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RETROFITTING OF STRUCTURAL STEEL CHANNEL SECTION USING COLD-FORMED STEEL ENCASING CHANNELS BY FEM

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Abstract: The retrofitting technique using CFS section transforms the open-channel HRS section to a closed composite (HRS-CFS) section, thereby increasing its torsional rigidity to inhibit failure due to lateral-torsional buckling (LTB). The integrity of the HRS-CFS section was ensured by adequate spot welding of the CFS section to the HRS at regular intervals along the length of the member. This technique has the advantage of accumulating minimum residual stress (spot welding) in addition to reduced manpower required for section fabrication. The analysis will be carried out by finite element analysis over 28 specimens where 4 HRS and 24 HRS-CFS built up sections will be there with 3 different slenderness ratios L/4, L/6, L/10 & L/15 with two different thickness of cold form section i.e., 1.5mm & 2.5mm.
Keywords: cold-formed steel (CFS), hot rolled sections retrofitting, field welding, lateral torsional buckling (LTB)

1 INTRODUCTION

One of the major challenges facing maintenance engineers and asset managers is retrofitting of deteriorated steel structures especially while the structure is in service. Equally difficult is identifying sustainable retrofitting technologies that can be carried out at the site with minimal human effort. The difficulty further increases when finding an effective retrofitting technique for structural members that fail in lateral-torsional buckling (LTB) mode due to large unbraced lengths, or due to combined local and global buckling for members in which the element and member slenderness is not sufficiently low to prevent such failure. The mode of failure of a structural steel member is typically a function of the shape or geometry of the cross section. The cross-sectional geometry is, therefore, an important parameter to be considered while devising retrofitting strategies for weakened steel members. The old industries are now facing problems of steel structure i.e., buckling of member, bending of sections & etc. to overcome from those situations we are going to retrofit the hot rolled section which are commonly in used for steel structure as a beam or column with cold formed channel section and connection are made by spot welding at different interval and a FEM analyses is being carried out to measure the lateral torsional buckling of the sections. The retrofitting technique using CFS section transforms the open-Channel HRS section to a closed composite (HRS-CFS) section, thereby increasing its torsional rigidity to inhibit failure due to lateral-torsional buckling (LTB).

2 LITERATURE REVIEW

Sivaganesh Selvaraj, [11] a four-point bending test was carried out to examine the feasibility of using cold-formed steel (CFS) channel for retrofitting of open hot rolled steel (HRS) channels.

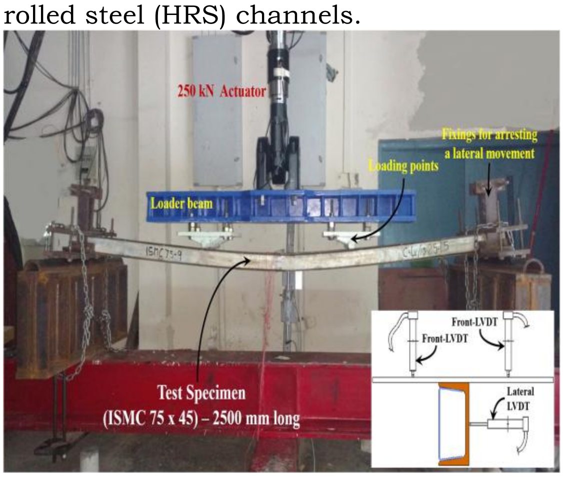

Fig.1. Four-point bending test arrangement (LVDT = linear variable displacement transducer) [11].

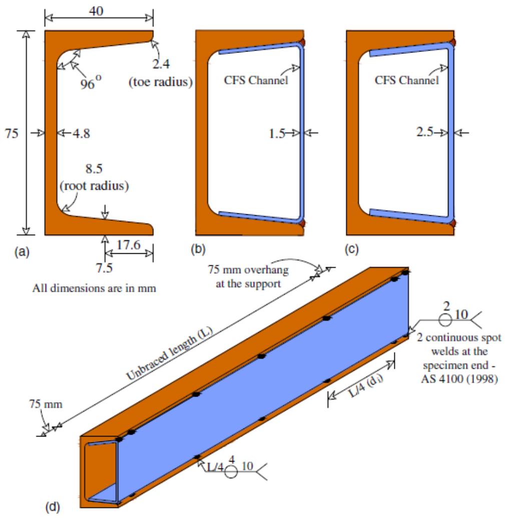

Fig.2. Test specimens: (a) control specimen; (b) retrofitted specimen with 1.5-mm-thick CFS channel; (c) retrofitted specimen with 2.5-mm-thick CFS channel; and (d) details of interconnection (spot welding) [11].

The cold-formed steel channels of appropriate size based on the size of the HRS channel were fabricated by press brake and inserted inside the HRS channel, resulting in the transformation of an open HRS channel to a closed built-up cross section. The connection between the HRS and CFS channels was made by spot welding (Ricker 1988; AISC 2002), such that they act together integrally. The proposed closed built-up cross-sectional specimen formed by the encased CFS channel to the HRS channel is shown in Figs 11 (a-d).

Selvaraj**,** (2016) An experimental study to investigate the stiffness and strength enhancement in a structural steel channel section strengthened by six different carbon fiber-reinforced polymer (CFRP) wrapping configurations is described in this paper. An approach of transforming the singly symmetric open section such as a channel section to a closed section by CFRP wrapping as a means to increase the stiffness and strength is demonstrated. Total of 21 specimens, both CFRP reinforced and bare steel specimens, were tested in four-point bending. Two different CFRPs, unidirectional and bidirectional fabrics, were used in wrapping the specimen. While the unidirectional layers contribute to the stiffness and strength, the bidirectional layer primarily contributes to confining the former in addition to increasing the resistance to lateral torsional

Buckling (LTB) of the specimens. The results indicate that the CFRP-strengthened closed sections confined by bidirectional fabrics are effective in enhancing the strength and stiffness compared to CFRP skin-strengthened sections (perimeter of bare steel channel sections overlayed with CFRP). The effectiveness of the closed section can be further improved by increasing the unidirectional CFRP layers prior to the final wrapping by bidirectional fibers. The variation in stiffness for all the CFRP configurations from the initial loading of specimens up to the ultimate is also investigated. This paper demonstrates that the strength and stiffness of steel channel sections can be significantly enhanced by means of appropriate CFRP wrapping configuration.

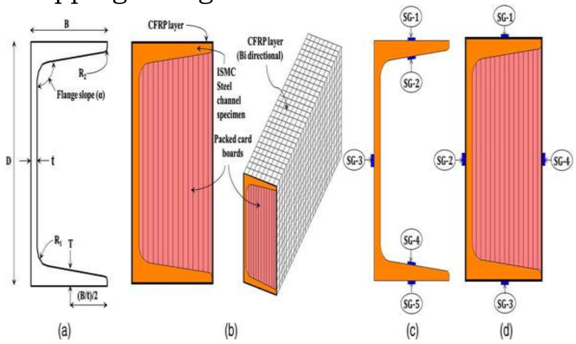

Fig.3. Test specimen: (a) cross-sectional dimensions of ISMC 75 specimen; (b) view of the ISMC specimen packed with cardboard and CFRP wrapping; (c) location of strain gauges at mid for wrapping configurations B, S_1U, and S_1B; (d) location of strain gauges at mid span for wrapping configurations C_1U, C_1B, C_1U_1B, and C_2U_1B [10].

The flexural behaviors of 21 channel specimens, strengthened by six different CFRP wrapping configurations, were studied under a four-point bending test. The findings from this experimental study have shown that the structural steel channel specimens can be effectively strengthened for flexural loadings using adhesively bonded CFRP layers. This improvement in strength is primarily due to the change in cross-section type by converting an open section such as a channel section to a closed section by means of an internal formwork using packed cardboard for wrapping of unidirectional CFRP layers, followed by wrapping of bidirectional CFRP layers to confine the former. The ability of the unidirectional CFRP layer to increase the strength and stiffness of the member can be enhanced by confining the same by means of bidirectional CFRP wrap resulting in no micro buckling or kinking of unidirectional fibers due to zero unbraced length. In addition, the bidirectional layer also increases the torsional stiffness of the doubly symmetric shell due to CFRP wrapping contributing to the resistance against LTB. The role of unidirectional fibers is akin to a main reinforcement (longitudinal) in a reinforced concrete structure. The bidirectional fibers provided over the unidirectional fibers play the role of stirrups, thereby confining the unidirectional fibers to ensure that they stay in place, resisting the axial stress that arises as a result of bending, thus enhancing the load-carrying capacity. In addition, the following conclusions can be drawn:

- The skin strengthened wrapping configurations S_1U and S_1B behave similarly to the control specimen B, indicating that the skin reinforcement has no significant effect in improving the Strength and stiffness of open channel sections.
- Configuration C_1U failed due to delamination at the initial stages of loading due to inadequate resistance offered by one layer of unidirectional fibre to adequately confine the cardboard and to maintain the shape of the closed section. Among the six various CFRP wrapping configurations, C_2U_1B (doubly symmetric closed-shell CFRP wrapping with two unidirectional layers followed by one bidirectional layer) have the maximum strength and stiffness gain of 25 and 69%, respectively, compared with the control specimen.

Jan Vale- (2017) the author describes two methods of FEM modelling of I-section beams loaded by bending moments. Series of random realizations with initial imperfections following the first Eigen mode of lateral-torsional buckling were created. Two independent FEM software products were used for analyses of resistance. The aim of the author is to carry out a stochastic analysis of load-carrying capacity of steel beams subjected to bending. A series of simply supported IPE200 beams are analyzed with respect to lateral-torsional buckling, which is a stability phenomenon that occurs when an unrestrained member is subjected to moment loads. The analysis is carried out by using geometrically and materially nonlinear imperfect analyses (GMNIA) so the effects of all initial imperfections can be taken into account.

Three different values of non-dimensional slenderness according to [12] are considered in this analysis:
Table no. 1 shows the relation between non-dimensional slenderness and length considering nominal material characteristics and cross-section dimensions.

Table1. Non-dimensional slenderness and beam length.

Slenderness	length
0.3	0.73 m
0.6	1.55 m
1.2	3.86 m

The commercial software program ANSYS [14] has been used for the finite element analyses using solid elements. The beams are modelled using the element SOLID185. It is an 8-node homogeneous structural solid element that is suitable for 3D modelling of solid structures. It has large deflection and large strain capabilities, plasticity, hyper elasticity, stress stiffening and creep. The enhanced strain formulation was considered. This formulation prevents shear locking in bending-dominated problems and volumetric locking in nearly incompressible cases. The element introduces nine internal degrees of freedom to handle shear locking, and four internal degrees of freedom to handle volumetric locking. All internal degrees of freedom are introduced automatically at the element level and condensed out during the solution phase of the analysis.

10 elements per flange width, 20 elements per web height and 2 elements per as flange as web thickness are used. Number of elements in the x-direction is not constant per length (non-dimensional slenderness). It was calculated in such a way that the maximal aspect ratio of the longest and shortest edges of an element does not exceed the maximal acceptable aspect ratio for quadrilaterals according to [13]. Boundary conditions are created the

same way as in the Abaqus model. There are three kinematic coupling constraints on both ends of the beam: two of them are for edges of the flanges, one is for the web axis, see Fig. 4

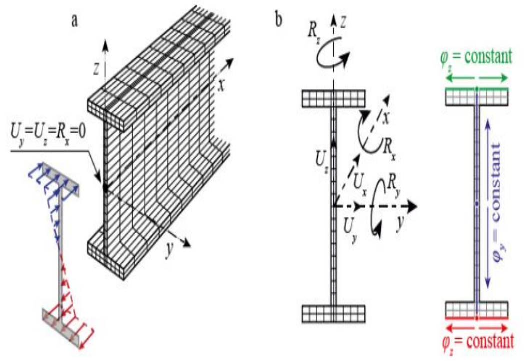

Fig. 5. Ansys solid model (a) loading; (b) kinematic coupling constraints.

The pure bending moments Mon both ends are applied as a surface load in the form of pressure p. The gradient of pressure is defined by a slope value (a ratio between moment M and second moment of area Iy) and ordinate z which represents the slope direction. Thus, the magnitude of pressure is given as p= M z/ Iy. The distribution of pressure is schematically illustrated in Fig. 4. Result defined by author is Analysis of load-carrying capacity of steel beams subjected to bending was carried out. The analysis was performed in two ways: with and without considering the residual stress. Mean values of load-carrying capacity of Abaqus shell models are higher than those of Ansys solid models, approximately 2-6 % the difference in the intermediate slenderness range, where it is well-known that imperfections influence the load carrying capacity the most (due to the member failing through in-elastic buckling) is negligible.

Selvaraj, (2017) Test study on simply supported built-up beams (plate on top of a channel section) with two different strengthening approaches using carbon fiber reinforced polymer (CFRP) fabrics by external bonding namely flange strengthened and modified cross section strengthened has been conducted. The study specimens simulated the flange restrained C-channel sections in lateral bracing of steel bridge superstructure and steel storage structures. A total of seven different strengthening configurations were made based on the two strengthening approaches. The results indicate that the flange strengthening approach is not an efficient method of retrofitting open cross section specimens with longer length compared to the modified cross section strengthening method with in filled core which significantly improved the flexural strength. In addition, the results indicate that with an increase in a number of confinement wrap using bidirectional CFRP fabrics the wrinkling can be prevented. The results also indicate that depending on the magnitude of camber imperfection (initial bent about major axis) different failure modes of CFRP can be observed.

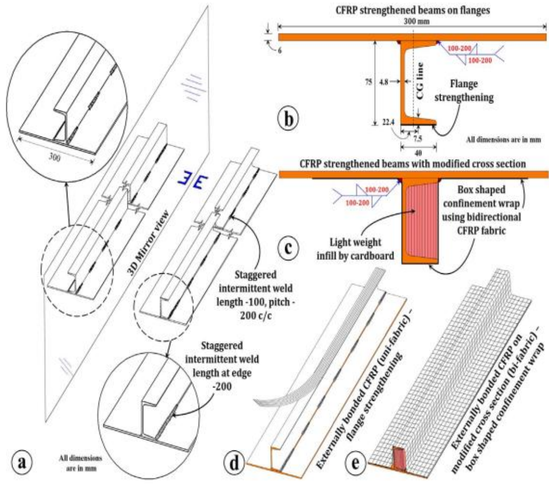

Fig.10. Built-up test specimen fabrication: (a) 3D normal and mirror view welding details; (b) Cross sectional view of the flange strengthening specimen; (c) Cross sectional view of the modified cross section strengthening specimen; (d) CFRP bonding method on flange strengthening specimens; (e) CFRP bonding method- box shaped confinement wrap [9].

The test results for long beams externally bonded with CFRP on flanges and after cross-section modification by a cardboard core have been presented. The strengthening approach developed in the present investigation was to increase the strength of the existing member (weakened), rather than replacing it. The following conclusions can be drawn from the present investigation.

A. It was validated that the approach of flange strengthening may not be effective in improving the ultimate strength of long open cross section beam and its associated failure modes.

B. The flange strengthening of open cross-section long beams can be made effective if the cross-section of the open channel section is transformed into a closed one.
C. The modified cross-section specimen with one layer of externally bonded unidirectional CFRP fabric on the bottom flange and one box-shaped confinement wrap using bidirectional CFRP fabric has resulted in an increased strength of the long beam by 14.3% compared to the control beam, which further improved to 26.4% after the number of unidirectional fabric layers on the bottom flanges increased to three.
D. The modified cross-section strengthened specimens improved the ultimate moment of the long specimen by a maximum of 32.2%.
E. The increase in the number of layers or thickness of the bidirectional confinement wrap may be a remedy to prevent wrinkling of CFRP fabrics.

3 CONCLUSION

A. The retrofitting method using the CFS channel improved the Flexural strength of the HRS channel by maximum of 29, 53, And 60% for slenderness of 46, 63, and 80, respectively. The performance improvement in the retrofitting scheme was based on the thickness of the CFS channels used.
B. The open cross-sectional (singly symmetric) HRS channel, which failed due to lateral bending and twisting, was effectively retrofitted by inserting a CFS channel inside the HRS section. The cross-sectional transformation has increased the torsional constant of the channel member (control specimen) by 29 and 40 times, respectively, for 1.5- and 2.5-mm thicknesses of the encased CFS channels. The shift in the shear center toward the CG could have also contributed to the inhibition of the LTB mode of failure.
C. The larger weld spacing affected the performance of the retrofit scheme due to local buckling of the flanges of the CFS channel. Expressions in the form of minimum flange plate slenderness as a function of the HRS channel global major axis slenderness and weld spacing in the CFS section are provided to avoid local buckling of the CFS channel in the built-up member.

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