First International Conference on Construction in the 21st Century (CITC2002)
"Challenges and Opportunities in Management and Technology"
25-26 April, 2002, Miami, Florida, USA

STEEL COMPOSITE BEAM STIFFENED WITH C-CHANNEL

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ABSTRACT
Cover plate was known to be used as stiffener in composite beam to increase the bending capacity. The size of plate was cut according to the design needs. A new method of stiffening the composite beam is introduced in this paper by means of C-channel. This paper is to discuss about experimental study on the flexural behavior of steel-concrete composite beams. Three full-scale composite beam specimens were carried out at UTM laboratory. Two of the specimens with C-channel sections where the opening part facing downward and upward act as a stiffener were welded to the lower flange of the steel beam. The stiffened length was provided at the center part of the beam, enough to the increase the bending capacity of the beam. Full shear connection was provided at the steel-concrete interface. The beams were simply supported and were loaded by two point loads. Measurements of ultimate load and maximum deflection were made in order to obtain the complete picture of the behavior of the beams. The experimental work shown that the initial flexural stiffness, k_i, for stiffened beams were about 50% higher compared to the conventional composite beam. The ultimate strength of the composite beam was improved by about 45%. It was concluded that the composite beam stiffened with C-channel contributes to the strength and stiffness of the composite section, at both elastic and ultimate condition.

KEYWORDS
C-channel, Composite beam, Moment Capacity, Stiffness

1. INTRODUCTION

The significant of composite beam compared to the conventional steel design is the improved flexural performance. The saving in term of steel weight alone between the two methods can reach up to 50 per cent (Mahmood, et.al, 2000). Composite beam is designed for both ultimate limit state and serviceability limit state. In designing the composite beam for ultimate limit state, the design is usually based on plastic moment capacity of the composite section (Lawson, R.M., 1989). The moment capacity is usually calculated under plastic section analysis where rectangular stress block method is used. For a simply supported beam, the most critical check is usually excessive deflection (Johnson, R.P., 1994). For serviceability limit state the deflection depends on the flexural stiffness of the beam (*EI*), which is a product of the modulus of elasticity (*E*) and the moment of inertia (*I*) (Cain, J. A and Hulse, R., 1990). This paper realizes that any attempt to enhance the flexural performance of a composite beam must address these two limiting conditions. Therefore, it is by introducing the stiffener at the lower flange of the composite beam with C-channel section, the performance of the composite beam can be improved. The approach is assumed to increase the first moment of area and the moment of inertia of the composite section. The former increases the plastic moment capacity whilst the latter increases the flexural stiffness of the composite beams which subsequently reduce the deflection of the beam.

2. DESCRIPTION OF TEST SPECIMEN

The work involved flexural testing on three full-scale composite beams. The cross-section of the beams is shown in Fig. 1. The first specimen identified as specimen CB is a control specimen with no stiffener. The second specimen identified as specimen SB1 is a composite beam stiffened by C-channel with opening facing upward and the third specimen identified as specimen SB2 having C-channel as stiffener with opening facing downward. The steel beams and the C-channel used were locally produced by Perwaja Steel Sdn. Bhd. The concrete slabs were cast in Universiti Teknologi Malaysia. A local supplier, Industrial Hardware Supply Sdn. Bhd, delivered the shear connectors.

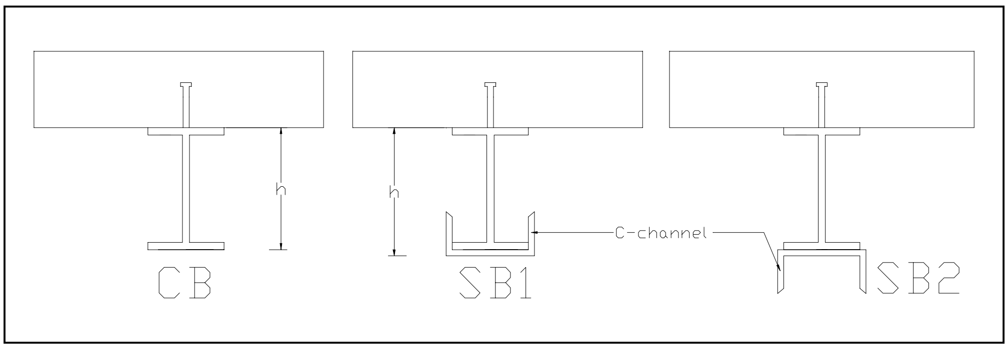

Figure 1: The Shapes of the Beams

The details of the specimens are given in Table 1. The concrete slab was designed for C30 or 30N/mm^2 of compressive strength. The width of the concrete slab was 1500mm and the thickness was 125mm. Transverse reinforcement of 0.9 per cent of the cross-section of the concrete was provided to prevent longitudinal splitting. Full shear connection was provided between the concrete slab and the steel beam. This has required an amount of sixty stud connectors, installed in each beam. The C-channel was welded to the lower flange of the steel beam through the whole length of the channel. The stiffening length was determined based on 'cut-off' length as in the design of cover-plated composite beam (Cook, 1977). Under that basis, the length of the C-channel must be long enough so that the unstiffened section can resist bending moment at the failure of the beam. SB2 is expected to have higher flexural capacity than SB1 due to the downward arrangement, which due to longer lever arm.

Table 1: The details of the Specimens

Specimen	Steel Beam	C-channel	Yield Strength, p_y (N/mm^2)	cube compressive strength, f_{cu} (N/mm^2)
CB	250 x 125 x 25.1 kg/m	-	275 (for both beam and channel)	30.4
SB1		152 x 76 x 17.9 kg/m		30.5
SB2				32.1

3. TEST PROGRAM

The beam's length was 6m with an effective length of 5.7m. The beams were simply supported at both ends and subjected to two point loads. Such loading was intentional to produce a region of pure bending moment at mid-span. The beams were laterally restraint at several points as shown in Fig. 2 to prevent any lateral torsional buckling. Stiffeners were welded at the steel web above the end supports to prevent crushing of the web. The loading was applied at an increment of 5kN for 3 minutes interval until reaching the elastic limit. The applied loading was then control by the deflection of every 2mm increment until failure.

Figure 2: Specimen in Test Rig

4. TEST RESULTS

Each of the specimens was tested to failure. Three linear vertical displacement transducer or LVDT were placed at mid-span to measure the vertical deflections. A graph of moment versus mid-span deflection and load versus mid-span deflection were plotted as shown in Figure 3, 4, 5 and 6 respectively. Significant increment in stiffness and moment strength of the stiffened beams compared to the conventional composite beam can be seen in Fig. 3 and in Table 2. It can be seen from Figure 3 to 6 and Table 2 that all beams exhibited good ductility where the deflections of up to 150mm were achieved. Beam SB2, which was expected to have higher moment capacity, was shown to have similar moment capacity as SB2. Both beams of SB1 and SB2 failed in an equal ultimate load. However, the initial flexural stiffness specimen SB2 value was 15 per cent more than specimen SB1. There was no longitudinal splitting observed at any stage of loading thus the beams were failed solely due to flexural stresses. The 0.9% of steel reinforcement used was sufficient to prevent the longitudinal splitting.

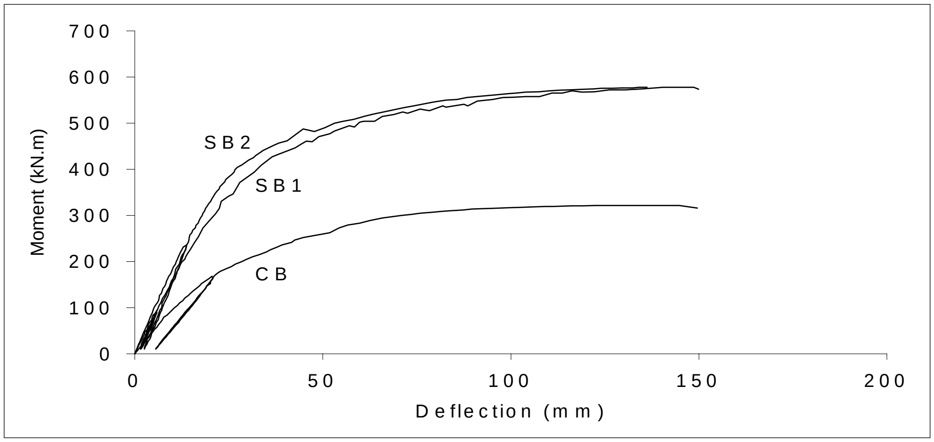

Figure 3: Plot of moment versus mid-span deflection for CB, SB1 and SB2

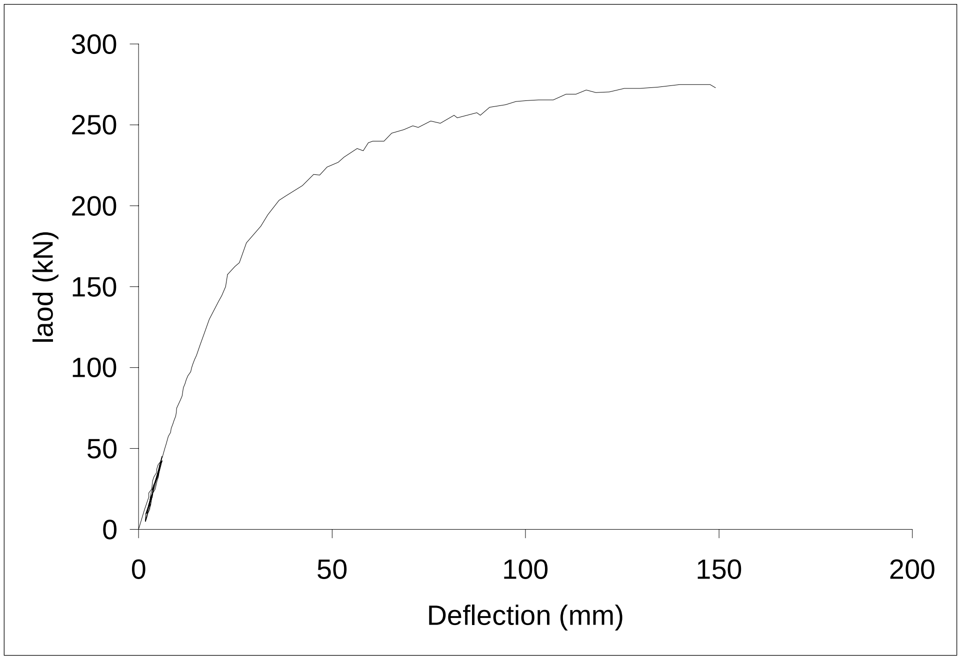

Figure 4: Plot Of Load Versus Mid-Span Deflection For CB

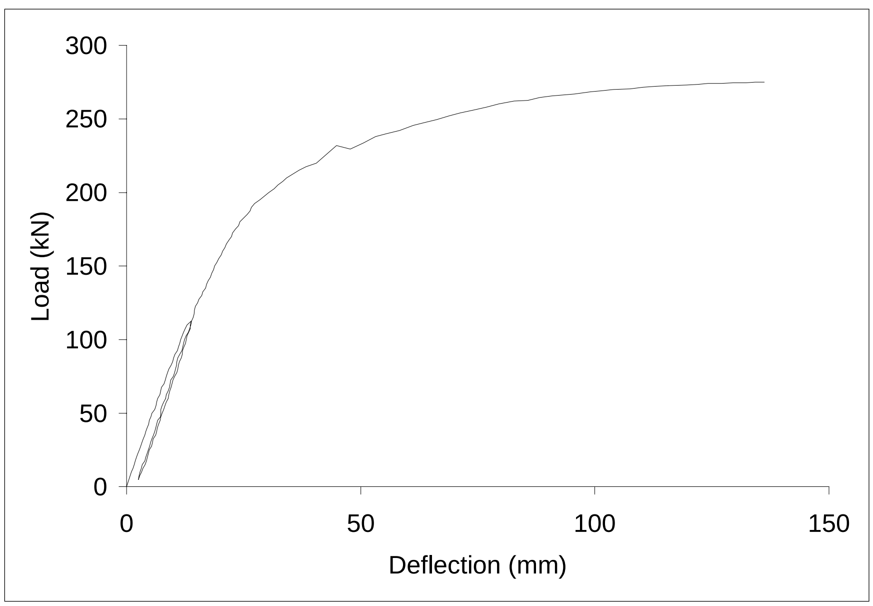

Figure 5: Plot Of Load Versus Mid-Span Deflection For SB1

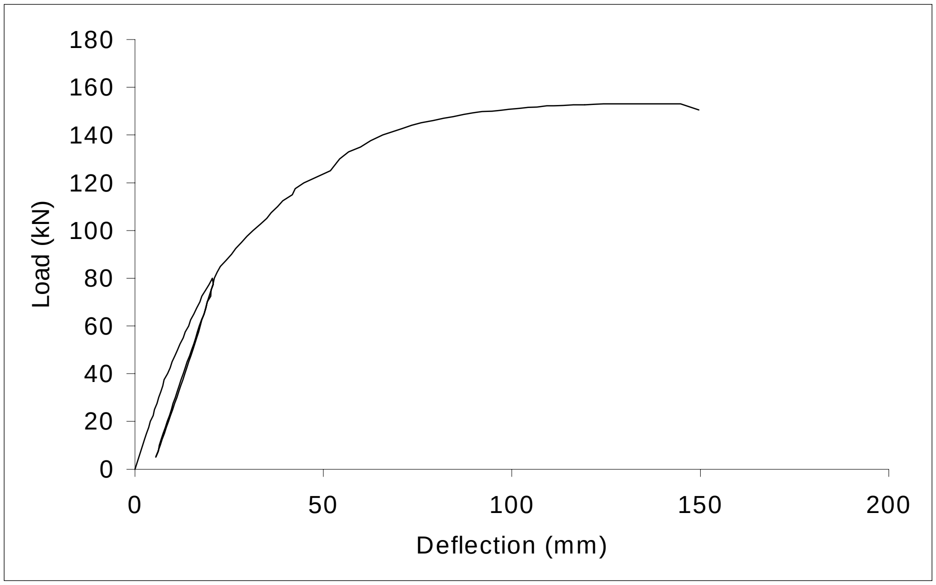

Figure 6: Plot Of Load Versus Mid-Span Deflection For SB2

Table 2: Test Results For Ultimate Load, Maximum Moment Capacity, Mid- Span Deflection, And Intial Flexural Stiffness.

Specimen	Ultimate load, *P* (kN)	Max. test moment, M_R (kN.m)	Mid-span deflection at M_R (mm)	Initial flexural stiffness, K_i (kN/mm)	Total beam depth, *h* (mm)
CB	150.5	316.5	149.8	3.85	248.0
SB1	275.0	577.5	149.9	6.9	254.4
SB2	275.0	577.5	138.5	8.1	348.0

Table 3: Test results of the ratio of unstiffened with stiffened specimens for moment, stiffness, and total beam depth

Specimen	Ratio of $M_R/M_{R(CB)}$	Ratio of $K_i/K_{i\ (CB)}$	Ratio of $h/h_{(CB)}$
CB	1.00	1.00	1.00
SB1	1.82	1.79	1.03
SB2	1.82	2.10	1.40

The initial flexural stiffness, K_i, is defined as the secant value measured at 50% of the ultimate test load (Lam, D. et.al, 2000). The increase in stiffness of SB1 and SB2 compared to CB of about 44% and 52% is very significant. The increase in depth of about 2.5% and 29% in order to achieve the increment of the stiffness is very minimal especially for the SB1 specimen. This shows that the effectiveness of the upward arrangement of the C-channel can be proposed as an alternative to the stiffening of composite beam using cover plate. More works need to be done to this area of research so that standardized design can be developed.

5. CONCLUSION

From the test results conclusions can be drawn as follows:-

1. Full-scale testing has shown that by stiffening the composite beam stiffened with C-channel, the stiffness and flexural strength of the beam can be increased.
2. The increase in stiffness of the composite beam can be represented by the increase in initial flexural stiffness, $k_{i,}$ in which the increment was about 50 per cent.
3. The increase in ultimate strength can be represented by the increase in maximum test moment, in which the increment was about 45 per cent.
4. The arrangement of C-channel, either downward or upward, has been found to have little influence on the overall behaviour of the stiffened beams.
5. The increase in maximum moment of about 54 per cent is accompanied by increase in beam depth of 29 per cent.

6. ACKNOWLEDGMENT

Both authors like to thank Perwaja Steel Sdn. Bhd. and Industrial Hardware Supply Sdn. Bhd. for supplying the materials in the work. Thanks also to the technicians of Dept. of Structure and Material of UTM for their assistance in the laboratory work. The second author would like to thank his employer,

UTM for allowing the study leave to complete his master degree. This work was part of IRPA Grant 72217 funded by the Ministry of Science and Environmental of Malaysia.

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