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Design of aluminium beam ends with flange copes

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ABSTRACT

This paper presents the results from an experimental investigation of the capacity of coped aluminium beam ends. Various tests were performed on top flange-coped I-beam ends loaded by a reaction force on the bottom flange and on top flange-coped and double flange-coped beam ends supported with end plate and web angle connections. The effects of the cope length and depth, the beam end moment and the buckling restraints from the connections were investigated. A design model for the top-coped beams supported on the bottom flange was proposed. Various capacity predictions from existing models for triangular brackets and models for coped steel I-beams were compared with the test results and were shown to provide reasonable results.

1. Introduction

Copes can be used in beam ends to enable the members of a structural frame to fit together at the joints or to connect beams at the same elevation. For I-section beams, coping normally implies the removal of one or both flanges and a part of the web.

Fig. 1 provides examples of coped beam connections. Flange coping reduces both the strength and stiffness of the beam end because it produces either a tee-shaped or a rectangular reduced section. The cope introduces a complex stress configuration in the beam web, with stress concentration at the cope corner, and without the support of the flange in the cope region, the web is less stable and may buckle due to an applied reaction at the beam end.

The present investigation was initiated by a design problem for a gate structure in a hydropower dam. Light-weight rectangular gates were constructed from extruded aluminium I-beams with a relatively thin web. Due to the height limitations of the C-shaped gate guides in the concrete dam, the beam ends had to be coped as shown in Fig. 1d. The structure could not be strengthened by welding stiffeners at the cope regions due to the large number of beams and the unfavourable HAZ softening that occurs when welding aluminium.

Several types of failures must be considered when designing coped beams. Locally at the beam end, a check of the yield resistance to bending moments and shear forces acting on the reduced cross-section (tee-shaped or rectangular) must be performed. Other local failures are block shear failures in the beam web around groups of bolts or welds and web buckling. A global failure may occur by lateral-torsional buckling of the entire beam in the case of a laterally unbraced beam with reduced stiffness properties at cope regions. An overview of investigations of coped beams was given by the present author in [1], which addressed seat-supported top-coped I-beams in structural steel. Recently, Yam et al. [2] published a comprehensive state-of-the-art review of various design issues related to coped beams.

Essential investigations of the local web buckling capacity of coped beam ends can be found in [3–5]. Experimental and numerical investigations were performed on steel beams and covered various cope sizes in combination with typical building connection types, e.g., partial end plates and web angles. Both Cheng and Yura [3] and Yam et al. [4] developed design models for the web buckling of top flange-coped beam ends, whereas Cheng [5] considered double-coped ends. The latter presented simulations and analytical models but no experimental results. The design recommendations of [3,5] were adopted in the AISC Manual of Steel Construction [6]. No investigations addressing coped aluminium beams were found in the literature. Because structural aluminium has an elasticity modulus equal to one-third of that of steel and possesses a different material hardening, the applicability of the existing models requires consideration.

Compared with the coped beam end designs discussed in previous studies [3–5], the design concerns of the seated beam ends (Fig. 1d) entail two additional difficulties. One difficulty is related to the lack of lateral support and rotational restraint along the vertical edge of the beam web at the end of the beam, where

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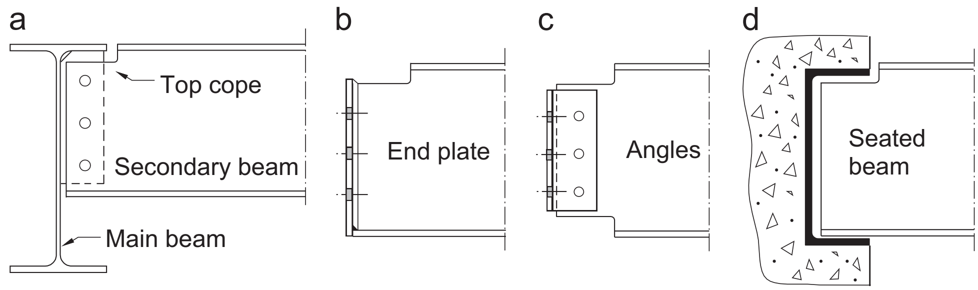

Fig. 1. Examples of coped beam connections.

such support would normally be provided by a regular beam shear connection. The other difficulty is related to the position of the beam end reaction force, where the reaction is applied under the bottom flange of the beam instead of along the vertical edge of the web via the components of an actual connection. Both issues enhance the buckling tendency of the beam web. Thus, a test program was designed to provide solutions relevant to the case at hand. To extend the scope of the investigation, the program was extended to include beam ends with more common connections such as end plates and web angles. Two specimens with a cope at both the top and bottom flange were also included.

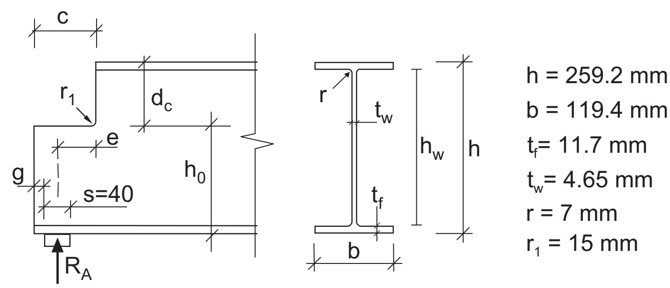

Fig. 2. Seated beam end.

2. Test specimens and setup

The test setup utilised in the present study was described in [1]. The present aluminium beam has a lower stiffness, and the conditions and properties of the test arrangements are important; thus, the main procedures are repeated.

2.1. Beam end design for seated beam ends

The investigated beam end design is shown in Fig. 2, with a definition of the cope geometry and the cross-sectional dimensions of the test beam. The cope has a length c and depth d_c.

In the basic setup for the tests on the seated beam ends, the beam end was supported on a steel block $s=40$ mm wide on a cylindrical roller bearing (Fig. 3). The beam reaction R constitutes the load. An overhang $g=10$ mm was used outside the support block. Uncoped beam ends were tested under the same support conditions. The main idea behind the simple test arrangement was to ensure a well-defined force application point.

2.2. Test beam

An extruded aluminium beam with an I-shaped cross-section was used for all tests. The beam had a nominal height of 260 mm and a web thickness of 4.6 mm. The measured dimensions are given in Fig. 2. The beam was a section XHP260 produced by Hydro Aluminium using aluminium alloy EN AW-6082 temper T6 [7]. The slenderness of the web, given by the ratio h_w/t_w, was 51, which means that the web was quite slender.

The material properties were determined from standard tension tests. Test coupons were taken in the longitudinal direction for the flanges, whereas coupons from three directions were used for the web. The obtained material curves were typical for the chosen alloy and heat treatment, i.e., with gradual yielding and minimal hardening. Ref. [8] shows a similar material curve. A certain anisotropy was observed in the web, as illustrated by the mean values $f_{02}=258$ MPa and $f_u=297$ MPa in the longitudinal (extrusion) direction, $f_{02}=244$ MPa and $f_u=279$ MPa in the 45° direction, and $f_{02}=270$ MPa and $f_u=306$ MPa in the transverse direction. Moreover, the longitudinal yield strength of the web material varied along the web height, from $f_{02}=263$ MPa at the middle to $f_{02}=235$ MPa near the fillets. Strengths of $f_{02}=237$ MPa and $f_u=282$ MPa were obtained for the flanges. The strain at ultimate strength was in the range of 6–8%.

In all resistance calculations in the following the yield strength f_{02} is taken as 258 MPa, which represents a mean value within the web.

2.3. Test rig

The test rig is illustrated schematically in Fig. 3. The test beam was supported on cylindrical bearings at points A and C, which were 1800 mm apart. A concentrated load (P) was applied under displacement control (1 mm/min) by a hydraulic actuator at a distance of 600 mm from the coped end (A). The reaction force (R_A) at the coped end was measured with a load cell.

Vertical web stiffeners were placed under the actuator, and the beam was braced by lateral support frames at the actuator (point B) and at support point C. The bottom flange of the beam was restrained sideways at support point A. The extension of the beam length beyond point C varied, but was at least 1 m. The support at point A was placed on a bracket bolted to a stiff reaction wall. This wall was later used as a support wall for the specimens with bolted connections (Section 4).

An optical displacement transducer was used to measure the vertical displacement w of the top flange at the coped end, measuring toward a small plate extending from the flange. The recorded displacement thus represents the decreasing distance between the top and bottom flange due to web deformations and buckling.

2.4. Cope geometries and web imperfections

Five cope geometries were tested for the seated beam end configuration: three lengths (c) and three depths (d_c), as listed in Table 1. The length of the longest cope was equal to the height of the beam section, i.e., 260 mm, whereas for the deepest cope, the depth was equal to half of the beam section height. The copes were cut by saw and machined to a radius $r_1=15$ mm at the corner (Fig. 2).