PERFORMANCE OF AN INNOVATIVE PRE-CAST COLD-FORMED STEEL AS COMPOSITE BEAM WITH SINGLE AND DOUBLE C-CHANNELS

1ANIS SAGGAFF, 2MAHMOODMD TAHIR, 3TALAL AL-HAJRI, 4POI-NGIAN SHEK, 5MOHAMMADAMIN AZIMI

1Civil Engineering Department, Faculty of Engineering, Sruwijaya University, Indonesia, 2,3,4UTM Construction Research Centre (UTM-CRC), Faculty of Civil Engineering, UniversitiTeknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia, 5Department of Quantity Surveying, Faculty of Built Environment, UniversitiTeknologi Malaysia (UTM), Skudai, Johor Bahru, 81300, Malaysia
E-mail: 1rektor@unsri.ac.id, 2mahmoodtahir@utm.my, 3t-alfahed@hotmail.com, 4shekpoingian@utm.my, 5mohammadamin@utm.my

Abstract- This research investigates the structural behavior of simply supported composite beams, in which a ferrocement slab is connected together with cold-formed steel (CFS) beam by means of shear connector. This system, called Precast Cold-Formed Steel-Ferrocement Composite Beam System, is designed to rely on composite action between the CFS sections and Ferrocement slab where shear forces between them are effectively transmitted via shear connector's enhancement. CFS sections have been recognized as an important contributor to structures in the developed countries, and a sustainable ‘green’ construction material for low rise residential and commercial buildings. However, it still remains as insufficient data and information on the behaviour and performance of CFS in composite construction in composite action is yet to be established. One limiting feature of CFS is the thinness of its section that makes it susceptible to torsional, distortional; lateral torsional, lateral distortional and local buckling. Hence, a reasonable solution is resorting composite construction of structural CFS section integrated with reinforced concrete deck slab. An efficient and innovative beam system of built-up CFS sections acting compositely with a concrete deck slab has been developed to provide an alternative composite system for floors and roofs in buildings. In this study, ferrocement is an alternative solution by providing concrete deck as a slab. Experimental tests comprised of a total of six full-scale simply supported composite beams with variable parameters were tested to failure. The main variables considered in the study are the shape of section (I and C as CFS sections and Ferrocement slab where shear forces between them are effectively transmitted via shear connector's enhancement) and number of layers of wire meshes (2, 4 and 6 layers). Four points load bending system was used to test the specimens.

1. INTRODUCTION

Composite construction has become popular construction method in recent years. It has been largely accounted for the dominance of steel frames in many countries. Composite steel concrete beams are one of the ideal composite members in construction industry. Savings in steel weight, higher stiffness, longer span, speedy erection and fire resistance are some of the advantages in construction [1-2].

The construction industry of CFS sections has rapidly grown and has been recognized as key contributors in the developed countries to sustainable structures. In construction of low rise residential and commercial buildings, CFS is considered as a sustainable ‘green’ construction material. The thickness of CFS sections ranges typically between 1.2 mm to 3.2 mm Yu et al., [3]. Their usage however is primarily limited to framing, metal buildings, and racks [4]. However, one limiting factor of CFS is its thinness which makes it susceptible to torsional, distortional; lateral torsional, lateral distortional and local buckling [5]. The resistance of CFS sections to such instability problems could be well improved by using composite construction method. By attaching concrete slab to CFS section using suitable means of shear connectors, the concrete slab could absorb the compressive bending stress whereas the CFS section could remain under tension stress. Thus, the potential of buckling at CFS section is prevented.

An efficient and innovative floor system called Precast CFS-Ferro-cement Composite Beam System is introduced and experimentally tested in this paper. It is a built-up system by means of a shear enhancement between CFS sections and Ferrocement slab to act compositely. With Ferro-cement slab by means of shear transfer enhancements. This system could provide and suggest an alternative composite system for floors and roofs in medium and small size buildings. Ferro-cement is a form of thin reinforced concrete structure in which a brittle cement-sand mortar matrix is reinforced with closely spaced multiple layers of thin wire mesh or small diameter rods, uniformly dispersed throughout the composite matrix [6]. Ferro-cement has taken a significant place among components used for construction due to its durability, strength specifications and small thickness. This makes it a suitable component material to construct many lightweight structures.

Performance Of An Innovative Pre-Cast Cold-Formed Steel As Composite Beam With Single And Double C-Channels
II. EXPERIMENTAL PROGRAMME

Connections between structural steel elements are generally designed as pinned joint where the beam usually acts as simply supported beam. Therefore, a full scale simply supported composite beam test was used in this paper. The purpose of full-scale tests was to evaluate and determine the flexural strength and behavior of CFS-Ferro-cement assembled together as composite beam. The full-scale beam tests were often used to verify the results developed from the configurations adopted in the push-out tests [7].

2.1 Test specimens and arrangement

In this study, six composite beam specimens were tested and their detailed descriptions are summarized in Table 1. The composite beam specimen was 4500 mm long and spanned 4200 mm between supports as shown in Fig. 1. The width of the ferro-cement slab was 1500 mm with thickness of 50 mm. I-section was formed by placing two lipped C-channels back-to-back (Double) and single C-channel (Single) attached with the top flanges to ferrocement slab by shear connectors (bolts-12mm). Bolts of 12 mm diameter were used as shear connectors. The bolt was fastened to the top flange of CFS beam using two nuts. The welded fabric reinforcement (Skeletal) consisted of 5 mm diameter bars spaced 80 mm x 80 mm were installed either 2, 4 or 6 layers of wire mesh (1.2 mm diameter). According to the work done by Richard et al., [8], the use of wire mesh in the slab resulted to a higher flexural stiffness and capacity. The ferrocement slabs of all composite beams were cast utilizing the same batch of mortar to ensure that its properties are similar in all beam specimens.

Table 1: Details of tested composite beams

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Type of shear connectors</th>
<th>CFS thickness (l) mm</th>
<th>Number of Layers</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCS1(simple)</td>
<td>Bolt of 12 mm dia.</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>FCD1(double)</td>
<td>Bolt of 12 mm dia.</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>FCS5(single)</td>
<td>Bolt of 12 mm dia.</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>FCD5(double)</td>
<td>Bolt of 12 mm dia.</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>FCS9(simple)</td>
<td>Bolt of 12 mm dia.</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>FCD9(double)</td>
<td>Bolt of 12 mm dia.</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

![Fig. 1: Large-scale test arrangement – strain gauges and transducers (all dimensions in mm)](image-url)

2.2 Test set-up and procedures

Four-point load system was deployed. This system of loading produced a constant region of pure bending moment between the point loads. Hence, the ultimate flexural capacity of the proposed composite beam was determined. The specimen was subjected to two point loads applied at 1400 mm apart from the supports (Fig. 1). The spreader beam was buttressed by the specimen then the load from the jack was applied on it. Test specimen was supported with a pinned and a roller supports to indicate it was a simply supported structure. Deflections of beam specimens were checked at the center and quarter points using LVDTs. A bubble level was used to level up the transducers to read the best possible vertical displacements. The slip between CFS beam and ferrocement slab was also measured. At the mid-span section of the specimen, strain gauges were installed to evaluate the stress-strain relationship in the bottom, top flange of CFS beam, and top fibre of ferro-cement slab. Strain gauges were also used in ferro-cement slab to monitor its strain. The strain gauges were placed longitudinally in the direction of the span to measure the longitudinal (flexural) stresses. All measuring points were connected to a data logger. Figure 2 shows the test set-up. All instrumentations were connected to data logger. The specimen was loaded to one-third of the...
predicted load, then unloaded and all readings were zeroed. This procedure was carried out to ensure that the specimen is in equilibrium state prior to the actual test. Load increment of about 5kN was used so that gradual failure of the specimen could be checked. The specimen was loaded until substantial deflection was observed. The loading was carefully controlled by deflection (increment of 5 mm) since even a small load increment caused great increase in the deflection. Test was stopped when the failure condition of the specimen is reached. When abrupt failure occurred, a significant reduction in the applied load or substantial deformation of the specimen was observed.

The test specimen comprised of self-compacting concrete, the CFS section, bolts and wire mesh. Self-compacting concrete (SCC) was used to cast the slab. Concrete cylinders were prepared from the same batch.

### III. RESULTS AND DISCUSSION

The experimental results of full-scale composite beam tests are presented in table 2. The failure modes observed for all specimens can be broadly attributed to ferro-cement crushing and CFS buckling.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>$f_{ck}$ (MPa)</th>
<th>Ultimate Load, $P_u$ (kN)</th>
<th>Deflection at $P_u$, $\delta_u$ (mm)</th>
<th>Ultimate Moment, $M_{u,exp}$ (kN.m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCS1</td>
<td>35.2</td>
<td>97.6</td>
<td>136.6</td>
<td>68.3</td>
</tr>
<tr>
<td>FCD1</td>
<td>33.4</td>
<td>188.5</td>
<td>136.2</td>
<td>131.9</td>
</tr>
<tr>
<td>FCS5</td>
<td>35.4</td>
<td>186.5</td>
<td>127.8</td>
<td>130.5</td>
</tr>
<tr>
<td>FCD5</td>
<td>35.8</td>
<td>361.3</td>
<td>122.1</td>
<td>252.9</td>
</tr>
<tr>
<td>FCS9</td>
<td>35.9</td>
<td>215.1</td>
<td>114.4</td>
<td>150.6</td>
</tr>
<tr>
<td>FCD9</td>
<td>36.2</td>
<td>413.3</td>
<td>116.4</td>
<td>289.3</td>
</tr>
</tbody>
</table>

### 3.1 Effects of Different Parameters Wire Mesh Layers

Figure 3 shows the effects caused by varying number of wire mesh layers on the strength capacity of CFS-ferro-cement composite beam specimens. The strength capacity of the specimen increased as the number of wire mesh layers increased. Significant improvement was achieved when the numbers of layers increased from 2 to 4 to 6 layers. However, the improvement was less significant when the number of layers were increased from 4 to 6 layers. Figure 4 also shows that the relationship between the first crack and the number of layers is proportional. It experienced that the wire mesh layers can absorb the stresses inside ferro-cement slab. This clearly shows that by increasing the number of layers the first crack could be delayed.
Effect of Steel Thickness
It was observed that the strength capacity of specimen increases significantly when the thickness of CFS section increases from 2 mm to 3 or 4 mm. However, this increase becomes less significant when CFS thickness increases from 3 to 4 mm. This increase in the strength capacity of the specimens could be justified by the increase of moment resistance of bare CFS beam. As CFS thickness increases, the moment of inertia of CFS beams increases resulting in its higher moment resistance. The variation in strength capacity was less significant on the specimens when CFS thickness increased from 3 to 4 mm. This could be attributed to the ferro-cement slab crushing which occurred before CFS beam reached its yielding point.

CONCLUSIONS
Six full-scale composite beams were tested. Based on the test results and observations, the following conclusions can be drawn:
1. Test specimens with CFS of 3mm and 4 mm thickness failed due to ferro-cement crushing; the specimens developed primary cracks below the loading positions until failure. However, the failure mechanism differs from specimens with 2 mm steel thickness of the CFS, which failed due to a sudden buckling of the CFS section.
2. Test specimens with CFS of 2mm exhibited a similar mode of failure, which was initiated by the formation of transverse cracks in the ferro-cement followed by the tension yielding of the C-sections in the region of maximum bending moment.
3. Specimens using more layers of wire mesh enhancements increased the strength capacity and improvement in crack formation was noted. It can be concluded that the ultimate moment resistance and crack formation improvement of CFS-ferro-cement composite beam with 6 wire mesh layers is better than the ones containing 2 and 4 layers of wire mesh.
4. In full-scale tests CFS, I shaped specimens with 4 mm thickness carried 114.4% and 219.3% higher ultimate moment than the 3mm and 2mm thick CFS. This was expected, because capacity of the member increases with a higher thickness of CFS.

REFERENCES


