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Experimental and numerical research on out-of-plane flexural property of plates reinforced SHS X-joints

Chaoyang Wang [a], Yu Chen [b,*], Xixiang Chen [c], Dongfen Chen [a]

[a] College of Civil Engineering, Huaqiao University, Xiamen 361021, China
[b] School of Urban Construction, Yangtze University, Jingzhou 434023, China
[c] College of Technology & Engineering, Yangtze University, Jingzhou 434023, China

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ABSTRACT

The static tests of 13 SHS X-joints with different brace to chord side length ratios and different types of plates reinforcement under out-of-plane bending in brace were carried out. Experimental test schemes, failure modes of specimens, moment–vertical displacement curves, moment–deformation of the chord, and strain strength distribution curves were presented. The effects of brace to chord side length ratios and plates reinforcement types on out-of-plane flexural property of SHS X-joints were studied. Results show that punching shear of chord face disappeared, concave and convex deformation of chord decreased when either collar plates or doubler plates were welded on chord face. Moment–vertical displacement curves of all specimens have obvious elastic, elastic–plastic and plastic stages. As brace to chord side length ratio increased, the out-of-plane flexural ultimate capacity and initial stiffness of joints with the same plates reinforcement type increased, but ductility of joints decreased. With the same brace to chord side length ratio, 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. Thickness of reinforcement plates had no obvious effect on out-of-plane flexural initial stiffness of SHS X-joints when the value of reinforcement plates to chord wall thickness ratio exceeds 1.0. As thickness of reinforcement plates increased, the ductility of reinforced X-joints decreased. The concave and convex deformation of every specimen had good symmetry. The design equations were proposed for collar and doubler plates reinforced SHS X-joints under out-of-plane bending, which were shown to be accurate and reliable.

1. Introduction

In offshore platform structures, the connection of joints can be reinforced by the provision of doubler or collar plates at the intersection between the brace and chord members. Both experimental [1] and numerical [2] results for axially loaded CHS T-joints had shown that the doubler and collar plates could significantly improve the static strength of CHS T-joints. The size of the plates might have important effects on the strength of the reinforced joints. The effects of the plates size on the static strength of CHS X-joints subjected to in-plane bending had been investigated by Choo [3]. But, the studies on out-of-plane flexural property joints were limited. Karamanos et al. [4] developed a methodology for the calculation of the maximum local stress, referred to as hot-spot stress, in a multi-planar DT-joint with particular emphasis on the effects of bending moments on the braces and the chord. Diaye et al. [5] used FEM to predict the location of hot-spot stresses in a welded tubular T-joint under axial, in-plane bending and out-of-plane bending. Liang et al. [6] studied the static strength of doubler plates-reinforced CHS X-joints loaded by out-of-plane bending. Kang et al. [7] studied the influence of chord length parameter and thickness parameter on the ultimate strength of Double-Tee tubular joints under brace out-of-plane bending. Frøydis et al. [8] investigated the effect of mean stress on fatigue strength in low cycle fatigue regions under out-of-plane bending loading. Chen et al. [9] studied the mechanical performance of reinforced concrete beam-thin-wall joints under out-of-plane bending moments. Jang et al. [10] investigated a higher-order beam analysis applicable to three thin-walled box beams connected at a joint under out-of-plane bending. Soh et al. [11] investigated the behavior of completely overlapped tubular joints under out-of-plane bending used in the eccentrically braced offshore jackets.

Due to lack of test evidence, the current design method and code for doubler plates or collar plates reinforced SHS joints is very

* Corresponding author.
E-mail address: kinkingingin@163.com (Y. Chen).

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Nomenclature

OPN	unreinforced SHS X-joints under out-of-plane moment
XSCO	collar plates reinforced SHS X-joints under out-of-plane moment
XSDO	doubler plates reinforced SHS X-joints under out-of-plane moment
a_0	chord side length
t_0	chord wall thickness
a_1	brace side length
t_1	brace wall thickness
a_d	reinforcement plates width
t_d	reinforcement plates thickness
β	race to chord width ratio (a_1/a_0)
λ	reinforcement plates to chord wall thickness ratio ($\lambda = t_d/t_0$)
τ	brace to chord wall thickness ratio (t_1/t_0)
f_y	tensile yield stress
f_{y0}	yield stress of the chord
f_u	ultimate tensile stress
δ	tensile elongation
E	elastic modulus
ν	Poisson's ratio
M_u	experimental values of out-of-plane flexural ultimate capacity
M_{uu}	design strength of the unreinforced SHS X-joints under out-of-plane bending obtained by using Eurocode 3
M_{uc}	collar plates plates reinforced SHS X-joints under out-of-plane bending
M_{ud}	doubler plates reinforced SHS X-joints under out-of-plane bending
N_u	jack load in ultimate limit state
N_y	jack load corresponding to first strain gauging points enter plasticity stage
k_i	out-of-plane flexural initial stiffness
Δ	vertical displacement
Δ_y	yield displacement
Δ_u	ultimate displacement
Δ_u/Δ_y	ductility ratio
$\delta_{concave}$	local deformation of the chord in compressive area
δ_{convex}	local deformation of the chord in tensile area
ε_i	strain intensity
ε_1	first principal strain
ε_2	second principal strain
ε_3	third principal strain
ε_0	0° strain
ε_{45}	45° strain
ε_{90}	90° strain
ψ_d	correction factor for doubler plates reinforced SHS X-joint
ψ_c	correction factor for collar plates reinforced SHS X-joint
COVs	coefficient of variations

elementary. Hence an experimental program has been designed to investigate the static behavior of SHS X-joints reinforced by doubler or collar plates under out-of-plane bending. A total of 13 joint tests have been conducted, with the results reported in this study. Besides the reinforcement scheme, unreinforced joints, doubler plates, or collar plates, the variables investigated are geometric

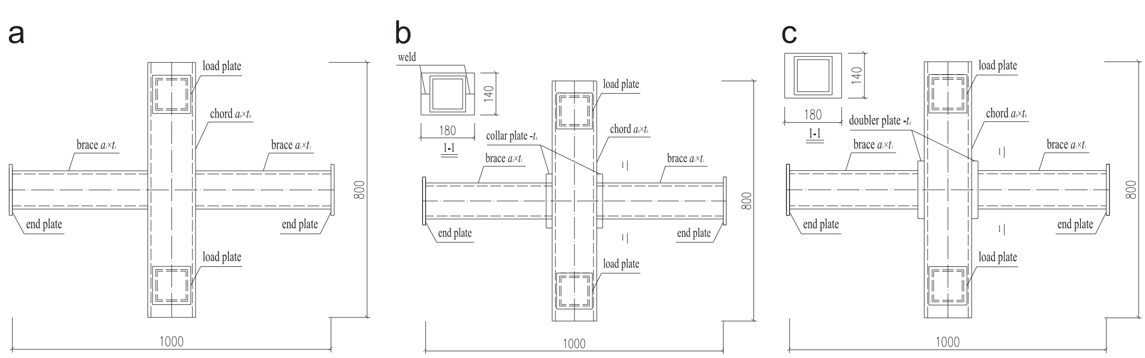

Fig. 1. Schematic diagram of SHS X-joints.

Table 1
Details of unreinforced and reinforced SHS X-joint.

Specimen	a_0 (mm)	t_0 (mm)	a_1 (mm)	t_1 (mm)	t_d (mm)	$\beta = a_1/a_0$	$\tau = t_1/t_0$
OPN08	150	6	80	5	–	0.533	0.83
OPN10	150	6	100	5	–	0.667	0.83
OPN12	150	6	120	5	–	0.800	0.83
XSCO0810	150	6	80	5	10	0.533	0.83
XSCO1010	150	6	100	5	10	0.667	0.83
XSCO1206	150	6	120	5	6	0.800	0.83
XSCO1208	150	6	120	5	8	0.800	0.83
XSCO1210	150	6	120	5	10	0.800	0.83
XSDO0810	150	6	80	5	10	0.533	0.83
XSDO1010	150	6	100	5	10	0.667	0.83
XSDO1206	150	6	120	5	6	0.800	0.83
XSDO1208	150	6	120	5	8	0.800	0.83
XSDO1210	150	6	120	5	10	0.800	0.83