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Lateral buckling behavior and strengthening techniques of coped steel I-beams

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ABSTRACT

An experimental study of the inelastic lateral torsional buckling of coped beams with simply supported ends is presented in this paper. Six full scale coped steel I-beam tests were conducted. The test parameters include the aspect ratio of cope length to beam depth at coped region as well as the ratio of cope depth to beam depth. The results of experimental tests were compared with finite element model results. The test results showed that a reduction in the inelastic buckling load due to coping could reach more than 60% of the uncoped buckling capacity. A group of twelve finite element models for steel coped beams is investigated. A comparison between uncoped models and coped models with different geometrical parameters is performed. The finite element results showed that both the cope length and cope depth have a significant influence on the lateral torsional buckling capacity. A parametric study of coped beams with stiffeners at coped region is reported in this paper. Based on the results of coped beams strengthened with either horizontal or vertical stiffeners, it is found that for cope depth to beam depth $(d_c/D) \geq 0.25$; both horizontal and vertical stiffeners are required to prevent local web buckling at the coped region.

1. Introduction

In steel construction, when beams are connected to girders at the same elevation, beam flanges must be coped to provide sufficient clearance for proper attachment as shown in Fig. 1. Beams can be coped at the top, bottom, or at both flanges. When a beam is coped, the lateral torsional buckling of the beam will be affected [1]. Cheng and Snell [2] carried out both experimental and analytical studies on elastic lateral buckling of coped beams. Very little experimental data are available regarding inelastic lateral buckling of coped beams. Michael and Lam [3] studied experimentally the effect of inelastic buckling of coped beams, and compared the results with the theoretical results by Cheng and Snell [2]. They found the maximum reduction in strength due to the effect of residual stresses and initial imperfections to be 35% for short and braced specimens. Maljaars et al. [4] presented numerical models to study the effect of lateral torsional buckling to coped beams with end plates. They recommended not using stocky beams with large copes in combination with short end plates, as this gives the largest reduction of the ultimate buckling resistance of all studied connections. Michael C.H. et al. [5] presented an experimental study of the strength and behavior of reinforced coped beams. They recommended that for a coped beam section with a larger d/t_w ratio, a stiffener arrangement consisting of longitudinal and transverse stiffeners is recommended. Michael C.H. et al. [6] proposed reinforcement details accounted for the effects of various cope details and the results show that the reinforcements were able to increase the capacity of the coped beam specimens.

Cheng et al. [7] studied both lateral and local buckling of coped beams, as well as possible strengthening of coped region. They recommended using stiffeners at the coped region in order to improve the buckling strength of coped beams. However, no theoretical data are available for stiffening coped I-beams for inelastic lateral torsional buckling.

An experimental study of coped I-beams under two symmetrical point loads is considered herein. The effect of coping on the type of failure of coped beams is also studied. Six tests are conducted for coped beams with different coping details. Fig. 2 shows the coped beam details. Finite element analyses of all test specimens are also presented in this paper. A parametric analysis of coped beams for inelastic buckling behavior is presented herein and is developed to investigate the influence of stiffened copes on coped beams lateral buckling resistance.

In light of these investigations, a finite element analysis methodology has been developed to investigate the influence of cope depth and length ratios. The results of the parametric study along with general recommendations are also presented.

2. Problem statement

The study of the elastic lateral torsional buckling of coped beams by Cheng et al. [7] investigated only coped beams under mid-span point load. Study of two symmetrical point loads is taken into consideration

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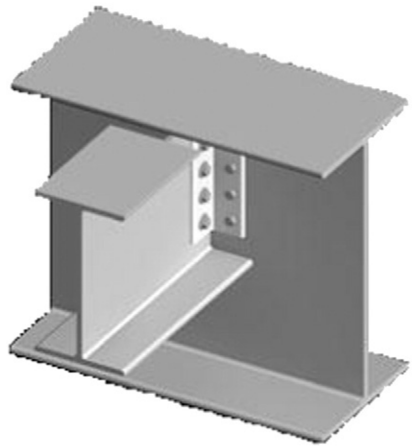

Fig. 1. Typical coped beam-to-beam connection.

in this study both experimentally and numerically. It also discusses the effectiveness of using different types of horizontal and vertical stiffeners for strengthening coped beams using finite element analysis.

3. Test program

3.1. Tested coped beams

Six tests were conducted to study the inelastic lateral torsional buckling strength of coped beams loaded at their flipped top flanges of the beams. The copes and connection details are shown in Fig. 3. Built-up sections with web 200 × 5 mm and flanges 125 × 8 mm of nominal yield strength of 345 MPa were investigated. All specimens have beam length of 3000 mm. The beam sections were selected to have limits of section compactness according to the AISC [8] specifications. The cross section is in the compact zone where $M_p < M_n < M_r$. The unsupported length L_b is kept between L_p and L_r to ensure the occurrence of inelastic lateral torsional buckling. The nominal strength "M_n" for lateral torsional buckling in the inelastic range is approximated as a linear relationship between points (M_p at L_p) and (M_r at L_r). The beam cross sections are classified as compact sections ($d/t_w = 40 < 3.76\sqrt{\frac{E}{F_y}} = 92.8$, $b/t_f = 7.5 < 0.38\sqrt{\frac{E}{F_y}} = 9.375$) to insure avoiding local web and flange buckling in the failure mode. The nominal measured dimensions are given in Table 1. Test beams have designations as described below:

180-B-0.25

C"cope length" - Beam - d_c/D"cope depth to beam depth"

The uncoped specimen is used as a pilot test for comparison with other coped types. Specimens 120 and 360-B-0.25 have the same cope depth but with different cope lengths. Conversely, 180-B-0.1 to 0.50 have the same cope length but with different cope depths. In order to minimize the end restraints, a conservative pined ended condition is assumed. A double clip angle connection is used in the tests as shown in Fig. 3. The clip angle was bolted between the web of the coped beam and that of the main girder. The size of the clip is 80 × 80 × 6 mm. It should be noted that the clips were bolted on both sides of the web. Two bolts grade ASTM A325 with nominal diameter 16 mm and 70 mm spacing in between were used for connection of the coped beams. The average tensile yield strength of the clips was 345 MPa and the average elastic modulus of clips and beams is 210,000 MPa.

3.2. Test setup

The test setup is shown, schematically, in Fig. 4 and in test lab in Fig. 5. The main girder that is supporting the coped beams has a web of 300 × 5 mm and flanges of 150 × 10 mm. This girder is 1000 mm in length. Vertical stiffeners with thickness 12 mm were placed at 1/3 and 2/3 of the main girder span. A distributer beam, (web 250 × 5 mm and flanges 150 × 10 mm), is used to apply the two concentrated loads on the tested beam. Transverse web stiffeners were used to strengthen the distributer beam at the loading positions.

The load is applied to the bottom flange of coped beam vertically upward, where the beam is flipped upside down. It was meant to have the beam in this position to avoid direct loading on the compression flange. A 200 kN tension loading cell was applied directly to the distributer beam by connecting the jack head and the distributer beam using a supporting system as shown in Fig. 6. For loading cell, 4-M24 anchors ST A36 were used as shown in the figure. Other two supporting plates were used with dimensions 200 × 400 × 25 mm and of nominal yield strength of 240 MPa. A steel rod with a diameter of 30 mm ST A36 is used to connect the distributer beam with the coped beam, see Fig. 6. This tie rod is designed not to have local deformations or bending. The local web buckling of the specimen at this location was also checked to prevent any excessive stress on the specimen web plate. The load is applied quasi-statically at intervals of 2.5 kN each and the load cell was used to measure the applied vertical loads.

3.3. Instrumentation

The in-plane deflection and lateral displacement of the tested beams were measured using six dial gauges as shown in Fig. 7. Two dial gauges were placed near the coped end to record the lateral and vertical movements of the beam. Another two dial gauges were placed at the loading position as well as two dial gauges at mid-span of the tested beam to measure lateral and vertical displacements. Three longitudinal strain gauges were mounted on the beam web near the end of the cope. Another two strain gauges were installed, to the web at beam mid-span, for comparison of the strain distribution across the beam depth as shown before in Fig. 4.

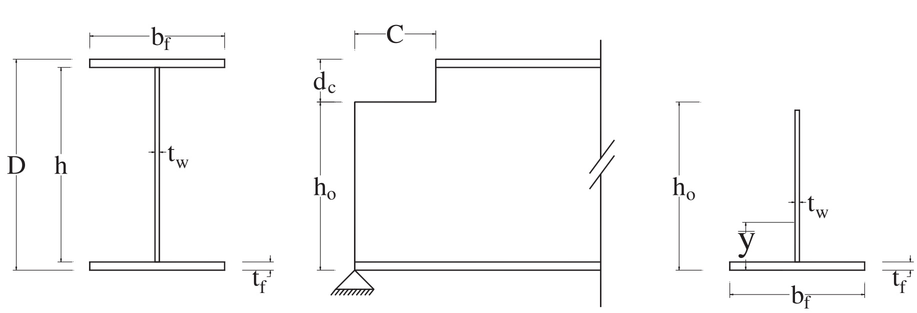

Fig. 2. Cope details designation "After Cheng and Yura" [5].