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Behaviour of Composite Beam Arranged as Boxed-Section With C-Channel of Cold-Formed Steel of Lipped Section

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Abstract. Cold formed steel (CFS) of lipped C-Channel sections are commonly use because of their simple forming procedures and easy to erect. To improve the flexural strength of the proposed composite beam, the C-channel of Lipped section is arranged toe-to-toe to form into boxed shape section and filled with self-compacting concrete (SCC). Reinforcement bars was used in a tension zone to increase the flexural strength of the proposed beam in this experimental study. A U-shape re-bars was installed to act as shear connections between concrete slab and beam of boxed section filled with self-compacting concrete. Two specimens were prepared and tested until failure. A C-channel section of size 250mm deep, 75mm width, and 2.4mm thick was used for the proposed composite beam section. Longitudinal rebar's size of 16mm and 20mm were installed at the bottom of the beam encased by the self-compacting concrete of 50MPa. A U-shape re-bar if size 12mm in diameter was used as a shear connector and functioned as vertical shear resistance for the beam system. The beam is kept restrained in position by a profiled metal decking installed on top of the beam to form a slab system also cast using by SCC. The specimens were tested under pure bending arranged as simply supported beams. It was found that the moment resistance of the experimental results agreed well with the predicted numerical analysis.

1. Introduction

Cold-forming represents an industrial process based on cold-rolling, brake- forming, and bending brake operation that is used to produce different section shapes starting from a simply flat steel panel. The strength of each section shape is provided by the number of the bending, angles and proportions between section walls [A]. Section thicknesses of typically ranging from 1.2 mm to 3.2 mm, cold-formed members have been fabricated with a common yield stress of 350 MPa up to 550 MPa [6]. The cold-formed steel (CFS) members are relatively easy method of manufacturing, beside the many advantages [3,2,6,7,17,18] such as (1)lightness, (2)high strength and stiffness, (3)fast and easy to transportation and install, (4) reduce delay due to weather, (5) no formwork needed, (6)easy to cut, (7)uniform size, (8)able to accommodate tolerance, (9)and that also has variety of shapes and configuration [2, 3, 4, 6,7]. To take advantages the characteristics, the CFS used double C section with lipped channel as structural members usually produced to built-up section. The oriented (Fig 1a) back to back and (Fig 1b) toe to toe are assembled toe to toe CFS section to form a box beam is widely used in composite structures.

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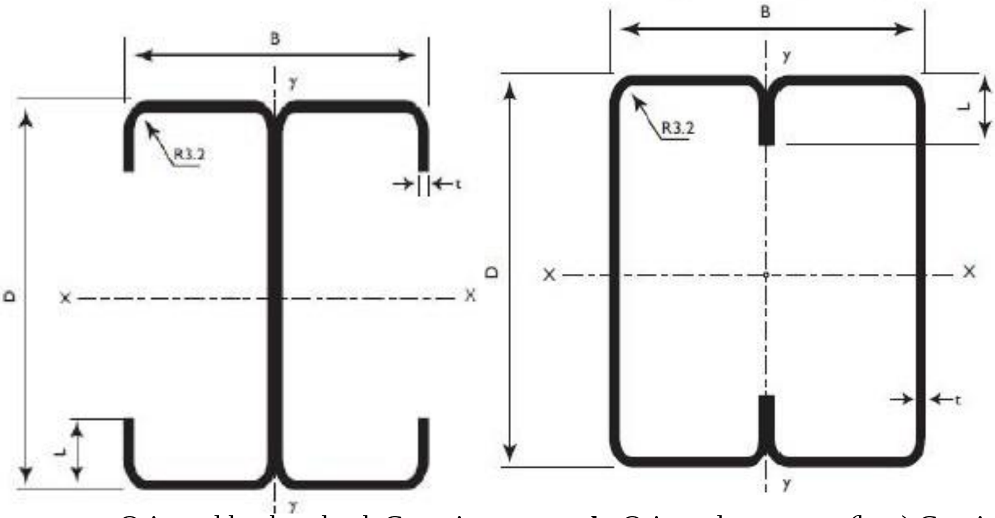

a. Oriented back to back C section **b.** Oriented toe to toe (box) C sction

Figure 1. Built up CFS section

The thinness of CFS is one of its limitations, making that section it vulnerable to torsional, distortional, lateral torsional, lateral distortional and local buckling [2, 6, 11, 12]. In general, the study developed to prevent this is to use bracing on CFS, Péter *et al.* [3], studied on a special type of polystyrene aggregate concrete (PAC) encased in CFS element as bracing material. Tests showed that bracing has beneficial effect on stability phenomena of CFS beams. The enchased of PAC was able to restrain the global and distortional buckling modes of steel elements, thus providing “full bracing” as reported by Samer Ahmad et al., [15] The structural steel sections are completely or partially encased in concrete type of beam provides higher strength and stiffness than traditional steel or reinforced concrete members. Concrete encasement offers many benefits including prevention of local buckling of the compression flange and it increases the resistance against lateral- torsional buckling of the beam. However, in order to achieve such advantages, it is vital to develop the composite action between steel and concrete through bond stress transfer either by natural bond or shear connectors in order to achieve full strength and stiffness of this type of beam.

The use of composite beam in buildings has known to be more economical against bare steel beams, possibility of reducing overall slab depth by using lighter sections at closer spacing, easy variation of the cross-section for irregular layouts, freedom in design of cross-sections. Cold-formed sections are made from flat sheets and can be designed and manufactured to order. Although the general principles of the design of composite beams apply equally to hot-rolled and to cold-formed sections, there is very little direct reference in the codes to the special problems involved in the latter application, and more surprisingly, very little information in the technical literature [20]. Composite structure is representing an efficient use of materials, quick to construct, cost effective, and sustainable construction. CFS composite beam a structural member with components of concrete and of structural or cold-formed steel, interconnected by shear connection to limit the longitudinal slip between concrete and steel and the separation of one component from the other EN 1994-1-1 (1.5.2) [19].

Alhajri et al.,[2] studied a pre-cast U-Shaped composite beam by integrating CFS with a ferro-cement slab and used 12 mm bolt as shear connector. They investigated on the effect of varying the number of layers of wire mesh installed and the variation in thickness of CFS. They concluded that as the number of layer increases, the proposed shear capacity increases. The shear capacity of the connectors also increases as the thickness of the CFS increases. Cheng-Tzu Thomas Hsu et al.,[4] they have developed a new composite beam system consists of three elements: reinforced concrete slab on corrugated CFS metal deck, back to back CFS joists, and continuous CFS furring shear connector. J.M. Irwan, A.H. Hanizah, I. Azmib, and H.B. Koha [6] has conducted an experimental an efficient and innovative floor system of built-up CFS sections acting compositely, that called the Precast CFS–Concrete Composite System designed to rely on composite action between the CFS sections and a reinforced concrete deck where shear forces between them are effectively transmitted via another

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innovative shear transfer enhancement mechanism called a bent-up triangular tab shear transfer (BTTST). M. M. Lawan, M. M. Tahir, S. P. Ngian, and A. Sulaiman [5] have revealed the composite characteristics of both the CFS-Concrete and Concrete-Ferrocement as composite elements. Considering the researches presented in this study, composite performance between CFS-Self Compacting Concrete (SCC) is yet to be established. The systematic investigation into and study of CFS composite beam in order to establish facts and reach new conclusions, however research for the use of CSF in composite structure needs to be developed with new CFS composite beam that is more innovative and applicable.

An innovative type of possible composite beam using box CFS section of lipped C-channel (toe to toe) are presented in this experimental. The performance promised of a composite construction of this proposed composite beam should be able to minimize the distance from the neutral axis to the top of the deck and reduces the compressive bending stress in the CFS sections. This can be achieved by arranging two CFS channel to form into boxed section (arranged toe to toe) encased with self-compacting concrete. The boxed shaped is kept restrained in position by a profiled metal decking installed on top of the beam as slab system act compositely with the connected beam by the proposed U-shaped rebar as shear connector. This profiled decking slab is cast by using self-compacting concrete (SCC) where the concrete is in compression when the flexural load is applied to the beam. Links or stirrups are installed of U shape rebar as a shear connector and also functioned as vertical shear resistance for the beam system. In order to balance up the compression force developed from the slab; reinforcement bars are positioned at the lower part of the beam as shown in Fig 2. Two box section of encased CFS composite beam developed in this research, the first configuration used to face each other with reinforcement 2No-16ϕ and the second configuration used to face each other with reinforcement 2No-20ϕ (see Fig 3.)

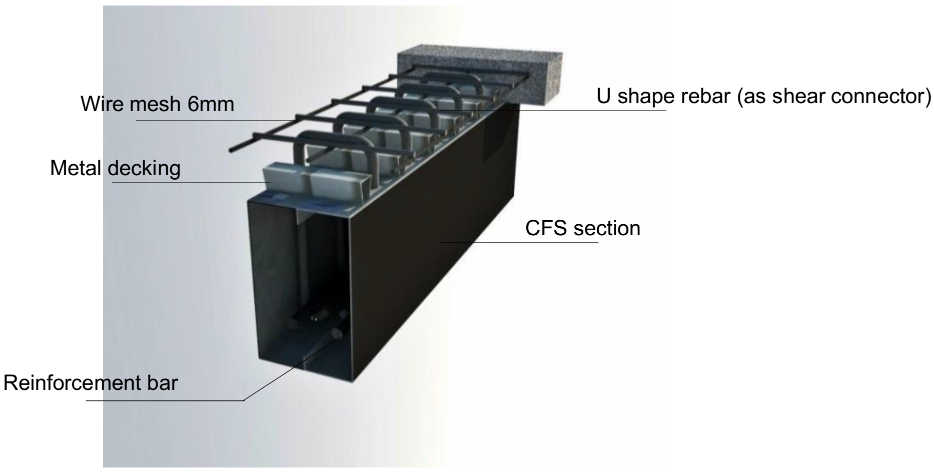

Figure 2. CFS Composite beam design with box section

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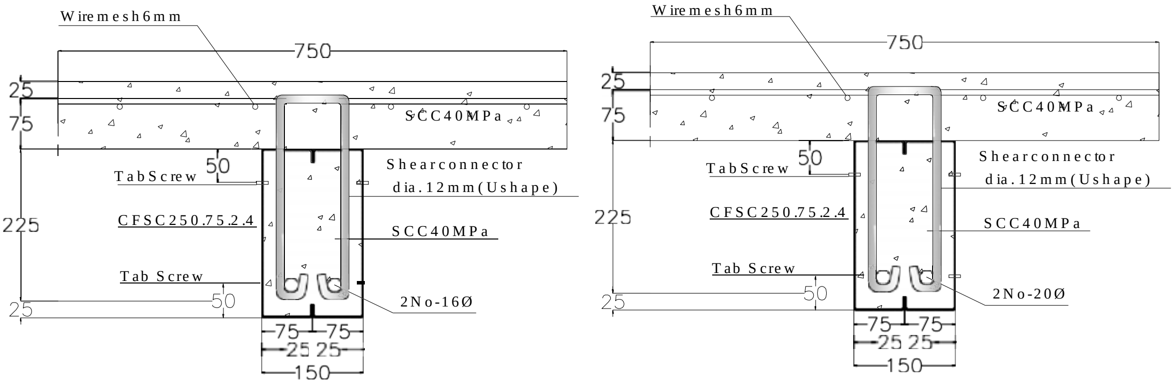

Figure 3. The type of cross section of developed in this research

2. Experimental investigation

Specimens Arrangements

In this study, two specimens prepared as box section (toe-to toe) with C-Channel of CFS of lipped section were tested to investigate the flexural strength of the proposed composite beam. All specimens used C-Channel of lipped section with the depth 250 mm, the width 75 mm, lipped depth 20mm and a thickness 2.4 mm. Two CFS of lipped C-channel sections were assembled together as box-beam built up (toe to toe) by connected together by tek-weld. This beam is kept restrained in position by a profiled metal decking installed on top of the beam to form a slab system. The profile metal deck with thickness 1.0 mm and profiled sheeting rib height of 50 mm was used. BRC welded wire mesh A142 diameter 6 mm and a spacing 200 mm was used as reinforcement. The link and stirrups are installed as U-shape rebar as shear connector and also functioned as vertical shear resistance made from deformed bent-up bar of diameter 12 mm with spacing 330 mm for the beam system. In order to balance up the compression force developed from the slab, reinforcement bars are positioned at the lower part of the beam with 2No-16ϕ and 2No-20ϕ rebars. Self-Compacting Concrete (SCC) was a ready mix of grade 40 at day tested for casting slab and enchased box-section beam without the need formwork. The details of the specimens and material properties are summarized in Table 1 and Table 2. The arrangement and preparation of specimnes are shown in Figure 4.

Tabel 1. Dimension of test specimen

Specimen	Length	CFS beam		Slab		Size of shear connection	Size of bottom reinforcement
	(mm)	Depth (mm)	Thickness (mm)	Width (mm)	Thickness (mm)		
TT.250.16	4000	250	2.4	750	100	12Ø-330	2No-16Ø
TT.250.20	4000	250	2.4	750	100	12Ø-330	2No-20Ø

Table 2. Properties of materials

Propeties	CFS	Shear connector	Bottom reinforcement	
	Thickness 2.4 mm	Rebar No-12Ø	Rebar No-16Ø	Rebar No-20Ø
Yield Stress (f_y in N/mm^2)	560.50	656.7	525	574
Ultimate Stress (f_u in N/mm^2)	636.75	746.7	599	666
Elastic Modulus (E_s in N/mm^2)	182000	213,333	218,333	214,333

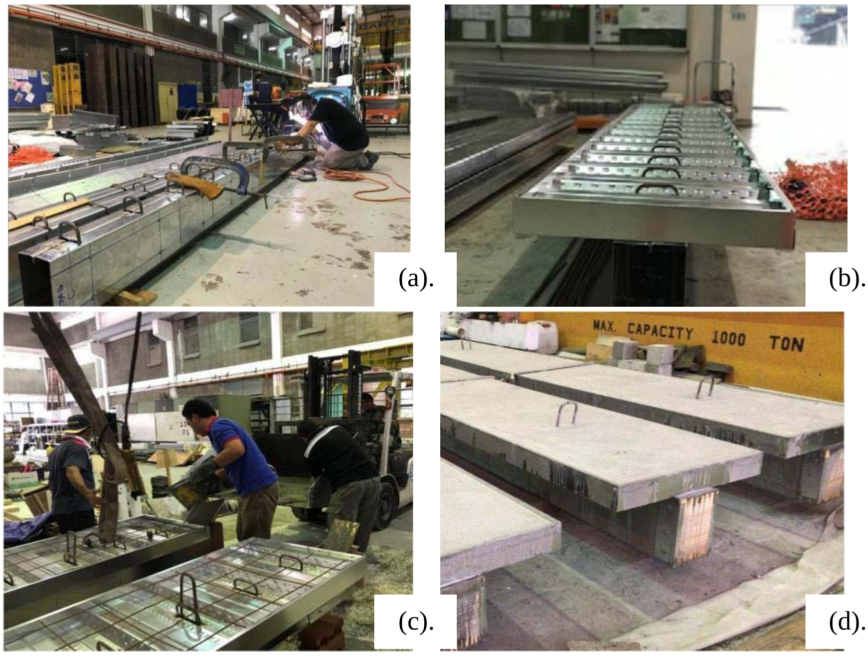

Figure 4. Proccessed for arragement specimens: (a) C-channel assembled box-section (b) Profile metal decking installed (c) Casting (d). Composite beam specicemen

Test Setup

A full-scale testing was set-up as shown in Fig 5 and Fig 6 where the specimen was tested as simple supported beam. The proposed composite beam specimen was loaded as two vertical loads by hydraulic jack machine with a maximum capacity of 800 kN, monitored the readings by calibrated load cells. A spreader beam was used to transfer the applied load to slab at two points symmetrically load at a distance of 1000 mm from the simple supported position. Two LVDTs were placed at the loading point, one at midspan to monitor the load-deflection characteristics and two at supports sides to observe the slip. Strains were measured at midspan throughout the depth of the cross section using strain gauges in the bottom, flange of the CFS beam, longitudinal rebar and the top SCC slab.

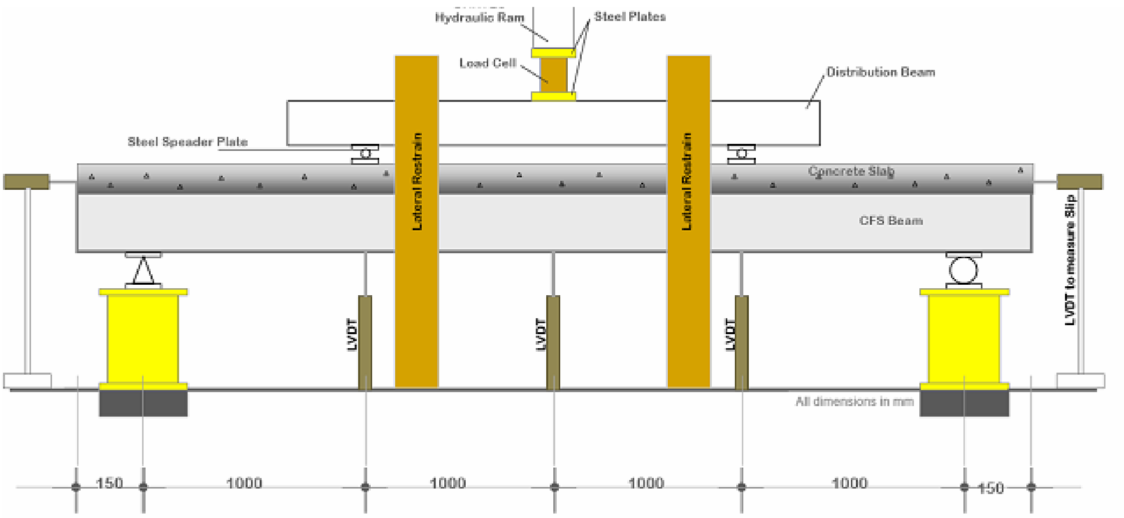

Figure 5. Test setup (scheme)

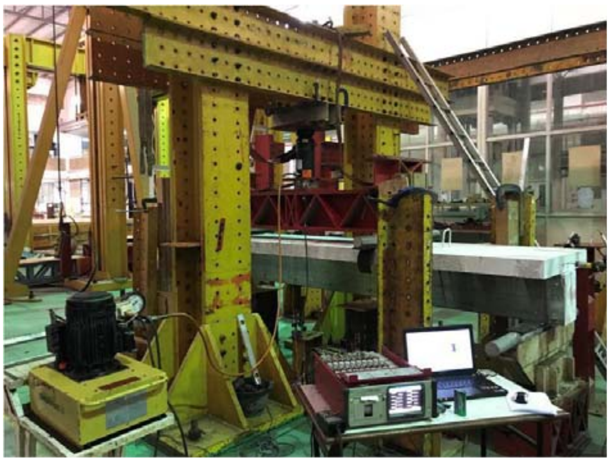

Figure 6. Test arrangement

3. Experimental results

The crack patterns observed from the tested specimens was recorded as longitudinal cracks on the slab surface (see Figure 7.) as the load increases. The initial crack starts in the area near the support zone and propagate towards the loading point, indicating initiation of concrete crushing due to compression which can be classified as failure due to shear splitting. The first crack observed for TT.250.16 when the loaded at 220 kN which was 72.70% of the ultimate load and TT.250.20 at 230 kN which was 94.07% of the ultimate load. At the maximum load which was very close to the total failure of the specimens, local buckling was developed at CFS box beam with encased SCC after yielding of CFS. Figure 8 shows that local buckling has occurred on both specimens at the loading zone.

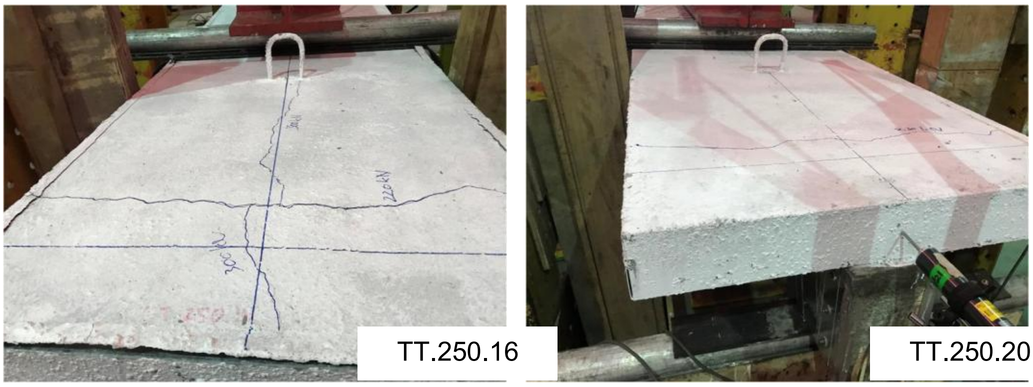

Figure 7. Crack pattern of specimens

Figure 8. Local buckling

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The variations of deflection at mid-span of the both full scale composite beam tested for the applied load are plotted in Figure 9. Load versus deflection of the specimens was plotted as shown in Fig. 9 where the results show that specimen TT.250.16 recorded a 23.76% increase in ultimate load as compared to TT.250.20. The ductility index measured as the ratio between ultimate load and deflection was recorded as 3.56 for TT.250.16 and 3.49 for TT.250.20 respectively.

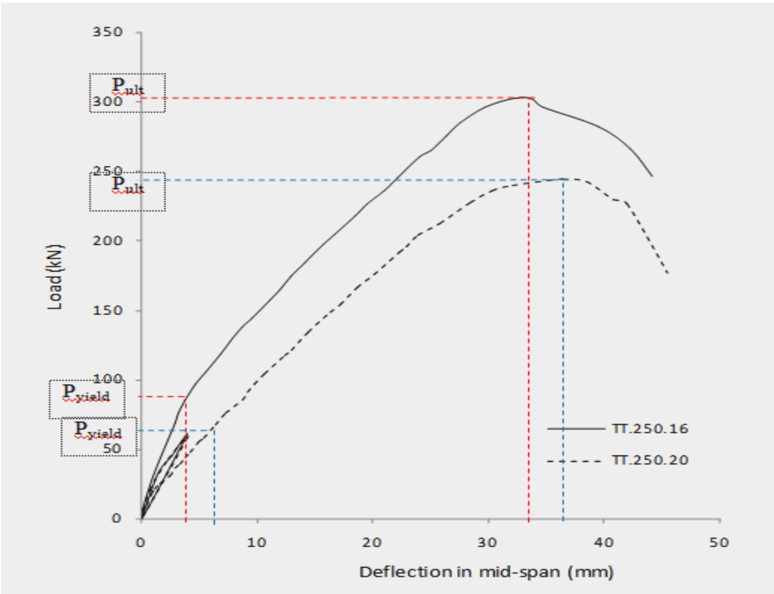

Figure 9. Load-deflection diagram

4. Experimental and comparison with theoretical predicted

In the previous investigation, M. M. Lawan [6] proposed equation for predicted the bending resistance of theoretical $M_{u,theory}$ determined based on BS EN 1994-1-1:2004, a composite section should be classified according to the least favourable class of its steel elements in compression. The class of a composite section normally depends on the direction of the bending moment at that section. Where ductile shear connectors are used, the resistance moment of the critical cross-section of the beam MRd was calculated by assuming that a rigid plastic theory can be applied, except that a reduced value of the compressive force in the concrete flange N_c should be used in place of the force N_{cf}. The ratio $\eta = N_c/N_{c,f}$ is the degree of shear connection. The location of the plastic neutral axis in the slab should be determined by the new force Nc. The theoretical analysis of bending capacity of composite beam as boxed-section with c-channel of CFS of lipped section can determined by the resistance moment of the critical cross-section of the beam $M_{p,Rd}$ at the load location. The modification plastic stress distribution is given below in Fig 10. Experimental and theoretical moment capacities are compared and presented in Table 3.

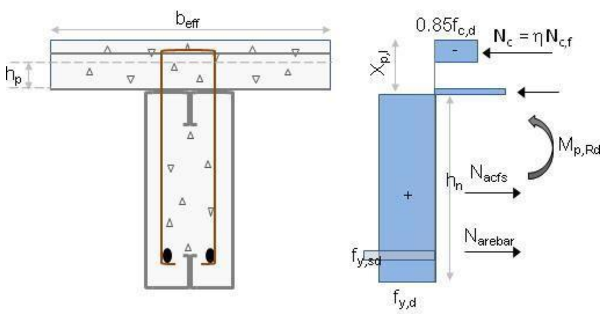

Figure 10. Plastic stress distribution CFS box section

Table 3. Experimental result and comparison theoretical moment

Experimental		**TT.250.16**	**TT.250.20**
Ultimate load, P_u	kN	302.60	244.50
Deflection in mid-span at $P_{u,}$, δ_u	Mm	32.29	36.43
Ultimate moment, M_u exp	kN m	151.30	122.25
Theoretical ultimate moment, Mu theory	kN m	107.04	120.88
M_u exp/ M_u theory		**1.41**	**1.01**

5. Conclusions

The test results of two full scale composite beam as box section can be conclusions as follows:

1. All specimens have a similar failure classified as shear splitting failure mode, which failed of concrete due to crushing of compression slab.
2. Composite beam specimen with 2No-16ϕ rebar carried 23.76% higher ultimate moment than 2No-20ϕ rebar as the neutral axis of the moment has been shifted to the upper side of the slab which resulted to higher stress in the composite slab.
3. Both specimens showed high ductility index of 3.56 for TT.250.16 and 3.49 for TT.250.20. This showed that the composite beam box section with encased SCC was able to provide composite beam with ductile flexural behavior.
4. The comparison of maximum moment between theoretical and experimental results agreed well with the ratio in the range of 1.01 to 1.41.

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