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Post-buckling resistance of gusset plate connections: Behaviour, strength, and design considerations

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ABSTRACT

This paper presents a numerical study on the buckling behaviour of gusset plate connections under compression. The main focus is given to the post-buckling resistance of relatively slender gusset plate connections, cases which are commonly found in thin gusset plates in light-weighted structures, and also potentially, as driven by the recent development in steel manufacture industry, in high-strength steel (HSS) gusset plates. The numerical modelling strategy was carefully validated using the results of eight full scale tests previously conducted by the authors and co-workers, and an extensive parametric study was subsequently performed covering a reasonably wide range of geometric configurations and material properties of practical gusset plate connections. Stable post-buckling equilibrium paths were observed for the models with relatively thin gusset plates, and the use of HSS further promotes remarkable post-buckling resistance. The influences of initial imperfection and material strain hardening on the buckling behaviour of gusset plate connections have also been discussed in detail. Based on the results from the numerical study, two design approaches were proposed, namely, Column Buckling Approach, which is based on a modified column analogy from the current design practice, and Plate Buckling Approach, which is based on a plate analogy and modified Winter formulae. While both methods can be used by practicing engineers, the latter may take account of the plate action of gusset plates in a more reasonable manner, and it is also more consistent with the common design rules for plated structures.

1. Introduction

Gusset plates are commonly used in building frames and bridges at member junctions. The typical failure modes for a bolted gusset plate under tension include block shear, plate tensile fracture, and plate bearing at fasteners, while for the gusset plate under compression, yielding accompanied by instability is the most common failure mode [1]. While early research on gusset plate connections was mainly focused on their stress distribution and tensile behaviour [2], major research interests on their compressive behaviour were not raised until the 1980s. Thornton [3] put forth a column-based approach to predict the buckling strength of gusset plate connections based on the early work performed by Whitmore [4]. It was assumed that the compressive stress is evenly distributed over an effective width (i.e. Whitmore width) underneath the bracing member, as shown in Fig. 1(a), and analysis was performed on an imaginary column which has a width equal to the Whitmore effective width. The Whitmore width was defined as the width enveloped by the two intersection points of the last bolt line with two other lines starting from the ends of the first bolt row towards to the last bolt line at a dispersion angle of 30°. More research work has been conducted subsequently [5–8], where both experimental and numerical investigations were attempted. It was later reported by Gross [9] that the Whitmore approach could significantly underestimate the actual compressive capacity of gusset plate connections. Yam and Cheng [10] enriched the test database by reporting thirteen full-scale tests, and it was also concluded that the Thornton's method could be too conservative. A modified dispersion angle of 45° (instead of 30°) based on Thornton's method was proposed, and good agreements were found through comparisons with the test results. In 2007, due to overstressed and buckled gusset plates [11], the Interstate 35W (I-35W) bridge in Minnesota, USA, collapsed, resulting in 13 deaths and more than 100 injuries. This catastrophic accident brought various design issues of gusset plate connections back to the fore, and extensive experimental and

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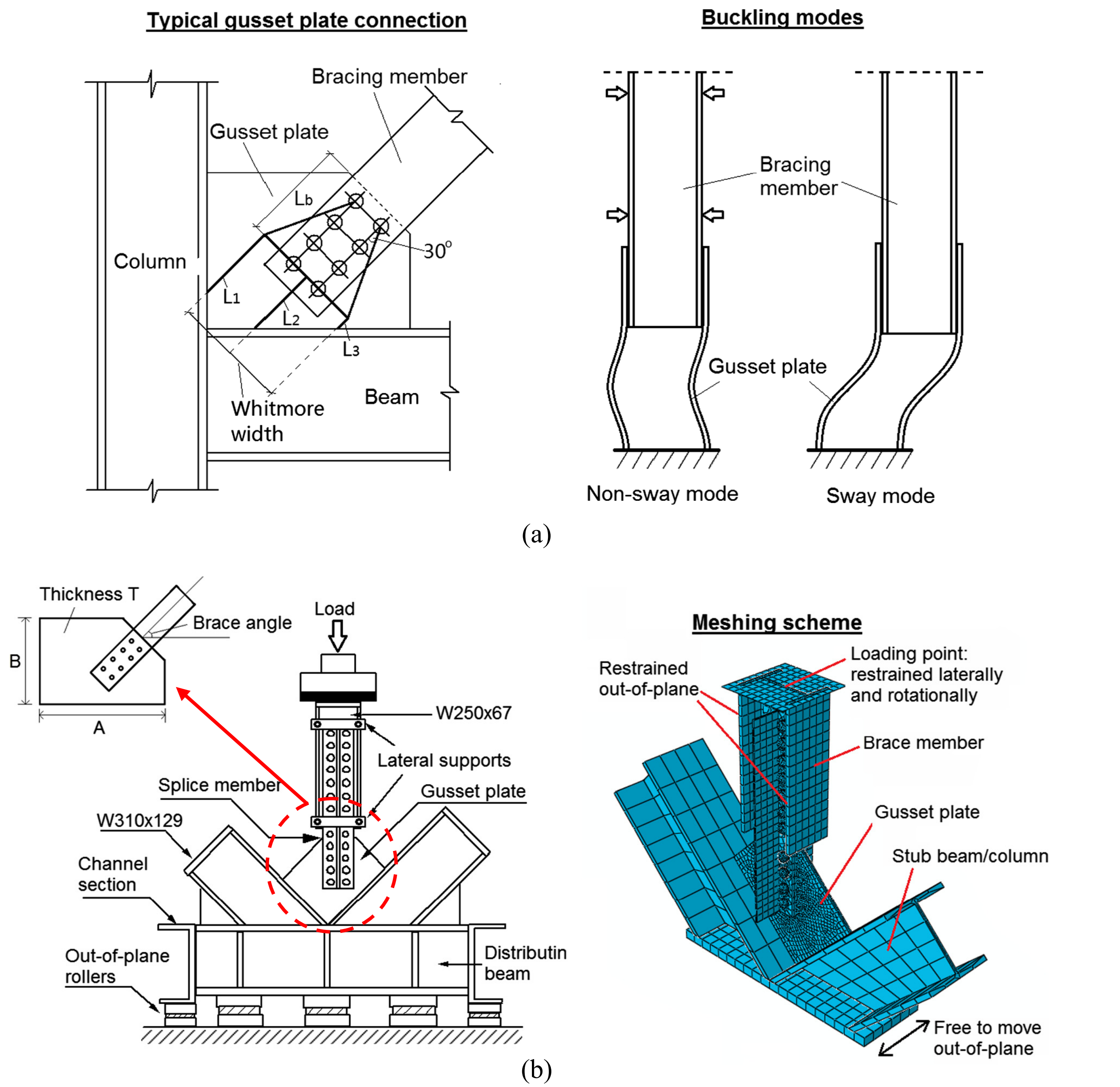

Fig. 1. Gusset plate connections: (a) typical configuration and buckling modes and (b) test setup and FE model (GP1).

numerical investigations were subsequently undertaken towards a better understanding of the behaviour of gusset plate connections [12–17]. A design guideline was also issued by the Federal Highway Administration (FHWA) [18].

It should be noted that although significant experimental and numerical investigations have been carried out on the compressive strength of gusset plate connection since the 1990s, it seems that limited progress has been made in the development of new analytical models for the buckling behaviour of gusset plate connections, noting that the newly issued FHWA design guideline [18] was also based on the early method proposed by Thornton [3]. To date, the response of relatively ‘slender’ gusset plate connections (e.g. those with a relatively thin gusset plate or using high strength steel, or with both) has not been adequately studied. Those connections, which are widely used in lightly-weighted structures such as light-gauge steel structures and timber structures [19], can be more susceptible to buckling, but post-buckling resistance, on the other hand, may be concurrently developed which benefits the load carrying capacity. Moreover, with the potential use of high strength steels (HSS) in construction works, the post-buckling behaviour of gusset plate connections with HSS needs to be considered. With the development of steel production technology, HSS (especially HSS plates) with yield strengths from 690 MPa to more than 1000 MPa are nowadays readily available at affordable costs. Using HSS in gusset plate connection design can offer stronger and more compact solutions for member conjunctions in building frames and bridges. The use of HSS can also decreases the overall weight of structures (and thus decreasing the load applied onto the foundation), and provides significant savings in delivery cost and material/energy consumption during steel production.

From the instability design point of view, however, the increase of the yield strength, which can be concurrently associated with