

## **Experimental Study and Behaviour of Encased Cold Formed Beam with Triangular Corrugated Web**

**Stebin Mathe**

Department of Civil Engineering  
SRM University  
Kattankulathur  
Chennai

**N.Parthasarathi**

Assistant Professor  
Department of Civil Engineering  
SRM University  
Kattankulathu  
Chennai

### **ABSTRACT:**

Whenever standard I-sections could not satisfy the moment carrying capacities, built-up I-sections have been extensively used. 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. The introduction of corrugated profile in web of I-sections consistently reduced the web instability and the application of transverse stiffeners. But even after providing corrugated webs, effects like lateral torsional buckling were observed. Thus measures are taken to reduce this buckling effect other than providing transverse stiffeners and corrugated webs. Giving an encasement in the corrugated web beam could improve the transverse deflections. The I-sections are encased with graded concrete mix not only improves resistance to transverse deflections but also show a considerable increase in strength.

**KEYWORDS:** Corrugated steel webs, Concrete Encasement, Lateral Torsional Buckling, Shear Strength, Cold Formed Steel Sections

### **1. 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. The light gauge steel members are defined as structural members cold formed to shapes in rolls or press breaks from carbon or low alloy steel sheets or strips or flats, generally not thicker than 12.5mm. Due to the heavy load materials used the dead load of the structure increases. To reduce this and improve the structural efficiency, corrugated plates may be used. Corrugated profiles are introduced in order to achieve adequate out-of plane stiffness and shear bulking 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 an 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. The use of hot rolled sections become uneconomical for the steel structures subjected to light and moderated loads, and for the structural members of short span lengths (e.g. joints, purlins, girts, roof trusses). Thin sheet steel products are extensively used in building industry, and range from purlins to roof sheeting and floor decking. Generally these are available for use as basic building elements for assembly at site or prefabricated frames or panels. These thin steel sheets are cold-formed, i.e. their manufacturing process involves forming steel sections in a cold state (i.e. without application of heat) from steel sheet of uniform thickness. Sometimes they are also called light gauge steel sections or cold rolled steel sections. Cold forming has the effect of increasing the yield strength of steel, the increase being the consequence of cold working well into the strain-hardening range. These increases are predominant in zones where the metal is bend by folding. The effect of cold working is thus to enhance the mean yield stress by 15% - 30% for purposes of design, the yield stress may be regarded as having been enhanced by a minimum of 15%.

### 1.1.CORRUGATED WEBS:

A corrugated web beam is a built-up girder with thin walled corrugated webs and flange plates<sup>[1]</sup>. 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. The flanges carry the moment due to accordion effect. Engineers have long realized that the corrugations in webs enormously increase their stability against buckling and can result in very economical design. Therefore, corrugated web beams have the potential to eliminate many costly web stiffeners. In addition, the use of thinner webs result in less raw material usage thus resulting cost savings estimated about 10-30% compared to conventional built-up sections and more than 30 % compares to standard I-beams. Corrugations are of different types. A triangular corrugated steel plate is composed of series of plane and inclined sub-panels.

In construction application, the webs usually bear the most compressive stress and transmit shear in the beam while the flanges support the major external loads. Thus by using greater part of the material for the flanges support the major external loads material saving can be achieved without weakening the load carrying capacity of the beam. Nevertheless, as the compressive stresses in the web has exceeded the critical point prior to the occurrence of the yielding, the flat web loses stability and deforms transversely. This can be improved by using corrugated web, as an alternative to the plane web, which produces higher stability and strength without additional stiffening and use of large thickness.

It has been found from earlier literature that when the beam length exceeds a given threshold value then compression element that is the corrugated web becomes unstable and tends to buckle laterally even after providing lateral stiffeners. Therefore, further lateral restraints have to be provided to control lateral buckling. But, lateral restraints cannot be provided in the form of steel stiffeners because of the limitation in welding in the corrugated web. Thus, corrugated web encased in concrete can be used as an effective lateral restraint and further increasing the load carrying capacity of the beam. Additionally, the concrete acts as a cover to web and improves the fire resistance of the beam

## 2. EXPERIMENTAL INVESTIGATION:

### 2.1.FABRICATION AND CASTING:

Cold formed steel plates of size 8 feet by 4 feet of 2 mm thickness were cut to desired dimensions by using cutting machine. These plates were folded by using a press breaker machine with 45<sup>0</sup> corrugation angle. After folding, the plates should be weld together in order to form an I-section. Flange plates are placed at top and bottom and welded to the corrugated web<sup>[1]</sup>. Figure 1 shows the welding procedure of web to flange. Fabricated beams are placed in horizontal direction with web facing upwards. Figure 2 shows I-sections after welding and placed for concrete encasement. Concrete with grade M30 is mixed and encased at both sides of the beam. The beams should left for 28 days of curing. Figure 3 shows beams after being encased with M30 grade concrete.



Figure 1. Welding Of Plates



**Figure 2. Beams Placed For Casting**



**Figure3. Concrete Encased On Both Sides of Beam**

### **2.2.TEST SET-UP:**

All specimens are tested for flexural strength under two point loading by using vertical load frame (reaction type)<sup>[6]</sup>. The specimens were arranged with simply supported conditions, adjusted for a effective span of 1.8 m (Figure 4). 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 three dial gauges were placed one at mid span and two below point of loading. For each load increment the deflection and crack were observed and tabulated.



Figure 4. Test Set-Up

**2.3.SPECIMEN DETAILS:**

Total of six built-up cold formed I-sections are tested and studied. Two normal web I-sections of 2mm thickness for both flanges and web are partially encased with M30 concrete with 150mm and 200mm height. Four sections of triangular corrugated web profile with corrugation angle 45°, thickness 2mm for both flanges and web and of height 200mm and 150mm, also encased partially with M30 concrete on both sides.

Top and bottom flange width  $b_f$ -100 mm.

Thickness of the section (Flange and Web)  $t_f$ -2mm.

Height of specimen -150 mm & 200 mm.

Span length – 2 m

The bonding between concrete and steel was expected to be provided by expansive nature of concrete.

Table 1 shows the beam designations.

**Table 1: Beam Designation**

| Serial No. | Beam Designation | Description                              | L/D ratio | Number of Specimens |
|------------|------------------|--|-----------|---------------------|
| 1          | ENB 150          | Encased Normal Beam Depth 150 mm         | 13.33     | 1                   |
| 2          | ENB 200          | Encased Normal Beam Depth 200 mm         | 10.00     | 1                   |
| 3          | EWB 150-I        | Encased Corrugated Web Beam Depth 150 mm | 13.33     | 1                   |
| 4          | EWB 150-II       | Encased Corrugated Web Beam Depth 150 mm | 13.33     | 1                   |
| 5          | EWB 200-I        | Encased Corrugated Web Beam Depth 200 mm | 10.00     | 1                   |
| 6          | EWB 200-II       | Encased Corrugated Web Beam Depth 200 mm | 10.00     | 1                   |

**3. RESULTS AND DISCUSSION:**

**3.1.FLEXURE TEST:**

All the specimens were tested for flexural strength under two point loading by using reaction type loading frames. Deflection readings are observed from dial gauges and load readings were observed from load indicator. The following observations were made during the progress of the tests. The observations are summarized in Table 2.

**Table 2. Ultimate Load And Deflection Of Specimens**

| Specimens        | Ultimate Load in KN | Max. Deflection at Mid-Span in mm |
|------------------|---------------------|-----------------------------------|
| ENWB 150MM       | 44.1                | 14.65                             |
| ECWB 150MM -I    | 61.3                | 25.36                             |
| ECWB 150 MM - II | 58.8                | 24.56                             |
| ENWB 200 MM      | 66.2                | 14.2                              |
| ECWB 200MM -I    | 80.9                | 23.44                             |
| ECWB 200 MM - II | 85.8                | 22.9                              |

**3.2.LOAD FACTOR:**

Load factor is defined as the ratio of strength of built up section against standard section. In Table 3, 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 1.39 times the strength of standard section for  $H/t = 75$  and for the aspect ratio 100, the load factor value is 1.29. From this, it is understood that both values are greater than 1. Also aspect ratio increases as the load factor increases.

**Table 3. Load Factor Values Of Specimens**

| Height of specimen | Height to thickness ratio | Ultimate load (KN) corrugated web | Ultimate load (KN) normal web | Load factor |
|--------------------|---------------------------|-----------------------------------|-------------------------------|-------------|
| 150mm              | 75                        | 61.3                              | 44.1                          | 1.39        |
| 200mm              | 100                       | 85.8                              | 66.2                          | 1.29        |

**3.3.RESIDUAL STRENGTH OF BEAM:**

The quantitative measure of residual strength of beam has been made with reference to the ultimate load. The percentage difference of ultimate load for normally encased beam and encased corrugated web beam gives a measure of residual strength (Table 4).

**Table 4. Residual Strength Of Specimens**

| specimen | Ultimate load (KN) corrugated web | Ultimate load (KN) normal web | Residual strength in % |
|----------|-----------------------------------|-------------------------------|------------------------|
| 150mm    | 61.3                              | 44.1                          | 17.2                   |
| 200mm    | 85.8                              | 66.2                          | 19.6                   |

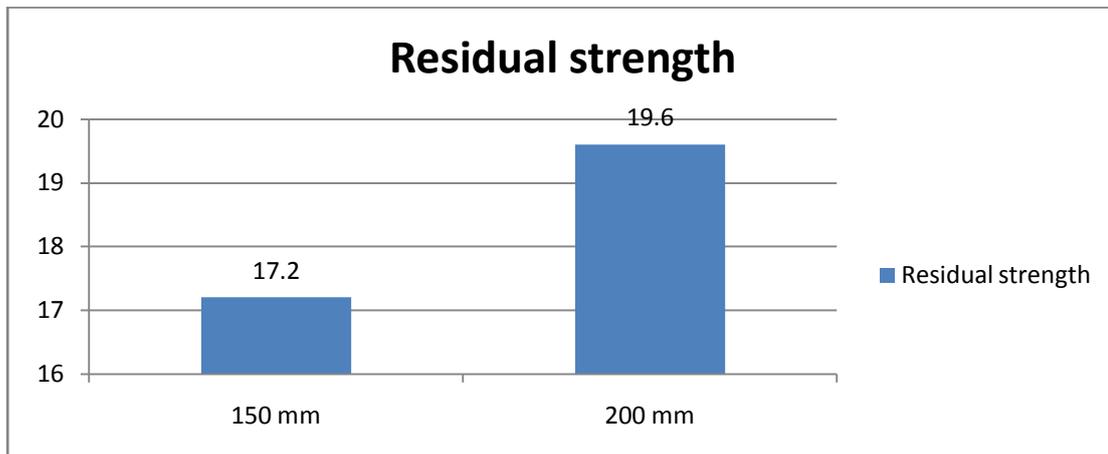


Figure 5. Residual Strength of 150 mm And 200 mm Beams

**3.4. 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 5 shows that the stiffness value increases along with the aspect ratio. Stiffness value of the specimen ENWB 200MM 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 5. Stiffness At Ultimate Loads

| Specimens        | Ultimate Load in kN | Max. Deflection at Mid- Span in mm | Stiffness KN/mm |
|------------------|---------------------|------------------------------------|-----------------|
| ENWB 150MM       | 44.1                | 14.65                              | 3.01            |
| ECWB 150MM -I    | 61.3                | 25.36                              | 2.417           |
| ECWB 150 MM - II | 58.8                | 24.56                              | 2.394           |
| ENWB 200 MM      | 66.2                | 14.2                               | 4.66            |
| ECWB 200MM -I    | 80.9                | 23.44                              | 3.45            |
| ECWB 200 MM - II | 85.8                | 22.9                               | 3.74            |

**3.5. DUCTILITY:**

The quantitative measure of ductility has to be with reference to the load-deflection response. Then, the ratio of the ultimate deformation to the deformation at the beginning of the horizontal path (or, at first 'yield') can give a measure of ductility.

Table 6. Ductility values of specimens

| Specimens        | Ductility |
|------------------|-----------|
| ENWB 150MM       | 5.86      |
| ECWB 150MM -I    | 5.28      |
| ECWB 150 MM - II | 6.14      |
| ENWB 200 MM      | 8.875     |
| ECWB 200MM -I    | 11.72     |
| ECWB 200 MM - II | 12.05     |

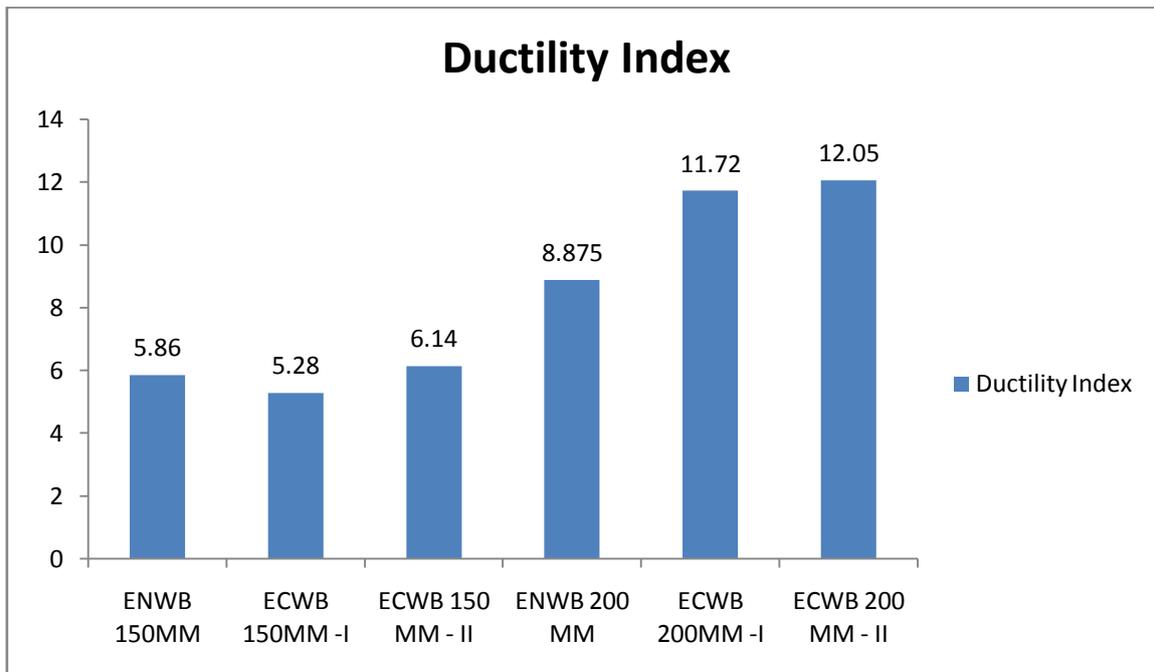


Figure 6. Ductility Values of Specimen

**3.6.LOAD – DEFLECTION GRAPHS:**

The dial gauges 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<sup>[6]</sup>. All the load deflection curve shows an increase in the load deflection which varies linearly 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 capacities are higher than encased normal web beam and for 200mm depth beams , the encased corrugated section ultimate load carrying capacities are again higher than that of encased normal web beam.

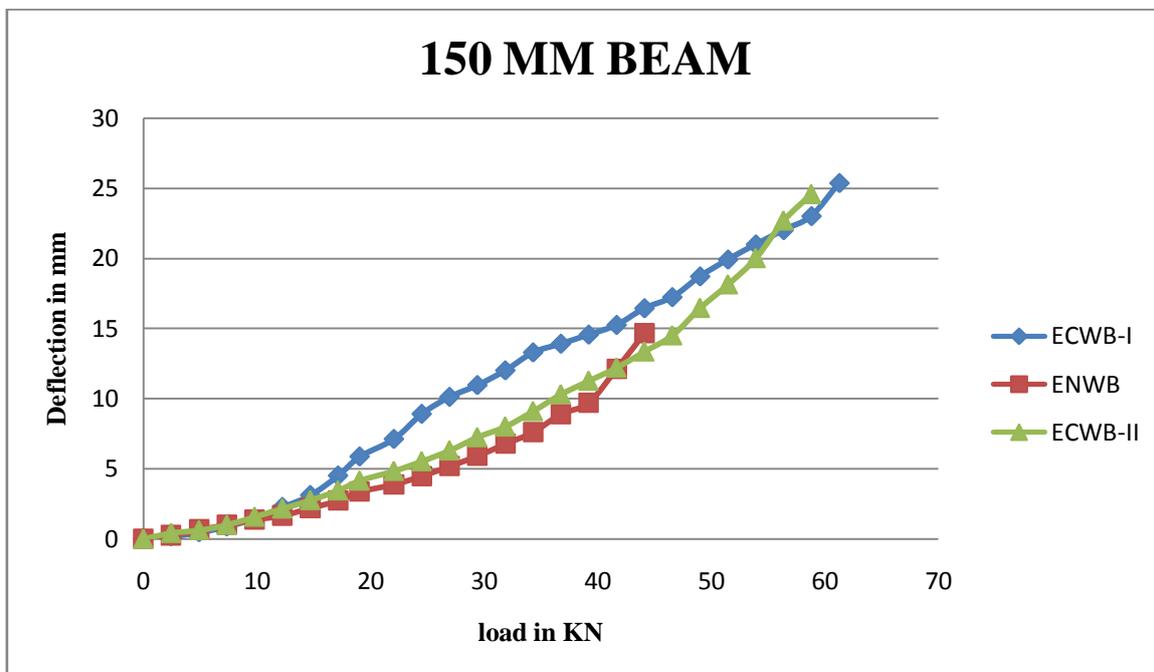


Figure 7. Load-Deflection Curve of 150mm Beam

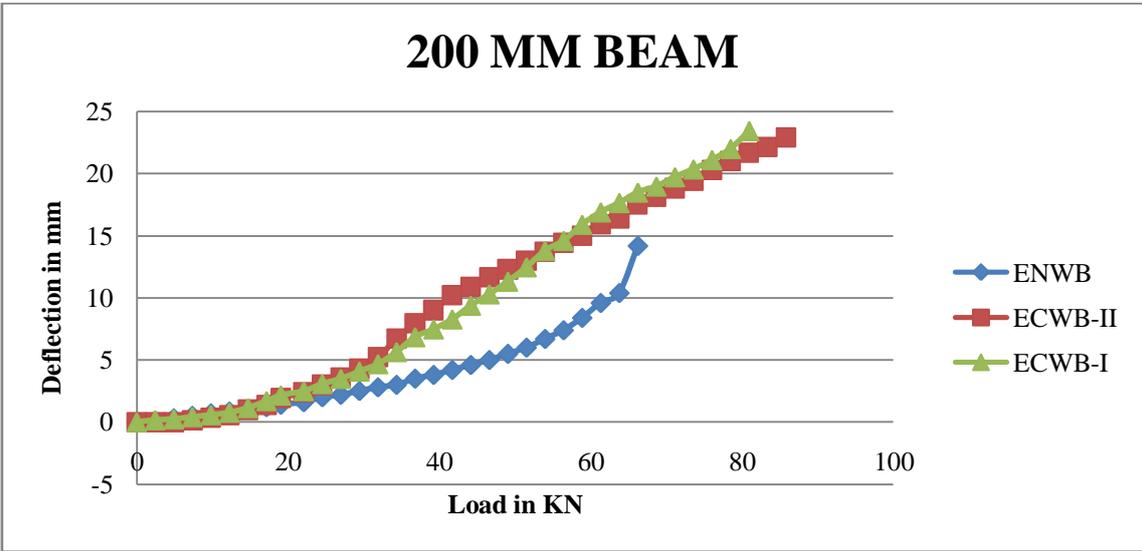


Figure 8. Load-Deflection Curve of 200mm Beam

3.7.COMPARISON OF ULTIMATE LOADS:

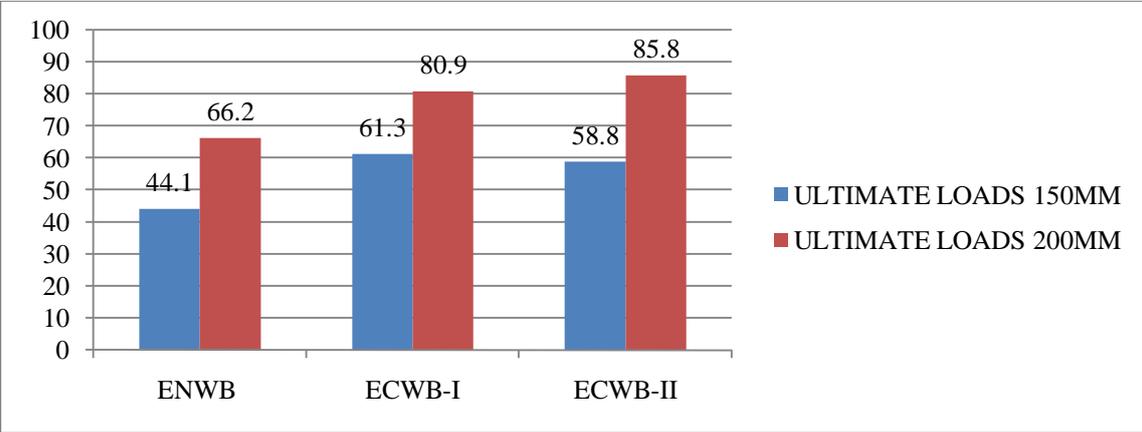


Figure 9. Comparison of Ultimate Loads

3.8.COMPARISON OF MAXIMUM DEFLECTIONS:

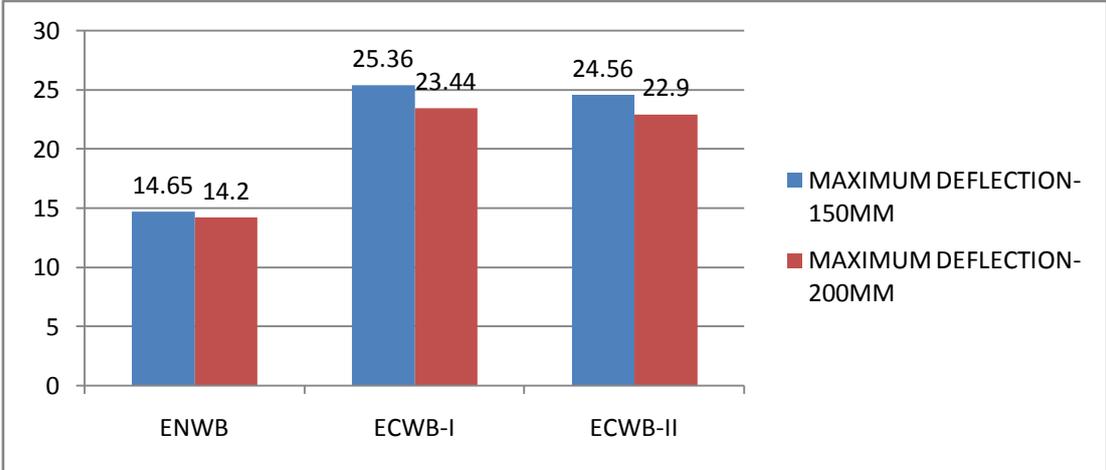


Figure10. Comparison of Maximum Deflections

### 3.9.MODES OF FAILURE:

From the results obtained the failure modes of different specimens were 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. Majority of cracks were formed between two point loading and some at the end supports. Failure pattern of encased normal beam and encased corrugated beam doesn't have much difference. But the load carrying capacities of encased corrugated beam is comparatively higher than that of normal encased beam. The buckling of flange in outward direction was observed due to the loss strength in spot welding between web and flange.



Figure 11. Failure Pattern of ENWB-200mm

### 4. CONCLUSION AND FUTURE SCOPE:

Cold-formed sections with concrete have resulted in increased resistance to lateral-torsional buckling.. For 150mm depth beams, the ultimate load carrying capacity of encased cold-formed corrugated web beams 25-30% higher than encased normal web beams. For 200mm depth beams , the ultimate load carrying capacity of encased cold-formed corrugated web beams is about 20-25% higher than that of encased normal web beam. The maximum deflection of encased cold-formed corrugated beams was 40-50% higher than encased normal beams. The ductility of the specimens are more than 5 thus can be used in earthquake-prone areas. For future research, the corrugation type can be changed and also special concrete can be used instead of conventional concrete.

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