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Residual stress distribution of roller bending of steel rectangular structural hollow sections

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ABSTRACT

Curved steel rectangular structural hollow sections, which have a wide range of applications in construction industry, are commonly produced by cold roller bending using pyramid-type 3-roller machine on hot finished steel hollow sections. The roller bending process induces local deformations and residual stress in the hot finished section walls. While the residual stress magnitude and distribution could have sufficient influence on the member's stability and buckling resistance, few studies have paid attention to the residual stress distribution caused by roller bending. In this paper, a proper numerical modelling procedure is employed to simulate the rolling process and reproduce the residual stress. In addition, a small scale parametric study is conducted to investigate the effects of some key roller bending parameters, including the rolling boundary conditions, the bending ratio, the steel yield stress, the thickness ratio and the shape factor, on the resulted residual stress distribution of the bended sections. Based on the results obtained from the parametric studies, a simple residual stresses model which could predict the residual stress distribution of the curved member is proposed.

1. Introduction

Due to their excellent mechanical properties and geometric tolerances, hot finished steel rectangular structural hollow sections are often employed for the construction of high load-bearing structures. In addition, curved steel hollow section members are required in many applications in structural engineering such as the construction of domes, arched roofs, bridges and aesthetic structures. Toward this end, one of the most common methods employed to produce curved steel hollow section members is by cold roller bending of a straight hot finished steel hollow section member using the pyramid-type 3-roller machine. During the cold rolling process, the straight hot finished steel hollow section member could be considered as a simple beam which is supported by two outer rollers and subjected to loading from the moving centre roller. Such loading together with the changing position of the centre roller eventually produce the required permanent radius of curvature of the final curved section. However, the loads applied during the rolling process also induce large permanent local deformations of the four walls of the steel hollow section and generates residual stresses in different parts of the section [1]. In general, the final residual stress is closely related to the member radius after roller bending. While some experimental and theoretical studies were conducted to study the relationship between the minimum radius of bending and the permanent deformations of the bended steel hollow section [1–3], the effect of roller bending on the residual stress distribution of steel hollow section member is relatively less studied.

The effects of residual stress on the behaviour and stability of *straight* hot finished steel hollow section member has been investigated and reflected by the inclusion of buckling curves in design standards such as the Eurocode 3 [4]. For the members subjected to *bending moment only*, the design guide [5] suggests that the influence of residual stress on curved members could be more important than straight members. Simple assumptions of residual stress distribution based on the bilinear material law were adopted to calculate the resistance of curved members [5]. However, some of the simple assumptions adopted, including no stress variation over *both* tension and compression flanges and no deformation of plane sections, may violate the real situation during the rolling process. Hence, a more comprehensive study on the residual stress distribution is worth investigating. Giorgi [6] conducted an Experimental analysis to access the residual stress evolution in cold-rolled steels. The results showed that the yield strength could play an important role in the residual stress field evolution. For open steel sections, experimental study was conducted by Spoorenberg et al. [7,8] to measure the residual stress distributions in both straight and curved members and the results were validated by finite element modelling. Based on the analysis results, a residual stress model was proposed for cold-rolled wide flange sections [9]. The effects of residual stress on in-plane inelastic buckling and lateral buckling strength of open sectional steel arches were studied by Pi and Trahair [10,11]. In their study, groups of arches with varying slenderness are subjected to

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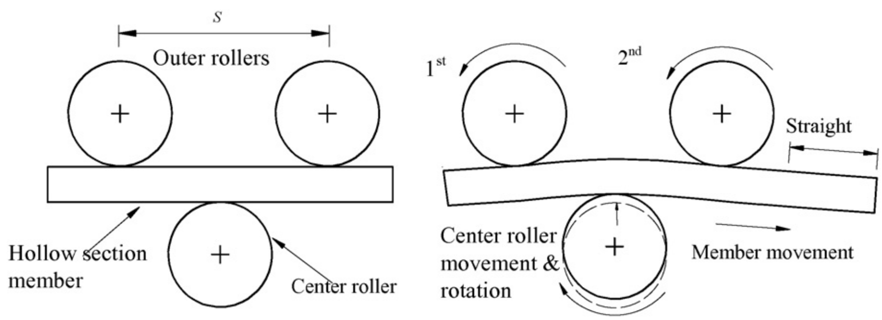

Fig. 1. Roller bending by pyramid-type bending machine.

different kinds of loads. The results showed that the residual stress could reduce the buckling strength significantly. For the straight steel hollow section members, the main focus in many previous studies was to investigate the magnitude and distribution of residual stress due to cold forming process [12,13]. Jandera et al. [14,15] explored the presence and influence of residual stress in cold-formed stainless steel box sections using experimental and numerical techniques. It was found that the influence of residual stress on the column buckling behaviours of square hollow section varies with the non-dimensional slenderness of the section.

As it is found that very few previous studies were focused on the residual stress of curved steel hollow section members produced by cold roller bending, the main objective of this study is to investigate the residual stress of curved steel hollow section. In addition, a numerical parametric study will also be conducted to evaluate the effects of some key parameters of the roller bending process. Based on the results of the parametric study, a simple residual stress model will be suggested. This model would allow engineers to estimate the residual stress distribution of the steel hollow section which could then be used as the initial stress state for further

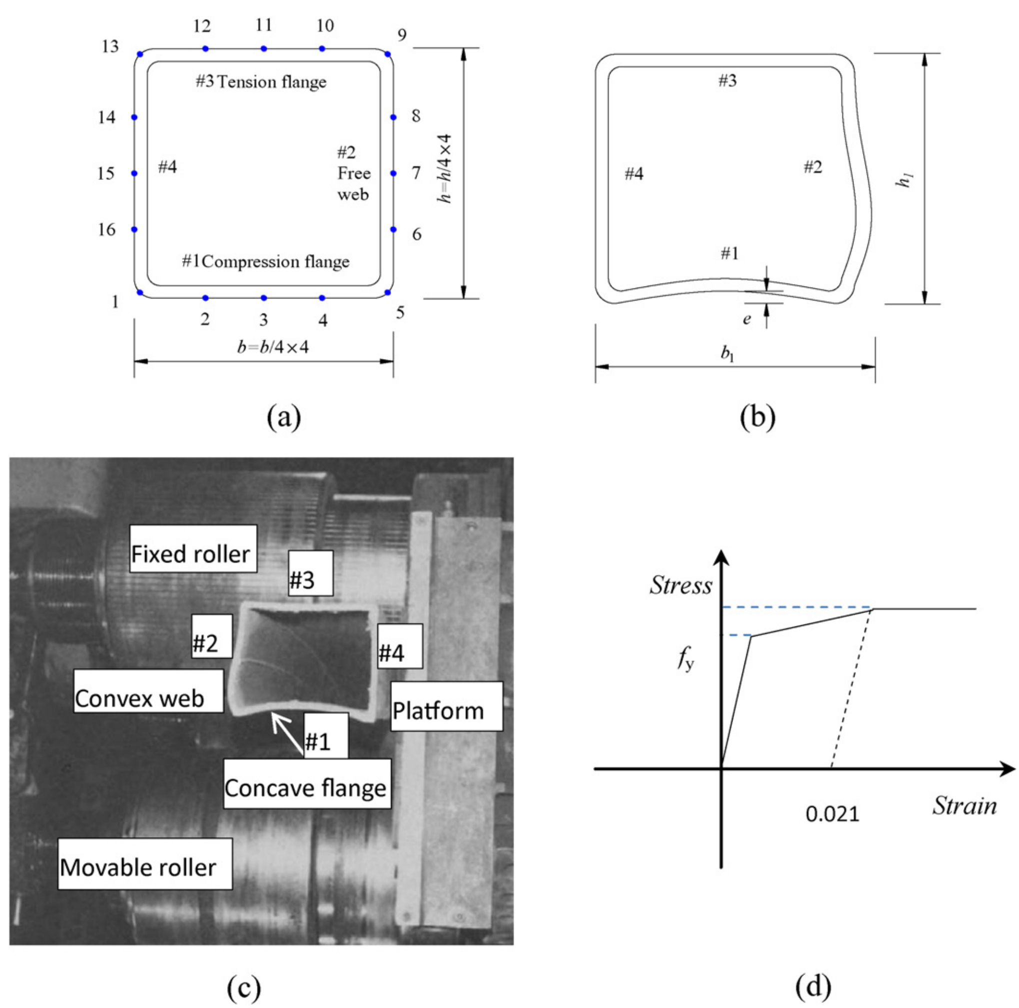

Fig. 2. Typical cross-sections distortion and material behaviour. (a) Section before rolling. (b) Section after rolling. (c) Distortion of section after rolling (adopted from Reference [2]). (d) Material behaviour