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Original Research Article

Elastic stiffness of reverse channel joint web components under bolt tension

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ABSTRACT

Reverse channel joint is a convenient method to make connection between steel beam and steel tubular column (with or without concrete infill). This paper presents analytical solutions for evaluating the elastic stiffness of reverse channel joint web component under bolt tension. The design parameters that affect the reverse channel web elastic stiffness include bolt position, edge distance, number of bolt rows, pitch between the bolts, depth of the reverse channel's flange, and type of the reverse channel. Starting from the load-deflection solution of an infinitely long plate with simply supported edges under lateral point load, this paper makes a number of simplifying assumptions to deal with the various issues of using practical reverse channel webs. These issues include finite length of reverse channel, rotational restraint from the reverse channel flanges, realistic reverse channel profile and more than one row of bolts. This paper presents validation for each simplification by comparing the analytical solutions with numerical simulation results using the general finite element software ABAQUS.

Accuracy of the final formulations was checked against available experimental results, some of which were carried out by the authors. For comparison, extensive numerical simulations were carried out to cover all possible ranges of practical design parameters, which included number of bolt rows, bolt positions (pitch, gauge, end/edge distances), reverse channel type (cut from square tube with equal flange/web thickness, cut from rolled channels with thicker flange/thinner web) and reverse channel dimensions (length, web width, flange width, thickness).

In all cases, the proposed analytical solution was shown to give sufficiently accurate results.

1. Introduction

Reverse channel is a newly developed connection for both steel and concrete filled tubular sections. Fig. 1 shows a sketch of this type of connection. Using a reverse channel, the difficulty of accessing inside the steel tube is avoided. This type of connection has recently been studied by some researchers (Ding and Wang [1], Jones [2], Malaga-Chuquitaype and Elghazouli [3], Elsawaf et al. [4], Liu et al. [5], Li [6], Elsawaf and Wang [7], Huang et al. [8], Wang and Xue [9], Jafarian and Wang [10–13], and Lopes et al. [14]) in which the performance

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Notations

a	surface flat length (mm)
a_t	gauge distance between bolts (mm)
b	length of plate (mm)
D	plate rigidity (kN/mm)
d_f	depth of the flange of reverse channel (mm)
e_1	edge distance (mm)
e'_0	edge distance on the longer side (mm)
E_s	Young's modulus of steel (N/mm^2)
$K_{initial}$	reverse channel initial stiffness
k_r	side wall rotational stiffness
p	pitch between bolts (mm)
r	root radius (mm)
t_w	channel web thickness (mm)
t_f	channel flange thickness (mm)
u_i	load distribution in X-direction (mm)
v_i	load distribution in Y-direction (mm)
W	channel width (mm)
w_i	reverse channel web deflection (mm)
x	distance to the edge of the flat surface of the reverse channel web (mm)
δ_{ij}	deflection in bolt i under load in bolt j (mm)
Δ_i	overall deflection in bolt row i (mm)
ϑ	Poisson's ratio

of this type of connection under static, dynamic and elevated temperature conditions was investigated. In particular, the experimental results of Wang and Xue [9] indicate that using reverse channel and extended endplate connection can provide semi-rigid and partial-strength connection behaviour according to the definition of Eurocode 3 (EN 1993-1-8).

The experimental results of Ding and Wang [1] also show that reverse channel connection can accommodate a high level of rotation owing to supreme deformation capacity of the reverse channel web, and can also provide a good level of resistance under tension in the connected beam. These features are essential needs for a connection to prevent the structure from sudden failure [15] under extreme loading conditions.

In order for frame design to take advantage of the rotational rigidity of the connection in semi-rigid design, it is necessary to be able to calculate the connection rotational stiffness [16]. Within the framework of Eurocode [22], the component-based method is preferred. In the component-based method, the load-deflection behaviour of each connection component should be available. Among the above-mentioned studies performed on reverse channel connections, Malaga-Chuquitaype and Elghazouli [3], Liu et al. [5], Heistermann et al. [17] and Li [6] have made some attempts to provide information for this component behaviour.

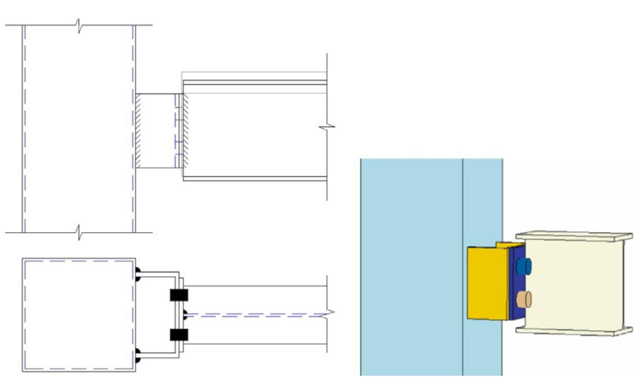

Fig. 1 – Typical reverse channel connection [7].

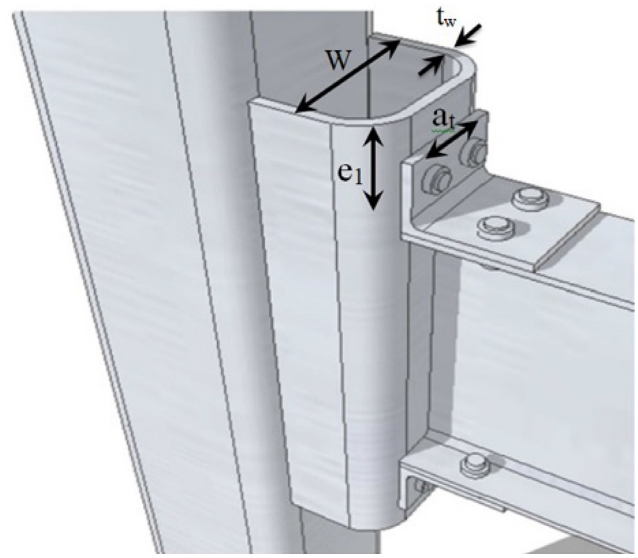

Fig. 2 – Connection used by Malaga-Chuquitaype and Elghazouli [3].

The formulation suggested by Malaga-Chuquitaype and Elghazouli [3] was based on regression analysis of numerical results for a small number of configurations and suffers from the limitation of not considering many of the parameters which affect the connection stiffness. Refer to Fig. 2, their proposed solution is:

$$K_i = \frac{\pi E_s t_w^3}{12(1-\vartheta^2)C_t((W)^2/4)} \quad (1)$$

where W is the channel width; t_w is the channel thickness; ϑ is the Poisson's ratio; E_s is the Young's modulus of steel and C_t is the a coefficient (=0.18 based on FE results).

As can be seen from Eq. (1), the formulation does not take into account influence of the following parameters:

1. Bolt position;
2. Edge distance;
3. Additional bolt rows;
4. Pitch between the bolts;
5. Depth of the reverse channel's flange;
6. Type of the reverse channel.

Despite these shortcomings, Liu et al. [5] further used Eq. (1) as the basis of their work. They proposed a further regression factor to include the effects of the gauge between the bolts and the edge distance. Their modified equation is:

$$K_i = \frac{\pi E t_w^3}{6(1-\vartheta^2)C_t((W-t_c)^2/4)} \quad (2)$$