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INTERACTION STRENGTH FOR CHS-TO-LONGITUDINAL PLATE JOINTS UNDER AXIAL LOAD AND IN-PLANE BENDING MOMENT

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The circular hollow section (CHS) has lots of advantages in excellent structural properties, architecturally attractive features. Thus, CHSs are used extensively in many applications in buildings, bridges, towers, and offshore. In CHS, it is necessary to understand the various complex shape of CHS joint because loads act simultaneously according to joint type. The use of high-strength steel has been continuously increased, but the current design equation in AISC 2011 or KBC 2016 limits maximum yield strength 360 MPa. This paper studies an interaction strength of high-strength CHS-to-longitudinal plate X-joint subjected to combination of plate axial load and in-plane bending moment. For the study, numerical analysis based on experimental tests was carried out. The analysis was performed according to variables for determining shape of joint, i.e., chord slenderness, plate width-to-CHS diameter ratio, and utilization ratio. Investigations have shown that a linear summation of the ratios for axial load and in-plane bending moment may be used as conservative approximation.

Keywords: Circular hollow section (CHS), Numerical analysis, High-strength steel.

1 INTRODUCTION

The circular hollow section (CHS) as a structural element has the excellent properties in resisting compression, tension, buckling, and torsion. These excellent properties of CHS are combined with an attractive shape for architectural applications. The use of high-strength steel has been continuously increased, CHS can also be produced in high-strength steel with yield strength up to 690 MPa or higher (Wardenier 2001). However, the nominal specified yield strength of circular hollow sections should not exceed 360 MPa (AISC 2011, KBC 2016) or 460 MPa (Wardenier *et al*. 2008) in some design standards. For this reason, many studies on behavior of high-strength CHS joints were carried out (Lee *et al*. 2012, Ling *et al*. 2007, Javidan *et al*. 2015). In addition, due to the various features of connection type, the joint capacity must be checked for interaction between axial load and in-plane or out-of-plane bending moment for each circular hollow section member.

In this paper, the finite element analysis based on the previous test (Lee *et al*. 2012) was conducted. The numerical analysis of high-strength CHS-to-longitudinal plate X-joint was performed according to variable, i.e., chord slenderness (2γ), plate width-to-CHS diameter ratio

(η), and utilization ratio (stress ratio in CHS, U or n), and the interaction relationship between axial load and in-plane bending moment was investigated.

2 FINITE ELEMENT ANALYSIS

The finite element package ABAQUS was used for the finite element analysis. The S4R shell element (4-node doubly curved general purpose shell) was used as a finite-strain element for large strain analyses. All finite element models were analyzed using Riks method which incorporates nonlinear material properties (ABAQUS 6.14 documentation).

2.1 Material Property

A material property based on the coupon test of HSB600 grade steel (KS D 3868) was used for the model. The yield strength F_y was 478 MPa and the tensile strength F_u was 630 MPa as plotted in Table 1.

Table 1. Property of high-strength steel (HSB600).

Test	Yield strength (MPa)	Ultimate strength (MPa)	Yield ratio (%)	Elongation (%)
Tensile	478	630	75.9	34.8
Short column compression	485	606	80.0	-

2.2 Parameter Analysis

Figure 1 shows the geometry of parameter analysis model and loading conditions (F: plate axial load, M: in-plane bending moment, P: axial load in CHS). In order to avoid the end boundary conditions effect caused by short chord length, a total chord length (L) more than 10D was used for parameter study (Vegte and Makino 2007). The analysis was performed on the variables that influence the joint strength. The variables are as follows:

(i) chord diameter-to-thickness ratio ($2\gamma=D/t$)

(ii) plate width-to-chord diameter ratio ($\eta=N/D$)

(iii) utilization ratio (U or n).

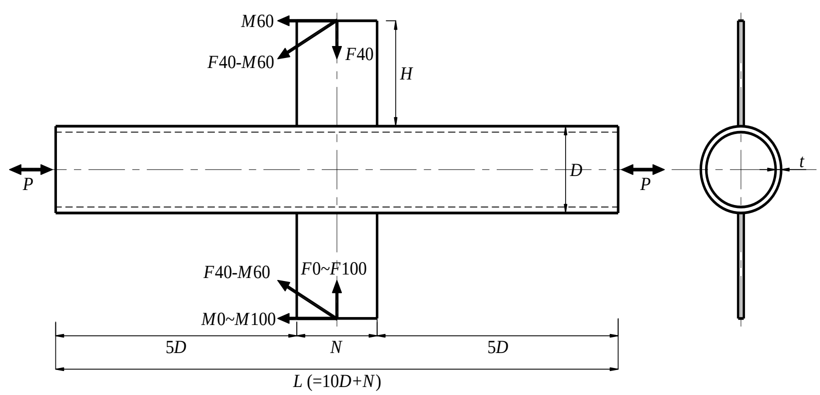

Figure 1. Scheme of parameter analysis.

The study considered chord diameter-to-thickness ratios 20 and 30, plate width-to-chord diameter ratios 1 and 2, and utilization ratio -0.8 to 0.0 (note that increment = 0.2, and the negative sign means compressive force acting on CHS) as shown in Table 2.

Table 2. Variables for parameter analysis.

chord slenderness, 2γ (t)	plate width-to-CHS diameter ratio, η (N)	utilization ratio, U or n	Loading distance, H	Chord diameter, D
20 (17.5 mm) 29.2 (12.0 mm)	1 (350 mm) 2 (700 mm)	-0.8, -0.6, -0.4, -0.2, 0	500 mm	350 mm

In FE model, mesh size around the connection between plate and CHS was set to be 6 mm long for precisely analyzing a joint strength. The FE model except joint was generated with mesh size 45 mm using quad shell elements with automatic mesh technique in Figure 2.

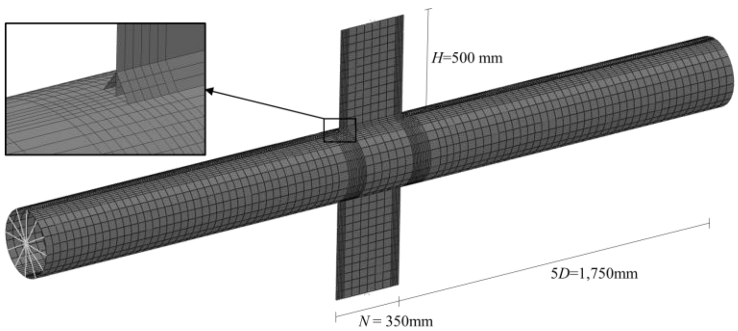

Figure 2. FE Model of specimen and mesh size distribution.

2.3 Analysis Result

The FE results shown in Figure 3 and 4. The load capacity at the indentation of 3% of the chord diameter (3%D = 10.5 mm) on the load or moment-deflection curve was determined as the joint strength (Lu *et al*. 1994). These joint strengths correlated well with maximum load or moment of FE results.

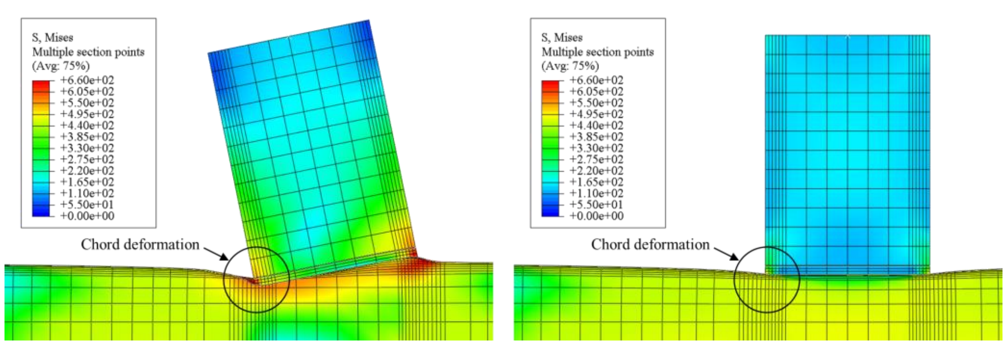

Figure 3. Results of von Mises stress (left: in-plane bending moment; right: plate axial load).

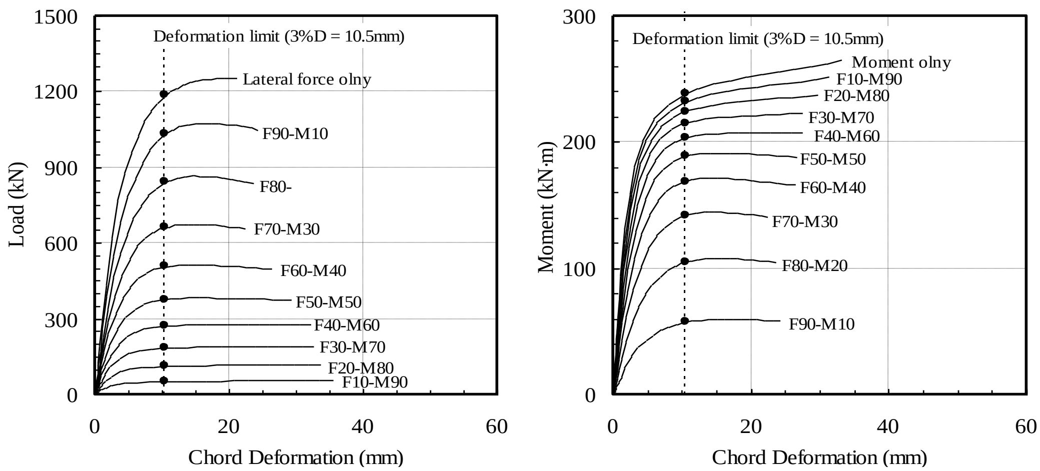

Figure 4. FE results (left: plate axial load, right: in-plane bending moment of $2\gamma = 20$, $\eta = 1$, and $U = 0.0$).

3 INTERACTION STRENGTH

For T-, Y- and X-connections of CHS with plate under combined axial load, in-plane bending and out-of-bending moments, Eq. (1) is used in current design standards (AISC 2011, KBC 2016, Wardenier *et al*. 2008). In this study, out-of-bending moment can be neglected and interaction strength of CHS-to-plate is shown in Figure 5.

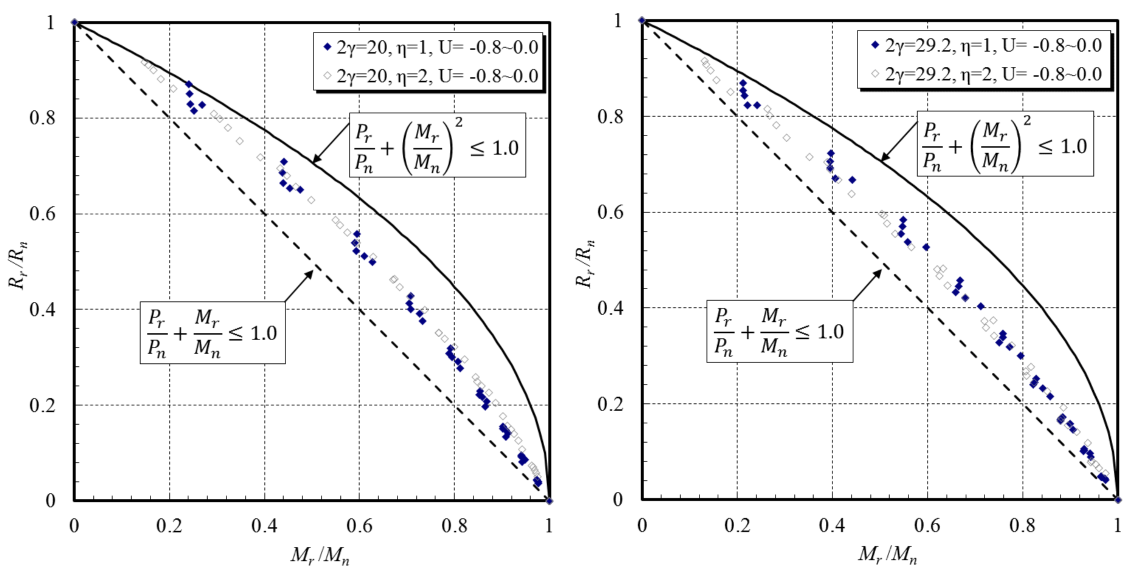

Figure 5. Interaction strength of FE models (left: $2\gamma = 20$ models; right: $2\gamma = 29.2$ models).

P_r, $M_{r\text{-}ip}$ and $M_{r\text{-}op}$ are the required strength, and P_n, $M_{n\text{-}ip}$ and $M_{n\text{-}op}$ are the design strength. As shown in Figure 5, interaction strength relationship obtained by FE analysis tend to be lower than the value of Eq. (1).

$$\frac{P_r}{P_n} + \left(\frac{M_{r-ip}}{M_{n-ip}}\right)^2 + \frac{M_{r-op}}{M_{n-op}} \le 1.0 \quad (1)$$

When in-plane bending moment is large, FE results are not in good agreement with design equation. The values, chord diameter-to-thickness ratio is 29.2 (2γ=29.2), show a trend that is close to a straight line.

4 CONCLUSIONS

In order to investigate interaction strength of CHS-to-longitudinal plate X-joint under axial load and in-plane bending moment, parametric studies have been conducted by using finite element models. The interaction strength of FE model tends to be lower than design equation and these can be expressed with trend line using specific value instead of square. However, linear summation of the ratios for axial load and in-plane bending moment may be used as conservative approximation for practical application.

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