beams. The concrete ends the composite mass, stiffness and compressive strength and reduces deflection and vibration in the slab. The steel members give the beam its tensile strength with excellent strength to weight ratios and rapid construction times.

Table 1. Properties of Cold Formed Sheet

t_s(mm)	f_{sy}(mpa)	E_p(mpa)
1.2	220.2	1.82×10^5
1.5	248.5	1.93×10^5

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D. CONFINED STEEL CONCRETE COMPOSITE BEAM (CSCC BEAM)

The greatest impetus for the composite construction was the development of the welded headed stud. In the 1950's headed studs provide mechanical shear connection between the top flange of the steel beam and cast in place of concrete floor slab. As a result of experimental investigation carried out in the past by many researchers with different ways of bonding between steel and concrete, an innovative study has been done in this project to understand the behavior of concrete beam shuttered with cold formed steel sheet which acts as a composite beam by means of shear connectors and bracings viz. 'Confined Steel Concrete Composite Beam' (CSCC Beam). This is the new idea to the composite structure world. And this can be a replacement for hot rolled steel beams or RCC beams in small to medium sized building.

The cold formed steel sheet is bonded to surface of concrete by means of shear connectors. Stud shear connectors are used to take up the bond between sheet and concrete. The passive confinement by the cold formed sheet in the sides and bottom influences the strength and ductility of the system. These beams are simple to fabricate and provides very good confinement of concrete.

E. SHEAR CONNECTORS

One of the most important parts of a composite beam is the fixing points of shear connectors between the two materials. The correct connection of the two parts of the composite allows the materials to act as a unit and gives the composite beam its inherent strength.

Composite action between the steel and the concrete is achieved by means of mechanical connectors by the effective transfer of shear at the interface between concrete and sheet elements. The shear connectors are typically connected by welding to the top of the flange of a steel beam and cast within the concrete slab. The transfer of longitudinal shear forces at the interface between both components is mostly realized by headed shear studs.

Shear connection significantly increases the strength and stiffness performance of composite beams. A composite beam can be made to be considered to have full shear connection or partial shear connection, proportional to the amount of shear connections. Shear connectors can take the form of either headed studs, channels or high strength structural bolts. These shear connectors are typically studs welded to the steel beams and set into the concrete slab. The number and size of these shear connectors are carefully calculated as they represent a critical part of the composites mechanical performance

F. Headed Connectors

Headed stud type shear connectors shown in Fig.1.3 were used to achieve proper bond between steel and concrete interface. Fe 415 grade stud of shank diameter 6mm head diameter 30mm and height 50mm are made as T- shaped. Stud type connectors were designed for full interaction at 10mm centre to centre along the length of cold formed steel plate at the sides and the bottom.

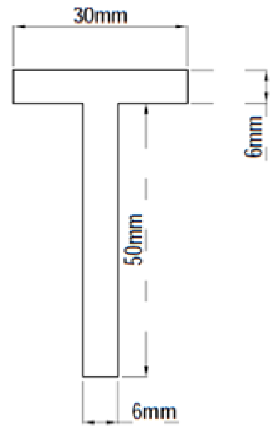

Fig. 1. Stud Shear Connector

G. COLD FORMED STEEL SHEET

Cold formed steel sheets are used as partial confinement for the beams. The beams using the profiled sheeting are called as profiled composite beams. They increase the compressive strength and the deformation of confined concrete by providing resistance to the lateral bulging of concrete.. These thin steel sections are cold formed. The thickness of steel sheet used in cold formed construction is usually 1 to 3 mm. With this least thickness the sheet is used as a form work and reinforcement. Much thicker material up to 8 mm can be formed if galvanized material is not required for the particular application. With this least thickness the sheet is used as a form work and reinforcement. The beams using the profiled sheeting are referred as profiled composite beams. There are other strength related aspects to profiled composite construction. However they increase the compressive strength and decrease the deformation of confined concrete by providing resistance to the lateral bulging of concrete.

II. FINITE ELEMENT ANALYSIS

The Finite Element Method (FEM) is a numerical analysis for obtaining approximate solutions to a wide variety of engineering problems. This has developed simultaneously with the increasing use of high-speed electronic digital computers and with the growing emphasis on numerical methods for engineering analysis.

A. GENERAL DESCRIPTION OF THE FEM

The basic concept behind FEM is that a body or structure is divided into smaller elements of finite dimensions called 'finite elements'. The original structure is then considered as an assemblage of these elements at a finite number of joints called 'nodes'.

The properties of the elements are formulated and combined to obtain the solution for the entire structure. The shape functions are chosen to approximate the variation of displacement within an element in terms of displacement at the nodes of the element. The strains and stresses within an

element will also be expressed in terms of the nodal displacement. The principle of virtual displacement is used to derive the equations of equilibrium for the element and the nodal displacement will be the unknowns in the equations.
The boundary conditions are imposed and the equations of equilibrium are solved for the nodal displacement. From the values of the nodal displacement for each element, the stresses and strains are evaluated using the element properties.
Thus instead of solving the problem for the entire structure in one operation, in this Finite Element Method attention is mainly developed to the formulation of properties of the constituent elements

B. *MODELING OF COMPOSITE BEAMS*

Finite Element Modeling of Composite beams in ANSYS consist of three stages, which are explained below.

- Selection of element type
- Assigning material properties
- Modeling and meshing the geometry

C. *ELEMENT TYPES*

Selection of proper element types is another important part in Finite Element Analysis. For composite beams, the C-R steel sheet trough and braces were modeled by using SHELL 63 element in ANSYS. The Concrete portion was modeled by using a special element developed particularly for Concrete by ANSYS, SOLID 65 element. The stud connectors and reinforcement were modeled by using LINK 8 Element. SOLID 45 elements were used to model the steel plates provided at support and loading points.

D. *MATERIAL PROPERTIES*

From the experiments conducted, the following values are found out and listed.

- Compressive strength of concrete cubes
- Yield stress of C-R steel sheet
- Yield stress of reinforcing bars.

Coupon tests are done in order to determine the yield stress and modulus of elasticity of C-R sheet and reinforcing bars.

E. *MODELLING THE GEOMETRIC SHAPE*

The dimensions of the full-size beams are 150 mm x 230 mm x 1200 mm. By taking advantage of the symmetry of the beams; a beam is modeled. In the ideal case of Composite beams, the bond between the concrete and steel plays a major role. There will always be a slip at the steel concrete interface. However, in this study, perfect bond between materials is assumed. By using the Merge option in ANSYS, the coinciding nodes of the C-R sheet and concrete are shared and thus composite action is assumed.

As per the ANSYS concrete model, two shear transfer coefficients, one for open cracks and other for closed ones, are used to consider the amount of shear transferred from one end of the crack to other.

Following are the input data required to create the material model for concrete in ANSYS.

- Elastic Modulus, (Ec)
- Poisson's Ratio, (ν)
- Ultimate Uniaxial compressive strength, (fc')

III. NUMERICAL INVESTIGATION

A. *DIMENSIONS OF BEAM*

- Size of beam: 150mm × 230 mm
- Length of beam: 1200mm
- Spacing of shear connectors: 75 mm
- Shear connectors: 6 mm φ rod
- Reinforcement steel and bracing: 8 mm φ rod
- Grade of concrete used is M_{25}
- Steel used is mild steel.

Table 2. SPECIFICATION OF CSCC BEAM

PARAMETERS	**DIMENSIONS**
LENGTH	1200mm
CROSS SECTION	150mmX230mm
SUPPORT	SIMPLY SUPPORTED
LOADING CONDITION	POINT LOAD
TYPE OF SHEAR CONNECTOR	T SHAPED STUD
DIAMETER OF SHEAR CONNECTOR	6mm
DIAMETER OF STEEL	8mm
GRADE OF CONCRETE	M25
GRADE OF STEEL	Fe415

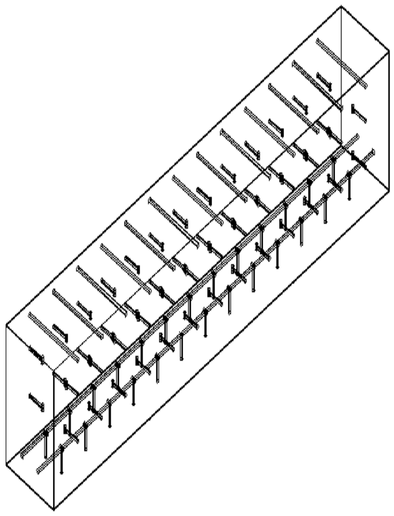

Fig.2. 3D MODEL OF A CSCC BEAM

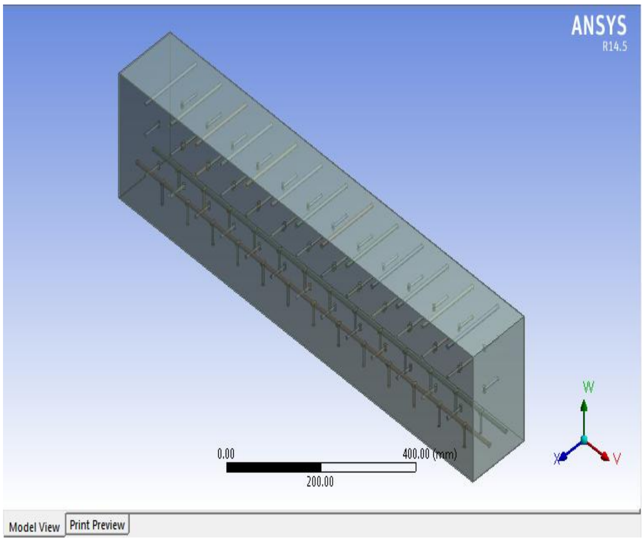

Fig.3. MODEL OF A CSCC BEAM in ANSYS

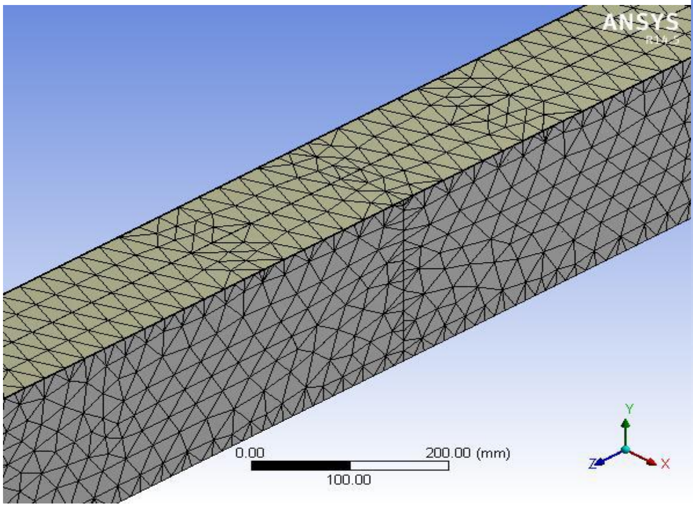

Fig.4. MESH MODEL OF BEAM IN ANSYS

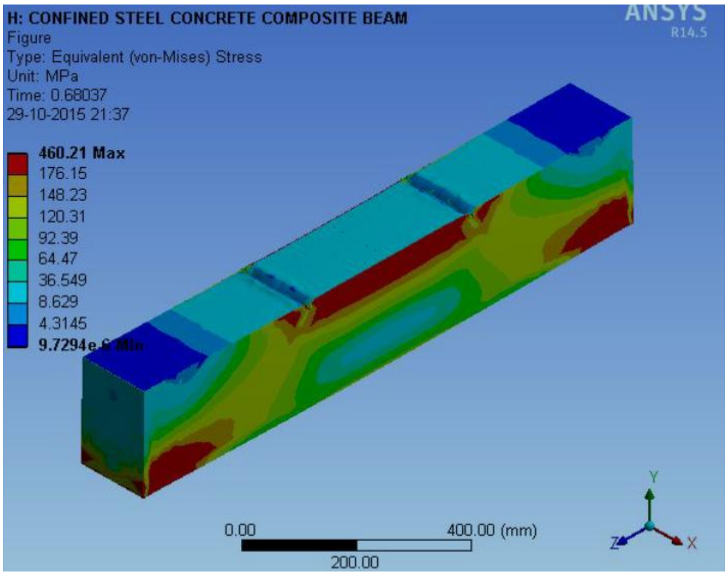

Fig.5. MAXIMUM STRESS IN CSCC BEAM

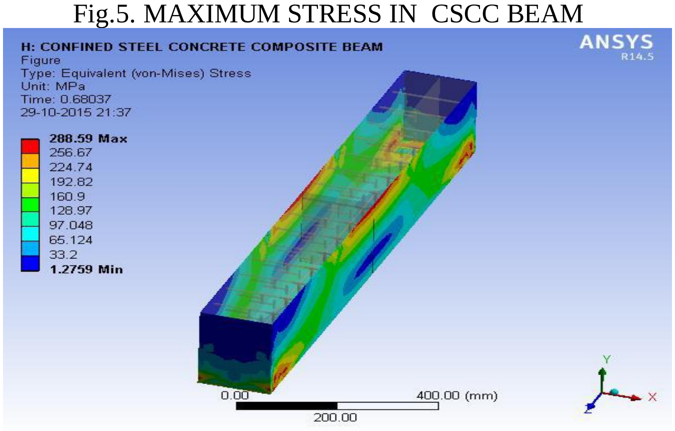

Fig.6. TOTAL DEFLECTION FOR COLD FORMED STEEL SHEET

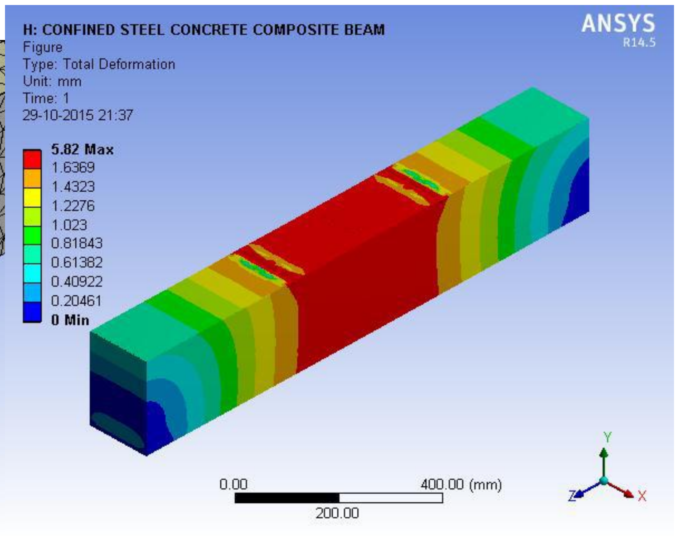

Fig.7. TOTAL DEFLECTION FOR CSCC BEAM

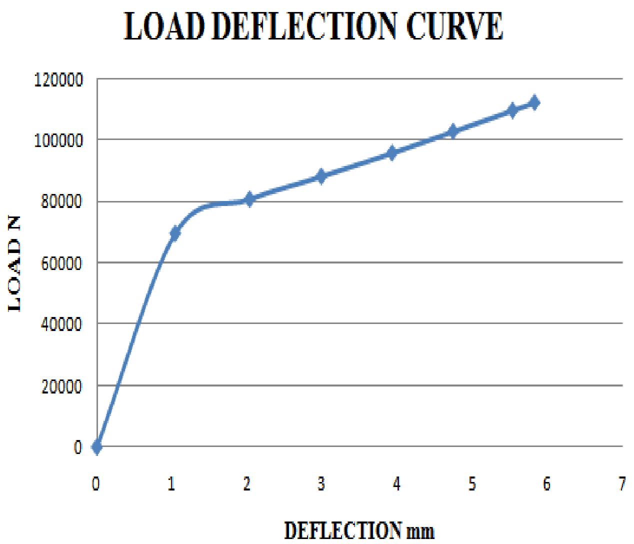

Fig.7. LOAD DEFLECTION CURVE FOR CSCC BEAM

IV. EXPERIMENTAL SETUP AND TEST PROCEDURE ON CSCC BEAM

For pure bending composite beams with an effective span of 1.3m were tested. The position of the supports, inclinometer and dial gauges points were marked on the beams. The beams were tested for two point loading. Two point loading was done in order to determine pure bending on the beam. All the beams were designed to fail by flexure. In order to determine the curvature, the inclinometer readings were taken. For the deflections measurement, dial gauges were located at five, one at mid-span, two at L/3 of the span at the bottom of the beams.The beams were tested at a rate of loading of 60 kN/min. The test was carried out until the formation of waves due to buckling of sheets in the beams. The beams started to yield and the behavior of the beam was observed from the beginning till collapse. A careful observation was made from the initial separation of sheet, propagations of cracks and failure of bracings connecting the sheet and concrete. The beams were tested to find the ultimate load carrying capacity by removing all the dial gauges.

A beams were of size 150mm x 230mm x 2300mm with thickness of sheet 1.2 mm and 1.5mm and 150mm x 300mm x 2300mm with thickness sheet 1.2mm and 1.5 mm were tested . The failure of this group of beams started with the initial separation of the sheet, local buckling, formation and development of cracks, crushing of concrete and yielding of tension steel.

The performance of the CSCC beam depends on an effective transfer of shear at the interface between the concrete and cold rolled sheet elements. Under increasing load, the natural bond at the interface once broken cannot be restored. As the load increases, vertical separation is initialized between the sheet-concrete interfaces. Hence the composite action is no longer maintained and the concrete carries additional load. At failure stage, side plates buckled outward and the studs failed at the welded points. Failure load depends on the number of connectors also. Shearing of studs delays the failure of concrete.

Cold sheet of required thickness say 1.2 mm and 1.5 mm and cube size of 150 mm were bent using plate bending machine. The braces of 10 mm width (a) of same thickness were welded with the side plates at 15 mm from top and bottom of the concrete. The braces can be considered as confinement at top to the beam. Two different spacing of bracings were considered. Within the standard moulds the fabricated trough was placed and concreting was done. After 24 hours from casting, the specimens were demoulded and cured for 28 days using gunny bags.

The loading frame is of the self straining type, made from rolled steel joist sections, channel sections and flats. The capacity of the loading frame is 50T.The supports for the test specimen were at a level, which is comfortable for taking deflection readings.


Fig.8. SKELETON OF THE BEAM


Fig.9. COMPACTION


Fig 10. FRESH CONCRETE BEAM

Fig.11. HARDENED BEAM

Fig.12. EXPERIMENTAL SETUP

V. ANALYTICAL INVESTIGATION

STEP : 1 DESIGN STRENGTH:

$Ys/\gamma m \leq Us/\gamma m$

Average Stress =254.5 N/mm^2

Y_s – Yield strength,U_s –minimum tensile strength

STEP : 2 COMPRESSIVE STRESS:

$P_0 = [(1.13\text{-}0.0019)xD/t\ x\sqrt{fy/280}\ ]P_y \neq F_y$

P_0 = limiting value of compressive stress in N/mm^2 , Fy = yield strength of cold formed steel sheet

STEP : 3 MOMENT

The ultimate moment capacity $M_{ult} = Z_C \times P_0$

$Z_C = B \times D^2 / 6$

STEP : 4 STRESS

Shear stress $Pv = (1000 \times t/d)^2$

where P_v = average shear stress in N/mm^2

STEP : 5 Bending moment

$Mb = ½ [\{ My + (1+\eta) Me\}\text{-}\sqrt{[My + (1+\eta)Me]^2\text{-}4 \times My \times Me}]$

Table 3. comparison of investigations

Type of investigation	Ultimate load	Ultimate Bending moment
Numerical	111.5KN	22 KN m
Analytical	120 KN	25 KN m
Experimental	115.78KN	23.8KNm

VI. CONCLUSION

The present numerical study is done on the behavior of confined steel concrete composite beam using cold formed steel sheet with T shaped shear connectors and bracings.

- Load deflection curve shows that the increase in load increases the deflection
.
- From the load deflection curve ultimate load predicted is 111.5 KN and the corresponding displacement is 5.82 mm
.
- The maximum stress obtained in numerical investigation is compared with both analytical and experimental.
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