

## **Effects of Stress-Strain Characteristics on the Strength Of CHS X Joints**

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### **ABSTRACT**

Most of current steel design standards forbid or limit the use of high strength steels to tubular structures because of concerns about their unique stress-strain characteristics such as the absence of yield plateau and high yield ratio. The mechanical background of current limitations appears unclear and unduly conservative, and their validity needs to be re-evaluated. In this study, the effects of stress-strain characteristics were systematically investigated based on experimental and test-validated numerical analysis of CHS (circular hollow section) X joints fabricated from different steel grades of SM490, SM570, and HSA800. The strength of high strength steel joints was dominantly governed by the widely-accepted 3% indentation criteria long before reaching the peak strength. The joint strength often exceeded the EC3 nominal strength with sufficient margin, although the margin tended to decrease as the yield strength of steel became higher or as the brace to chord diameter ratio became smaller. Overall, the experimental and supplemental numerical results of this study indicated that high-strength steel CHS X joints show satisfactory performance, just slightly inferior to ordinary steels, from the perspective of serviceability, ultimate strength and ductility even when the yield strength of steel is as high as 800MPa.

### **1. INTRODUCTION**

The use of circular hollow sections (CHSs) is being increased more and more in a wide range of structural applications because of their many technological advantages over open steel shapes and aesthetic appeal as well. The use of high-strength steel

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tubular members can bring about further advantages from design to erection. However, most of current internationally representative design standards such as 2008 CIDECT guide (Wardenier et al., 2008), 2010 AISC Specification (AISC, 2010), and EC3 (CEN, 2005) forbid or impose restrictions on the use of high strength steels for structures with hollow sections depending upon steel yield strength and/or yield ratio. The mechanical background of these limitations appears unclear and often unduly conservative, and their validity needs to be further investigated. As is well-known, current design standards for tubular joints were proposed based on the screened test database and extensive test-backed numerical results. Although fairly extensive experimental and associated analytical studies were conducted for CHS X joints in the past (for example, Sammet 1962, JSSC 1972, Gibstein 1973, Boone et. al 1982, Weinstein et al. 1986, Van der Vegte 1995, Kanatani 1996, Noordhoek et al. 1996 and others), the database on high strength steel joints is still quite limited. In this study, the effects of stress-strain characteristics were systematically investigated based on experimental testing and test-validated numerical analysis of CHS X joints fabricated from different steel grades of SM490, SM570, and HSA800 in order to augment the database and examine if current design standards could be extrapolated to high strength steels.

## **2. MATERIAL LIMITATIONS AND JOINT STRENGTH EQUATION**

The limitations on steel materials and the joint strength equations for CHS X joints are first briefly summarized in this section. According to the 2010 AISC Specification, the applicable range of hollow section connection configuration is limited to steels whose yield strength ( $F_y$ ) and yield ratio ( $F_u$ ) are within 360 MPa and 0.8, respectively; the application of high strength steels to tubular structures is virtually forbidden. The joint resistances given in CIDECT guide are basically for steels with a nominal yield strength up to 355 MPa. For nominal yield strengths greater than this value, the joint resistances given should be multiplied by 0.9. However, the nominal specified yield strength should not exceed 460 MPa based on the finished tube product and should not be taken larger than  $0.80F_u$ , where  $F_u$  is the nominal ultimate tensile strength. The reduction factor 0.90 was introduced on one hand due to concerns about relatively larger deformations in CHS joints with  $F_y$  approaching 460 MPa and on the other hand probable lower deformation/rotation capacity of other joints with yield strengths exceeding 355 MPa (Wardenier et al., 2008). The CIDECT guide is more flexible and generous in that it provides some room for the application of high strength steels to tubular structures. EC3 (CEN 2005) gives additional rules for the use of very high strength steel or S700 whose nominal yield strength is 700 MPa. In this case, a reduction factor of 0.80 to the joint capacity equations has to be used instead of the factor 0.90.

Figure 1 shows typical geometrical configuration and the symbols of CHS X joints. Equation (1) below gives the generic form of the CHS X joint strength corresponding to the limit state of chord plastification. It is implied from equation (1) that the connection geometry and the chord stress are assumed to affect the joint strength in an uncoupled manner or in the form of  $Q_u \times Q_f$ . Table 1 summarizes the joint strength equation and range of applicability per EC3. Other standards also provide the joint strength provisions similar to EC3.

$$P_u = \frac{f_{y0} t_0^2}{\sin \theta} Q_u Q_f \quad (1)$$

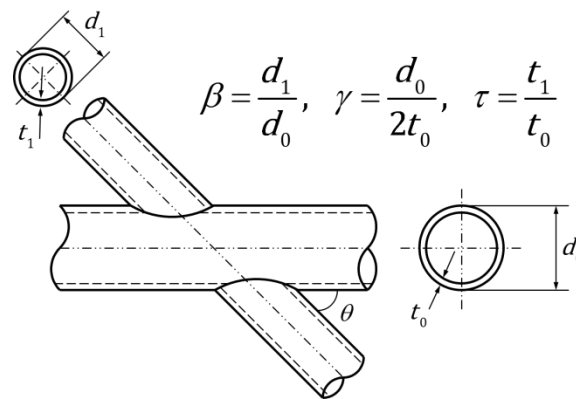


Figure 1: Geometrical configuration and definition of symbols of CHS X joints (see table 1 for the definition of  $Q_u$  and  $Q_f$ )

Table 1: Joint strength equation for CHS X joints: chord plastification limit state per EC3

$Q_u$ (geometry factor)	$Q_f$ (chord stress factor)		Range of applicability: material		Range of applicability: geometry		
	Chord in tension	Chord in compression	$F_y$	Yield ratio	$\beta$	$2\gamma$	$\theta$
$\frac{5.2}{1 - 0.81\beta}$	1.0	$1 - 0.3n_p (1 + n_p) \leq 1.0^a$	355MPa <sup>b</sup>	0.9	0.2-1.0	$\leq 50$ (for $\theta < 90^\circ$ ) $\leq 40$ (for $\theta = 90^\circ$ )	$30^\circ - 90^\circ$

<sup>a</sup>  $n_p = \frac{\sigma_{p,Ed}}{f_{y0}}$  ( $\sigma_{p,Ed}$  : maximum compressive stress in the chord at a joint,  $f_{y0}$  : yield strength of a chord member.)

<sup>b</sup> Steels whose yield strength is between 355MPa and 460MPa can be used with the reduction factor of 0.9, and steels from S460 up to S700 can be used with the reduction factor of 0.8.



Table 1). The brace to chord diameter ratio  $\beta$  was chosen as 0.62 and 0.75 to induce chord plastification. The stress-strain diagrams obtained from the coupons of each steel plate (or before press bending) are plotted in Figure 2. As expected, Figure 2 shows that SM490, as an ordinary-strength steel, has a stress-strain characteristics desirable for ductile behavior at member and structural levels; they have a sharp yield point, a distinct yield plateau, significant strain-hardening, and a low yield ratio. However, the two high strength steels, SM570 and HSA800, lack these properties. Recently the effects of these different post-elastic properties on the strength and the rotation capacity of I-shaped beams were experimentally and analytically investigated by Lee et al. (2013). This study may be viewed as an attempt to investigate such effects on CHS X joints.

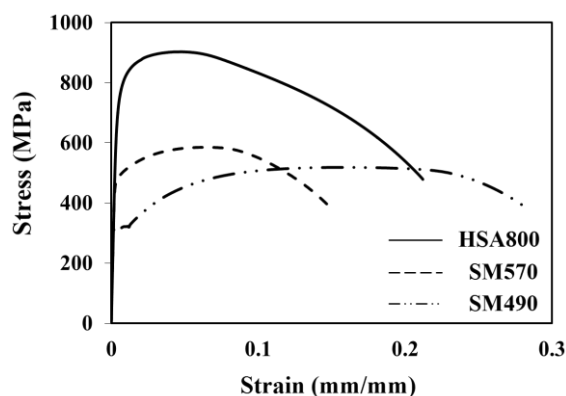


Figure 2: Measured stress-strain diagrams

Figures 3a and 3b show an overall view of typical test setup. A universal testing machine of 10,000 kN capacity was used to apply pseudo-static axial compression to the X joint specimens. Both ends of the chord were set free except the lateral restraint provided to prevent out-of-plane displacement if any. No load was applied to the chord; or all the tests were conducted under the condition of the chord stress factor ( $Q_f$ ) of 1.0. A total of six LVDTs were attached around the joint to measure the out-of-face deformations at the saddle and crown points (see Figure 3c). Additional LVDTs were also provided to measure global displacements of brace and chord members. A lot of strain gages were installed around the joint to monitor more detailed behavior.



















