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Ultimate capacities formulae of collar and doubler plates reinforced SHS X-joints under in-plane bending

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ABSTRACT

This paper presents two finite element model of collar and doubler plates reinforced SHS X-joints under in-plane bending, which were verified by the corresponding test results. The parametric study was carried out to reveal the failure modes and plasticity propagation of collar and doubler plates reinforced SHS X-joints under in-plane bending. The effects of SHS brace width to SHS chord width ratio (β), reinforced plates thickness to SHS chord wall thickness ratio (λ), and reinforced plates length to SHS brace width ratio (Δ) on the ultimate capacities of collar and doubler plates reinforced SHS X-joints were evaluated. The typical failure modes of collar and doubler plates reinforced SHS X-joints under in-plane bending were obtained from the finite element analysis, which included braces inclination, chord face concave in compression stress zone, convex in tension stress zone, collar or doubler plates bending. The ultimate capacities of joints with large β value significantly increased with the increase of reinforcement plates thickness. The in-plane bending ultimate capacity increased with the increase of β value. The ultimate capacities formulae are proposed by using multiple linear regressions for collar and doubler plates reinforced SHS X-joints under in-plane bending based on the current design equations of unreinforced SHS X-joints given in the Eurocode 3. It is shown from the comparison that the joint strengths of collar and doubler plates reinforced SHS X-joints under in-plane bending calculated using the proposed formulae agreed well with the finite element analysis results, which means the proposed formulas are verified to be accurate and safe.

1. Introduction

In the onshore and offshore structures, when some SHS joints of a structure need to be reinforced due to additional loading conditions, a convenient and effective method is reinforced to the tubular joints with collar or doubler plate [1]. This method can effectively reinforce the SHS joints of aged structure [2]. The two methods of reinforcement are illustrated in Figs. 1 and 2, respectively. For the SHS X-joint reinforced with collar plates, the brace is first welded directly to the chord, after which the collar plate parts are welded to the brace and chord, as shown in Fig. 1. For a SHS X-joint reinforced with a doubler plate, the brace is welded directly to the douber plate through a penetration weld whereas the doubler plate is welded to the chord through fillet welds, as shown in Fig. 2.

Literature reviews show that extensive researches were conducted on stress concentration factor and ultimate capacities of collar and doubler plates reinforced circular hollow section (CHS) joints. A parametric stress analysis of doubler plate reinforced CHS T-joints under axial tension was performed using the finite element technique by Soh et al. [3]. The doubler plates reinforced T-joints were as good as the corresponding unreinforced joints in withstanding axial tensioning. The ultimate capacity of doubler plate reinforced CHS T-joints was experimentally and numerically studied by Fung et al. [4]. The ultimate capacity was greatly improved by the inclusion of the doubler plate. A large scale CHS T-joint reinforced with a doubler-plate was fabricated, strain-gauged and tested to study its stress behavior under the combined action of 3 types of basic load as in axial load, in-plane bending and out-of-plane bending by Hoona et al. [5]. Under basic loadings, the stresses in the reinforced joint were generally lower than an unreinforced joint of similar geometry and sizes except for axial tension and in-plane bending moment, the stresses on the doubler plate at the doubler plate and brace intersection were slightly higher than its unreinforced counterpart. Stress concentration factors of doubler plate reinforced CHS T-joints subjected to

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Notation

SHS	square hollow section
a_0	chord width
t_0	chord wall thickness
a_1	brace width
t_1	brace wall thickness
l_c	reinforced plates length
t_d	reinforced plates thickness
M_{ip}	ultimate capacity of the unreinforced SHS X-joints under in-plane bending
M_{ipc}	ultimate capacity of the collar plates reinforced SHS X-joints under in-plane bending
M_{ipd}	ultimate capacity of the doubler plates reinforced SHS X-joints under in-plane bending
ψ_c	correction factor of collar plates reinforced SHS X-joints
ψ_d	correction factor of doubler plates reinforced SHS X-joints
f_{y0}	yield stress of chord
γ_{M5}	resistance factor
β	SHS brace width to SHS chord width ratio
λ	reinforced plates thickness to SHS chord wall thickness ratio
Δ	reinforced plates length to SHS brace width ratio

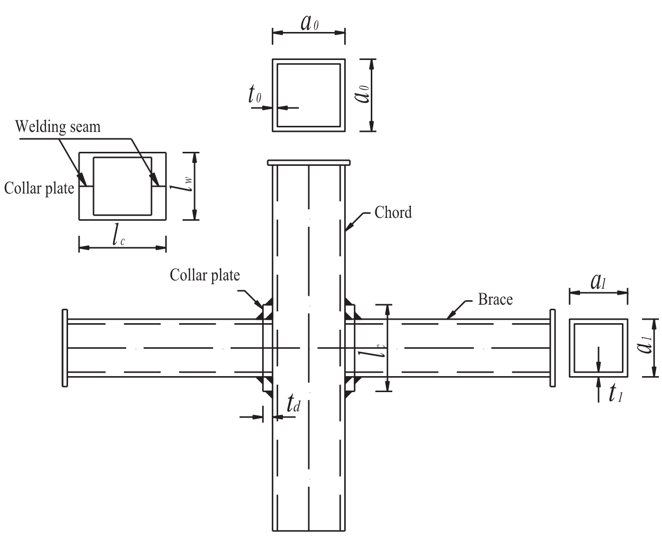

Fig. 1. Collar plates reinforced SHS X-joints.

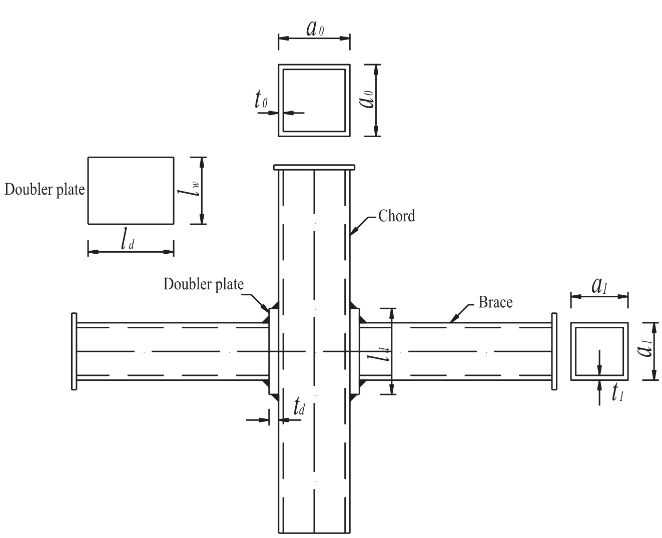

Fig. 2. Doubler plates reinforced SHS X-joints.

various types of basic loading were numerically investigated by Fung et al. [6]. Static strength of collar and doubler plate reinforced CHS X-joints under in-plane bending was numerically and experimentally investigated by Choo et al. [7–10]. Strength equations of collar and doubler plate reinforced CHS joints were established. The static strength of doubler plate reinforced Y-joints under compression loading was numerically investigated by Feng and Tan [11]. The ultimate strength of Y-joints reinforced with appropriately proportioned doubler plates can be greatly improved nearly up to three times to un-reinforced Y-joints. CHS T, Y, K, X, and DT-joints with and without doubler plates are compared against past studies and the recommended design formulas used in international codes by Nazari et al. [12]. Sensitivity analysis was performed describing the effect of joint geometry variations on the stress concentration factor values. Static and hysteretic performance of collar and doubler plates reinforced CHS joints were experimentally and numerically investigated by Shao et al. [13,14]. The hysteretic behavior of tubular T-joints reinforced with doubler plates was experimentally and numerically investigated by Gao et al. [15]. Parameters τ and ε had little influence on the post-fire hysteretic behavior of the joint, but joints with a large γ or small α, β, or ξ values had a low capacity for hysteretic behavior after fire exposure. The fire resistance behavior of tubular T-joints was experimentally and numerically investigated by Gao et al. [16].

The mechanical behavior of collar and doubler plate reinforced SHS X-joints under out-of-plane bending was researched by Chen et al. [17]. The out-of-plane flexural initial stiffness and ultimate capacity of collar plates reinforced joints, doubler plates reinforced joints and unreinforced joints decreased progressively. Thickness of reinforcement plates had an obvious effect on out-of-plane ultimate capacity of SHS X-joints. Up to the authors' knowledge, there is no any research report for ultimate capacities formulae of collar and doubler plate reinforced SHS X-joints under in-plane bending, which have been further investigated in this study.

This paper mainly focuses on the nonlinear finite element analyses of collar and doubler plate reinforced SHS X-joints under in-plane bending. Accurate finite element models were developed to reveal the static behavior of the two types of reinforced joints, which were verified by the corresponding test results. An extensive parametric study was carried out using the verified finite element models to evaluate the effects of main non-dimensional geometric parameters on ultimate strengths of collar and doubler plate reinforced SHS X-joints under in-plane bending. The design formulae of the joint strengths for collar and doubler plate reinforced SHS X-joints under in-plane bending are proposed for based on the numerical results.

2. Finite element analysis

2.1. FEA model

The specimen dimensions of collar and doubler plate reinforced SHS X-joints under in-plane bending in the finite element analysis are detailed in the corresponding experimental work [18]. Details of specimens are shown in Table 1. Ten joints specimens under in-