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Prediction on Flexural Strength of Encased Composite Beam with Cold-Formed Steel Section

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Abstract. A flexural strength of composite beam designed as boxed shaped section comprised of lipped C-channel of cold-formed steel (CFS) facing each other with reinforcement bars is proposed in this paper. The boxed shaped is kept restrained in position by a profiled metal decking installed on top of the beam to form a slab system. This profiled decking slab is cast by using self-compacting concrete where the concrete is in compression when load is applied to the beam. Reinforcement bars are used as shear connector between slab and CFS as beam. A numerical analysis method proposed by EC4 is used to predict the flexural strength of the proposed composite beam. It was assumed that elasto-plastic behaviour is developed in the cross –sectional of the proposed beam. The calculated predicted flexural strength of the proposed beam shows reasonable flexural strength for cold-formed composite beam.

INTRODUCTION

Cold Formed Steel (CFS) sections have been rapidly used in the construction of commercial and industrial buildings and residential buildings.CFS are made from steel sheets and are formed into different shapes either through press-braking sheared form sheets or coils or more commonly, by rolling done at room temparature. The most common of CFS sections are the C and Z sections, with thickness ranged from 1.2 mm to 6.4 mm and depth ranged from 51 mm to 305 mm.

The benefits of CFS sections in building construction as compared to other building material such as concrete and timber. The advantages of CFS as structural steel can be listed as follows :

- Lightness
- High strength and stiffness
- Fast and easy to fabricate and install
- Reduce delay due to weather
- No formwork needed, easy to cut, uniform size, and able to accommodate tolerance.
- Recyclable material

Beam when loaded laterally on its axis tends to bend and the am axis deformed into a curve. Stress and strai n occur due to bending moment and shear force when the beam is loaded. The CFS sections usually used as structural beams in construction are the C and Z sections with or without lipped and fabricated CFS I-section, but they suffer from certain buckling modes. There are three types of buckling specifically local buckling [11], distortional buckling and Euler's buckling (flexural or flexural-torsional), generally called as global buckling [11,12]. It is composite beam section.The aim of this paper is to predict the moment resistance of proposed section beam where CFS as boxed section is used to form composite action with the attached composite slab by

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means of reinforced bars. Beam with lipped channels section is assembled to C-sections oriented toe to toe so that stability and bearing performance could be increased (see Fig. 1).

However, to enhance further the use of CFS section, conceptual design of composite beam with cold-formed is proposed in this paper. The proposed composite beam is introduced in such a way that the advantages of CFS section can be combined with concrete slab. The shear connection between steel and concrete slab in composite beams is inherently significant, as it resists separation between the two component as well as enhanced longitudinal shear transfer[3]. The most common form of shear connection in composite beam system is the use of mechanical devices known as shear connectors.

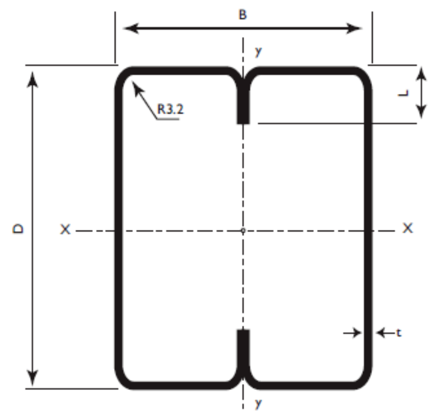

FIGURE 1. Lipped channels (Blue Scoope) CFS beam section

COMPOSITE BEAM WITH CFS SECTION

The use of composite beam in buildings has known to be more economical non-composite steel beams, which the composite action between steel and concrete has results in significant savings in steel weight and reduce the beam depth[5]. The advantages of composite beam contributed to the dominance of composite beam in the commercial building in steel construction industry. To date, the advantages of composite beam have been further extended with the use of pre-cast floor and metal decking floor, to minimize or eliminate the use of formwork. The performance of such floor systems depends on the interaction of the concrete slab and the steel section connected together by shear connectors. This interaction depends on the strength of the studs, the concrete strength, and the continuity preserved along the horizontal interface so that the concrete slab and the steel section respond as one unit.

Proposed CFS Composite Beam with Boxed Section

The proposed composite beam which assembled as boxed section is purposely done to as to enhance the stiffness and the capacity of beam. The increase in stiffness and capacity could be further increased by confinement effect of the proposed boxed shape. The boxed shaped is kept restrain in position by profiled metal decking installed on top of the beam to form a slab system. This profiled decking slab is cast by using self-compacting concrete where the concrete is in compression when the flexural load is applied to the beam. Links or stirrups are installed 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, and the cross-sectional section of the proposed composite beam is shown in Fig. 3

FIGURE 2. CFS Composite beam design with box section

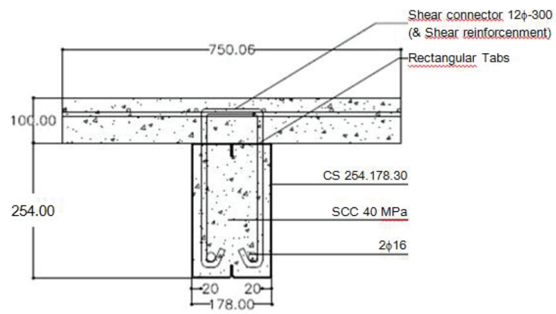

FIGURE 3. The cross-sectional section of the proposed composite beam

Moment Resistances

The bending resistance can determined by elasto-plastic theory based on the BS EN 1994-1-1:2004. The following assumptions should be made in the calculation of $M_{pl,Rd}$:

- There is full interaction between structural steel, reinforcement, and concrete
- The effective area of the structural steel member is stressed to its design yield strength f_{yd} in tension or compression
- The effective areas of longitudinal reinforcement in tension and in compression are stressed
- Design yield strength fsd in tension or compression. Reinforcement in compression in a concrete slab may be neglected.

The prediction of plastic stress distributions for fully composite beam where plastic neutral axis in the concrete slab as show in Fig 4.

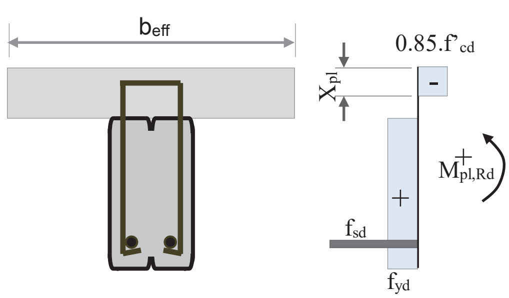

FIGURE 4. Plastic stress distribution for effective sections

The prediction shear resistance of stud in accordance with EN 14555 is determined from equation 1 and 2. The actual shear resistance the taken as the smaller of the two equations :

$$P_{Rd} = \frac{0.8\, f_{yd}\pi d^2/4}{\gamma_V} \tag{1}$$

or

$$P_{Rd} = \frac{0.29\; \alpha d^2 \sqrt{f_{ck}E_{cm}}}{\gamma_V} \tag{2}$$

where $\alpha = 1$

Prediction of Moment Resistance

Details on the configuration of the proposed composite beam is shown in Table 1. The length of the beam is taken as 3.2m and the depth of the slab is 100mm with 50mm the depth of the profiled decking.

TABLE 1. Geometrical configuration of proposed box section

Box Section CS-25/LL2540-16				
Size of bottom reinforcement	**Size of shear connector**	**Strength of self-compacting concrete**	**Size of slab**	
			Width (mm)	**Thickness (mm)**
2 No-16ϕ	12ϕ-300	40	750	100

The moment resistance of the proposed beam is based on the tension zone of steel section plus reinforcement steel bars interacted together with compression zone developed from self-compacting slab by means of shear connector[8,9]. However, the shear connectors which are contributed from the rebar of size 12 mm Ø diameter is assumed to perform as fully shear connectors. Shear connector is embedded in a solid slab and performed as full shear connector. EC4 is adopted to predict the shear strength of the shear connector as shown below equation 1 and 2. The smallest value is used to establish the total shear resistance of the connectors the slab.

$$P_{Rd} = \left(\frac{0.8x450x\pi x12^2/4}{1.25}\right)x10^{-3} = 32.6\;kN \tag{3}$$

or

$$P_{Rd} = \left(\frac{0.29x1x12^2\sqrt{40x31476}}{1.25}\right)x10^{-3} = 37.5\;kN \tag{4}$$

Use $P_{Rd} = 32.6\;kN$

In this example there are 7 ribs (300mm spacing in decking) available for the positioning of shear connectors per half (span 2000mm) of the beam

For $n_r = 2$, $N_c = n_r \times P_{Rd} = 2 \text{ x } 7 \times 32.6 = 455.8$ kN

Compressive resistance of the concrete flange

Design compressive strength f_{cd}= 40/1.5 = 26.7 N/mm^2

$N_{c,Rd} = 0.85xf_{cd} \text{ x } b_{eff} \text{ x } h_c$

= 0.85 x 26.7 x 750 x 58 x 10^{-3} = 986 kN

Where the ratio $\eta = \frac{N_c}{N_{c,Rd}} = 0.462$is less than 1.0 so connection is partial.

Tensile resistance of steel member

$N_{pl,a}$ = $(fyA)_{CFS}$+ $(fyA)_{re\text{-}bar}$

= 500 x 2760 x 10^{-3} + 460 x 200.96 x 10^{-3}

= 1380 + 92.4

= 1472.4 kN

With ductile shear connector and cross section of the composite beam in class 1, the moment resistance of of the beam $M_{pl,Rd}$ is calculated by means of elasto-plastic theory is determined from:

$M_{pl,Rd}$ = (1380 [254/2 + 100/2]+ 92.4 x 254) x 10^{-3}

= 244.3 + 23.5

= 267.8 kN.m

For composite cross-sections with structural steel grade S460, where the distance X_{pl} between the plastic neutral axis and the extreme fibre of the concrete slab in compression exceeds15% of the overall depth h of the member, the design resistance moment M_{Rd} should be taken asβ $M_{pl,Rd}$ where β is the reduction factor given in Fig. 5

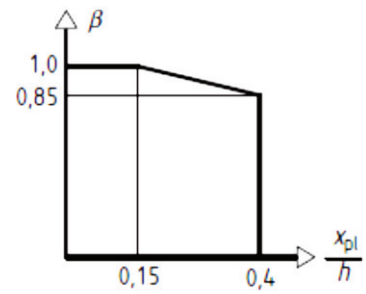

FIGURE 5. Reduction factor of plastic bending resistance

The predicted moment resistance M_{Rd} for specimen is calculated as 247.7 kN.m. The moment capacity is equivalent to moment capacity of bar steel of rolled steel section of size 406 x 140 x 46 where the moment resistance equal to 244.2 kN.m for S275 steel. As a results, the composite beam as boxed section CFS is expected to be able to replace the hot-rolled steel section. However, the actual strength of the proposed bealm c an be well understood if a full scale testing is carry out which will be conducted in a near future.

CONCLUSIONS

The composite beams as boxed section have been proposed in this paper. The proposal is done in order to solve the problem of low flexural capacity of CFS designed as non-composite. The proposed composite beam is expected to enhance the use of CFS as composite beam. The conclusions of the proposal from this research work can be listed as:

- The use of CFS section can improve the flextural strength of composite beam design using CFS section..
- The reinforcement bars used as link and tension reinforcement are expected to further stiffen the proposed beam and increase the flexural and shear resistance of the proposed composite beam system.
- The confinement contributed by concrete with stiffer proposed beam are predicted to decrease the local buckling of the proposed composite beam system.

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