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Behaviour and design of high-strength steel beam-to-column joints

Dongxu Li*, Brian Uy [a] and Jia Wang [b]

School of Civil Engineering, The University of Sydney, Sydney, NSW 2006, Australia

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Abstract. This paper presents a finite element model for predicting the behaviour of high-strength steel bolted beam-to-column joints under monotonic loading. The developed numerical model considers the effects of material nonlinearities and geometric nonlinearities. The accuracy of the developed model is examined by comparing the predicted results with independent experimental results. It is demonstrated that the proposed model accurately predicts the ultimate flexural resistances and moment-rotation curves for high-strength steel bolted beam-to-column joints. Mechanical performance of three joint configurations with various design details is examined. A parametric study is carried out to investigate the effects of key design parameters on the behaviour of bolted beam-to-column joints with double-extended endplates. The plastic flexural capacities of the beam-to-column joints from the experimental programme and numerical analysis are compared with the current codes of practice. It is found that the initial stiffness and plastic flexural resistance of the high-strength steel beam-to-column joints are overestimated. Proper modifications need to be conducted to ensure the current analytical method can be safely used for the bolted beam-to-column joints with high-performance materials.

Keywords: high-strength steel; beam-to-column joint; numerical analysis; design codes

1. Introduction

High-strength steel (HSS) is a relatively new generation of structural steel that has exhibited enhanced mechanical properties over conventional mild steel. Based on the current manufacturing technology, HSS is normally produced through the thermo-mechanical process or quenched and tempered process. HSS represents a family of structural steels with a nominal yield strength over 460 MPa and offers higher performance in tensile stress, toughness, weldability and corrosion resistance compared to the conventional mild steel grades (Günther 2005). The most significant advantage of using HSS is the reduced weight of the structural members. With the higher strength being utilised, the dimensions of the structural members can be reduced considerably, which lead to further cost savings, such as less welding, transportation and erection costs (Gogou 2012).

Despite all these advantages of HSS, several concerns from the construction industry still limit the wider application of this type of structural steel. One of these limitations is that the initial costs for HSS are higher than conventional mild steels (Shi *et al*. 2012, Li *et al*. 2016c). Moreover, the current international design provisions just allow the HSS with a nominal yield strength up to 690 MPa to be utilised, such as AS4100 (1998), AS/NZS 5100.6 (2017), AS/NZS 2327 (2017) and EC3-1-12 (Eurocode 2007). However, most of the design requirements for steel members and joints are still based on the conventional mild steels. The concerns about the ductility of HSS members and lack of sufficient plastic deformation of joints with these high-performance materials significantly limits their application. These concerns have also influenced the design concepts that are used in the current codes of practice, which only allow the elastic behaviour of HSS to be used for design purposes (Coelho *et al*. 2006). Thus, there exists an increasing awareness that more research on joints with HSS should be performed. The applicability of plastic analysis on high performance steel members and joints should be investigated to avoid over design, through which the benefits of HSS can be fully utilised.

In a typical steel frame structure, the behaviour of beam-to-column joint is more complex than the connected steel members owing to the discontinuities in the connection zones (Fig. 1). Many design details could potentially affect the performance of these types of joint, such as the bolt strength and diameter, endplate type and thickness, as well as the presence of stiffeners in the connected members. The complexity of this joint behaviour and the significant influences on the global analysis of steel frames has been attracting the attention from researchers. Abidelah et al. (2012), Augusto *et al*. (2016), Morrison *et al*. (2017), Tartaglia *et al*. (2018) and Francavilla *et al*. (2018) performed both experimental and numerical analysis on bolted steel beam-to-column joints with open section members, the effects of various design parameters were investigated. More recently, Liu *et al*. (2017) and Tahir *et al*. (2018) proposed innovative joints to connect steel beams and box columns, the prefabricated members can be readily assembled through the bolted connections.

In addition to the bolted steel beam-to-column joints,

*Corresponding author, Ph.D., Research Associate,
E-mail: dongxu.li@sydney.edu.au
[a] Ph.D., Professor
[b] Ph.D., Research Associate

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