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Behaviour of Encased Cold-Formed Trapezoidally Corrugated Web Beam

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Abstract

Built-up I-sections have been extensively used whenever standard I-sections could not satisfy the moment carrying and shear capacities required. In these built up sections it has been common practice to use more steel in webs rather flanges. This results in uneconomical sections as steel is an expensive material. So introducing corrugated profile in web reduced the web instability and also the need for providing transverse stiffeners. But, even after in corrugated webs and lateral stiffeners, effects like lateral torsional buckling were observed. Thus measures other than providing conventional transverse stiffeners and corrugated webs were to be found. This paper deals with the investigation on Behaviour of encased cold formed built up I section with trapezoidally corrugated web and encased cold formed built up I section with plane web, under two point loading by varying H/T ratio of the beam specimen. The experimental results of encased trapezoidally corrugated web and that of plane web are compared and the behaviour and failure modes are discussed. Encasing the corrugated web of steel beam with concrete could improve the resistance to transverse deflections.

Keywords: Corrugated steel web, Concrete encasement, Lateral torsional buckling, Shear strength

Introduction

Light gauge elements have been used for built-up beams and in case of heavy loads thickness of the web plate required is more and also intermediate stiffener plates are to be used in case of heavy loads. So the dead weight of the structure increases. To reduce this and improve the structural efficiency, corrugated plates may be used. The use of corrugated webs is potential method to achieve adequate out-of plane stiffness and shear bulking resistance using without using stiffeners Therefore, further lateral restraints have to be provided to control lateral buckling. But, lateral restraints cannot be further provided in the form of steel stiffeners because of limitation in welding in corrugated web. Thus, corrugated web encased with concrete can be used as a effective lateral restraint and further increasing load carrying capacity of beam. Additionally, the concrete acts as cover for the web and improves the fire resistance of the beam.

A corrugated web beam is a built-up girder with thin walled corrugated webs and flange plates. The profiling of the webs avoids the failure of the beam due to loss of stability before plastic limit loading of the webs is reached.The primary characteristics of corrugated steel plates are negligible bending capacity and adequate out of plane stiffness. To take advantage of these characteristics, the corrugated steel plates have been considered an alternative to conventional concrete or steel girder webs. When used as the web, the corrugated steel web carries the vertical shear.

Corrugated steel plates can ensure higher resistibility against shear buckling, leading to elimination of stiffeners. Uy [1] conducted an extensive experimental program to investigate the behavior of eight composite beams subjected to hogging moment. The results showed affirmative outcomes for the application of partial shear connection (PSC) design within the hogging moment regions of continuous and semicontinuous composite structures. Chen [2,3] tested four groups of prestressed composite beams with external tendons in negative moment regions to investigate the cracking behaviors and the ultimate negative moment resistances. Ryu [4] conducted a full-scale model of a steel-concrete composite plate girder with prefabricated slabs under hogging moments to investigate crack control. Moreover, the flexural behavior of composite girders with Class 3 section under 4-point non-monotonic service load was studied to investigate the stiffness and strength of the composite girder under hogging moments by Ryu [5]. He

[6] performed static experimental tests on four half-scale models of steel and concrete composite girders with different shear connectors such as studs and PBLs under hogging moments in order to investigate the reduction of flexural stiffness and the inelastic behavior after cracking. In order to improve the structural performance of continuous composite girders under hogging moment, Nakamura [7,8] proposed two measures around support areas: concrete casting on the bottom flange for twin-girder section and on the bottom plate for box girder section to form double composite section. Therefore, flexural rigidity was enhanced so that instability problems in the ultimate limit state were avoided not only in bottom flange but also in web, resulting in the low position of neutral axis and deformation restriction by concrete encasement.

Nakamura [7] proposed the use of partially encased composite I-girders around support parts. Reinforcing bars were welded to the upper and lower flanges, and concrete was poured into the area surrounded by the flanges and web. Bending and shear tests were performed, showing that the bending strength of the partially encased girder model is 2.08 times higher and the shear strength is 2.98 times higher than that of the conventional steel I-girder model. A new type of partially concrete filled steel narrow box girder was also proposed by Nakamura [8]. It was expected that no shear connectors are required at the interface of steel plates and concrete because of the confined effect of concrete surrounded by steel box. Static bending loading tests were conducted with these new type girders, showing that the ultimate bending strength of the concrete filled steel box girder model was 40% larger than that of the steel box girder model. The ductility also increased about 8 times.

Kim [9] proposed double composite section at hogging moment areas to enhance the structural performance of existing twin-girder bridges. The structural performance of the lying stud shear connection and mixed stud shear connection was evaluated experimentally. Wright et al. [10–12] proposed the concept of composite walling, comprising vertically aligned profiled steel sheeting and an infill of concrete, which was similar to composite webs with corrugated steel plate. Composite walling had many advantages when used in conjunction with composite flooring, and was thought to be especially applicable to shear or core walls in a steel framed building. Wright [10,11] and Hossain [12] performed small-scale model tests to study the structural behaviors of composite walling and its components under in-plane shear and axial load, including load-deflection response, strength, stiffness, failure modes and sheet-concrete interaction.

At present, there are few reports about design specifications for partially encased composite I-girders with corrugated steel web. Also, only little research has covered the following aspects: the influence of concrete encasement on the strength and deformation capacity; the effects of connection degree between concrete and corrugated steel web to the mechanical behavior of composite girders. Thus, experimental studies and theoretical analyses are conducted to understand the structural performance and to improve the design methods. The main objects of the shear tests on partially encased composite I-girders with corrugated web in this paper are described as follows: (1) To design the cold-formed corrugated web beam encased in concrete. (2)To find out experimentally the load carrying capacities of encased cold-formed corrugated web beam and compare with encased normal web beam. (3) To study the possible modes of failure of the members under static loading. (4)To find out the ductility of encased cold-formed corrugated web beam and compare with normal web beam.

Experimental Investigation

Fabrication and Casting of beams

The Cold-formed Steel plates of size 8 feet by 4 feet of 2.5 mm thickness were cut by means of cutting machine to make flanges and webs of desired dimensions, the webs being cut to desired depth and width. The web was corrugated with a fold angle of 45^o by using a press break machine.

Figure 1(a) shows the top view of the beam with after being welded to the bottom flange. Figure 1(b) shows the unstiffened trapezoidally corrugated web after the preliminary welding. The beams were encased with M30 grade concrete by placing the Built-up sections in H-shape. The concreting was done on one face and left to set for one day and same procedure was followed for the other face also and left for 28days curing.

Fig.1 Top view of corrugated beam without top flange

Fig.2 Unstiffened trapezoidally corrugated beam

Specimen details

In this study, built-up cold-formed normal and corrugated web beams are studied. The normal sections (both flange and web portions) are made of 2.5mm thick mild steel plates of depths 150mm and 200 mm. The corrugated web sections were also of 2.5mm thick mild steel plates of 150 mm and 200 mm. The corrugation profile was of trapezoidal shape was made by means of press breaking machine with angle of corrugation 45^0.The flanges and web are welded along the beam length on the web and flange junctions. Top and bottom flange width b_f -100 mm, thickness of the section (Flange and Web) t_f -2.5mm, height of specimen -150 mm & 200 mm.

TABLE I
BEAM DESIGNATION

Beam Designation	Description	L/D ratio	Number of Specimens
ENB 150	Encased Normal Beam Depth 150 mm	14.67	1
ENB 200	Encased Normal Beam Depth 200 mm	11.00	1
ECWB 150-I	Encased Corrugated Web Beam Depth 150 mm	14.67	1
ECWB 150-II	Encased Corrugated Web Beam Depth 150 mm	14.67	1
ECWB 200-I	Encased Corrugated Web Beam Depth 200 mm	11.00	1
ECWB 200-II	Encased Corrugated Web Beam Depth 200 mm	11.00	1

Test set-up

All the specimens were tested for flexural strength under two point loading by using reaction type vertical loading frame. The specimens were arranged with simply supported conditions, centered over bearing blocks adjusted for a effective span of 1.8 m. Loads were applied at one-third distance from the supported without shock, increased at a uniform rate till the ultimate failure.

Deflection of the beam was measured by 5 LVDT's placed one at mid span, two below point of loading and the other two near end supports. Strain gauges were also fixed to record strain measurements. For each load increment the deflection, strain and crack were observed and tabulated. In addition to the above, load cell and LVDT are connected to data logger and the observations were recorded automatically in the DATA logger.

Fig.3 Experimental set-up

Results and Discussions

Flexure test results

All the specimens were tested for flexural strength under two point loading by using reaction type movable loading frames. Deflection and strain readings are observed from DATA logger. The following observations were made during the progress of the tests. The observations are summarized in the following table

TABLE II
ULTIMATE LOAD AND DEFLECTION OF SPECIMENS

Specimens	Ultimate Load in kN	Max. Deflection at Mid-Span in mm
ENB 150MM	71.3	41.7
ECWB 150MM -I	79.2	35.7
ECWB 150 MM -II	83.4	34.1
ENB 200 MM	50.8	19.6
ECWB 200MM -I	100.6	18.5
ECWB 200 MM -II	105.8	17.6

Ductility

Using the data obtained ductility of all specimens were arrived and summarized in the table below. From

Table III it it known that the ductility of the specimens are more than 5.

TABLE III
DUCTILITY VALUES OF SPECIMENS

Specimens	Ductility
ENB 150MM	7.54
ECWB 150MM -I	8.44
ECWB 150 MM -II	7.35
ENB 200 MM	6.12
ECWB 200MM -I	10.31
ECWB 200 MM -II	10.80

Load factor

Load factor is defined as the ratio of strength of built up section against standard section. In Table IV, the flexural capacity of built up I section and the standard I section of same dimensions were compared. From the results, it was observed that the Built up section with corrugated web has high flexural capacity than that of standard I section.

Flexure strength of the corrugated specimen is 1.169 times the strength of standard section for H/t = 60 and for the aspect ratio 80, the load factor value is 2.083. From this, it is understood that both values are greater than 1. Also aspect ratio increases as the load factor increases. This may be due to increase in the height of the specimen leading to failure of section by twisting.

TABLE IV
LOAD FACTOR VALUES OF SPECIMENS

Height of specimen H	H/T ratio	Ultimate load in KN (corrugated steel section)	Ultimate load in KN (normal web)	Load Factor
150MM	60	83.4	71.3	1.169
200MM	80	105.8	50.8	2.083

Stiffness

Stiffness may be defined as the load required causing unit deflection. The stiffness values of the specimen at ultimate load were presented in the table. Table-V shows that the stiffness value increases along with the aspect ratio. Stiffness value of the specimen ECWB 200MM-II is higher of all the values, which shows the specimen is stiffer than all other specimen. This may be due to the deflection of the specimen under ultimate load which is lesser than all other specimen.

TABLE V
STIFFNESS VALUES AT ULTIMATE LOADS

Specimen	Ultimate Load in kN	Max. Deflection at Mid-Span in mm	Stiffness kN/mm
ENB 150MM	71.3	41.7	1.709
ECWB 150MM -I	79.2	35.7	2.218
ECWB 150 MM -II	83.4	34.1	2.446
ENB 200 MM	50.8	19.6	2.591
ECWB 200MM -I	100.6	18.5	5.438
ECWB 200 MM -II	105.8	17.6	6.011

Load Vs Deflection

The Linear Variable Displacement Transducers were used to measure deflection for the specimens at mid-span and one-third of the span length. The obtained deflections were plotted against their corresponding load values obtained from the experimental results.

All the load deflection curve shows an increase in the load deflection which varies linearly with some undulations up to the Ultimate value. The maximum deflection occurs in mid-span. The plots also show that, for 150mm depth beams, the encased corrugated section ultimate load carrying capacity was 20-25% higher than encased normal web beam and for 200mm depth beams , the encased corrugated section ultimate load carrying capacity was about twice that of encased normal web beam. Also, the deflection of encased corrugated section was 4-8% lesser than that of encased normal web beam.

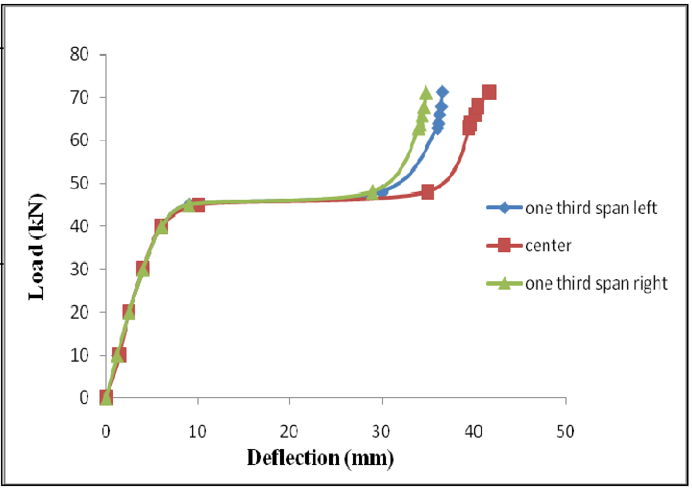

Fig.4 Load-deflection curve of ENB-150MM

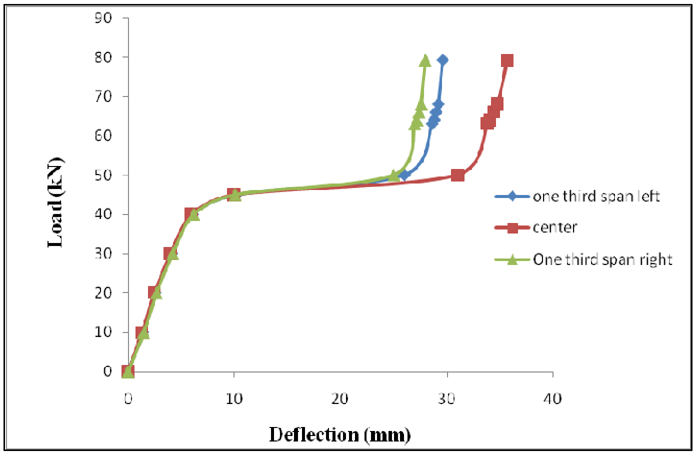

Fig.5 Load-deflection curve of ECWB-150MM-I

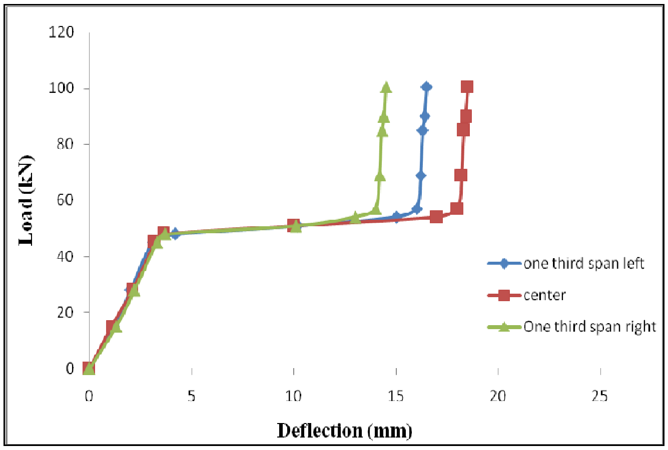

Fig.8 Load-deflection curve of ECWB-200MM-I

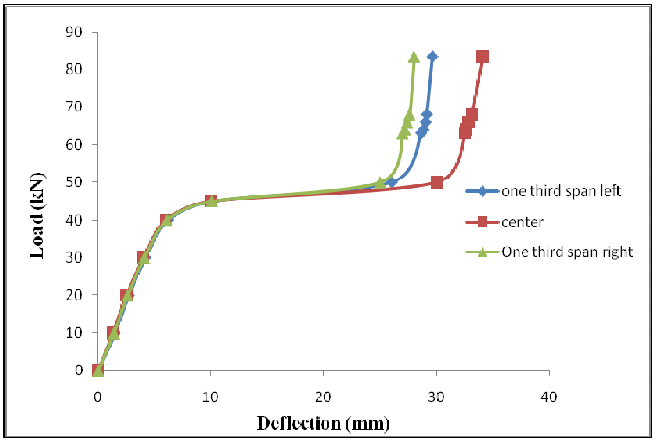

Fig.6 Load-deflection curve of ECWB-150MM-II

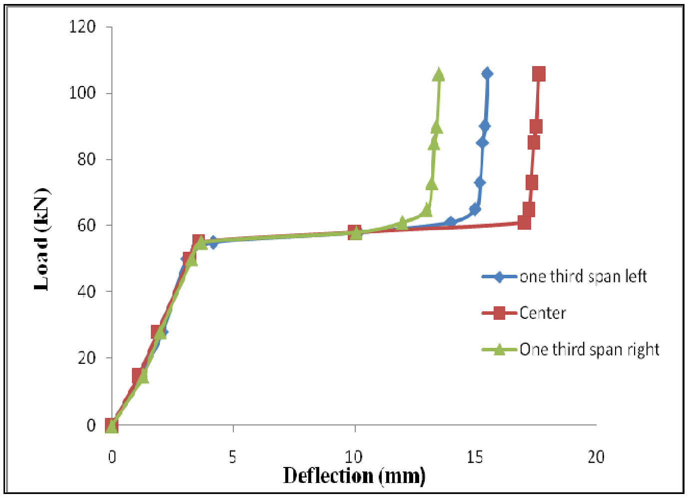

Fig.9 Load-deflection curve of ECWB-200MM-II

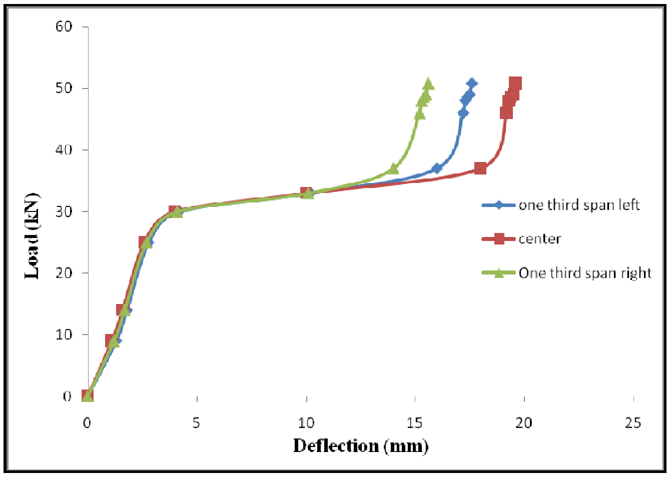

Fig.7 Load-deflection curve of ENB-200MM

Comparison of ultimate loads

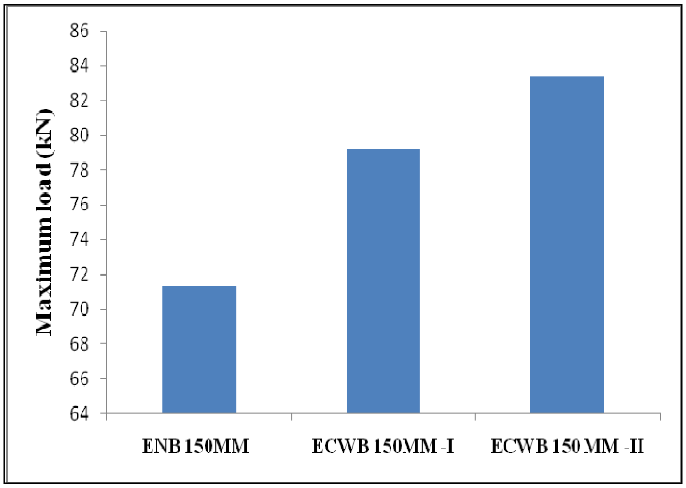

Fig.10. Comparison of ultimate loads for 150MM depth beams

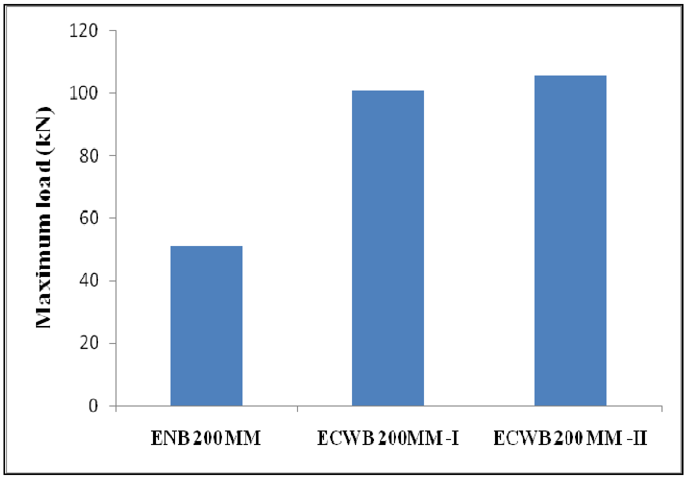

Fig.11. Comparison of ultimate loads for 200MM depth beams

Comparison of ultimate deflections

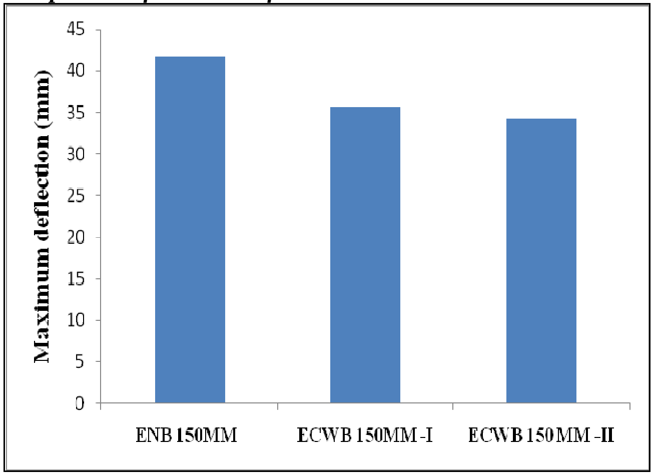

Fig.12. Comparison of ultimate deflections for150MM depth beams

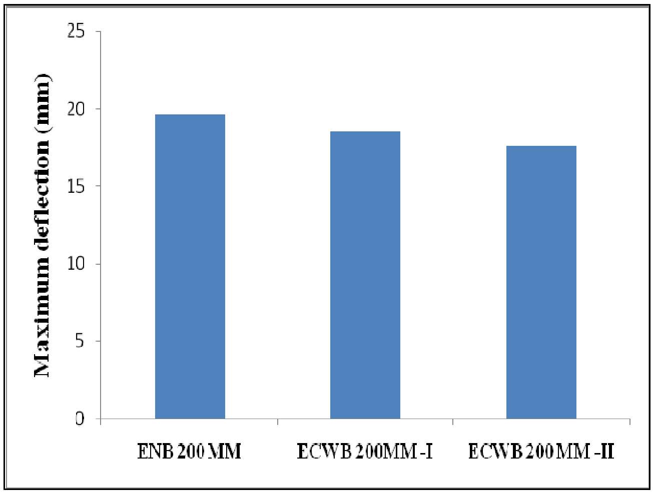

Fig.12. Comparison of ultimate deflections for 200MM depth beams

Modes of failure

From the results of experimental analysis the failure modes of the specimens are discussed.The failure was typically in the form of flexural cracks originating from the bottom of the specimen and extending towards the top of the specimen. The majority of cracks were formed between the zone of two point loading and also some cracking was also observed near the support ends.There wasn’t much difference between the failure undergone by encased normal beam and encased corrugated web beam. But the load carrying capacity of encased corrugated web beam was significantly higher than that of encased normal web beam.

Though failure because of loss of bond between steel web and concrete was expected such a failure did not occur. The expansive nature of concrete and interlocking effect provided by the corrugated web was found to be enough to ensure bonding for beams tested depth. The buckling of flange in outward direction was observed due to the loss of strength in spot welding between web and flange

Fig.13. Failure pattern of ENB-150MM

Fig.14. Failure pattern of ECWB-150-II

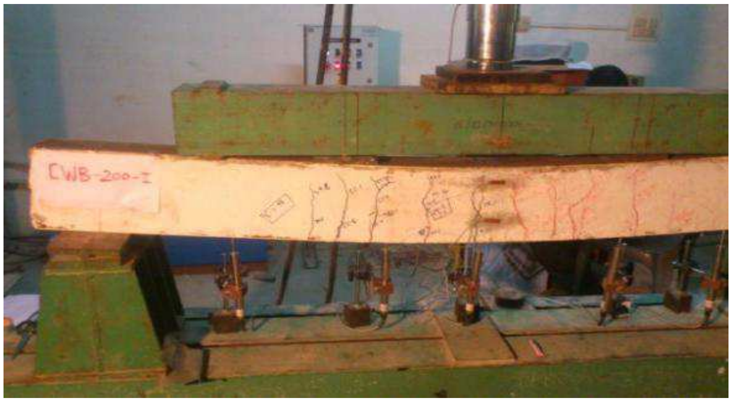

Fig.15. Failure pattern of ECWB-200-I

Conclusion

Cold-formed sections with concrete have resulted in increased resistance to lateral-torsional buckling. The ultimate load of ENB 150 was 71.3 kN and the ultimate deflection 41.7mm.The ultimate load of ECWB 150-I was 79.2 kN and ultimate deflection 35.2 mm. The ultimate load of ECWB 150-II was 83.4 kN and ultimate deflection of 34.1 mm. The ultimate load of ENB 200 was 50.8 kN and ultimate deflection of 19.6 mm. The ultimate load of ECWB 200-I was 100.6 kN and ultimate deflection of 18.5 mm. The ultimate load of ECWB 200-II was 105.8 kN and ultimate deflection of 17.6mm. For 150mm depth beams, the ultimate load carrying capacity of encased cold-formed corrugated web beams is 20-25% higher than encased normal web beams. For 200mm depth beams , the ultimate load carrying capacity of encased cold-formed corrugated web beams is about 2 times that of encased normal web beam. The maximum deflection of encased cold-formed corrugated beams was 4-8% lesser than encased normal beams. The ductility of the specimens are more than 5 thus can be used in earthquake-prone areas.

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