

Full length article

Assessment of the bending capacity of welded hollow spherical joints with pit corrosion

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ABSTRACT

Welded hollow spherical joints (WHSJs) are widely used in space lattice structures. Corrosion is inevitable for WHSJ during service, and this phenomenon will significantly reduce loading capacity and seriously threaten the structural safety. Pit corrosion is a typical corrosion type for steel structures. In this study, nonlinear numerical analyses were conducted to investigate the influence of several parameters on the bending capacity of a WHSJ. A numerical model of the WHSJ with random pit corrosion was proposed to investigate the mechanical behavior of the corroded WHSJ. Results indicated that the moment capacity of the WHSJ with random corrosion pits was normally distributed. A probabilistic distribution model of the corroded WHSJ was proposed. The failure probability could be deduced based on the formulae of the upper and lower bounds of the moment capacity.

1. Introduction

Welded hollow spherical joints (WHSJs) are widely used in space lattice structures. These joints were developed in 1965 and first applied in a project of the Science and Technology Hall in Tianjin [1,2]. Many studies have been conducted on the mechanical behavior and influence of WHSJ on integral structures [3–5]. Han [6] studied the ultimate bearing capacity of the WHSJ, while Wang [7] used finite element (FE) approach to study the axial flexibility and flexural stiffness of WHSJ. Gu [8] studied the influence of WHSJ on single-layer latticed domes using refined finite element analysis (FEA). Zhao [9] investigated the influence of welding residual stress on the ultimate loading capacity of WHSJ.

However, the influence of corrosion, which would reduce the loading capacity of WHSJ, has not been discussed. Corrosion is inevitable for steel structures during service, especially for swimming pool and marine structures. The roof enclosing the swimming pool of the Tianjin University manifests signs of corrosion (Fig. 1). Corrosion always initially occurs at the conjunction of a pipe and a spherical body and the bottom of the spherical body, because water is frequently retained in these areas. This phenomenon can be verified by the absence of corrosion at the side of the WHSJ in the roof. The corrosion expanded to other locations with time. The dimensions of the corrosion in actual condition were closely related with the corrosion time and surrounding environment. The corrosion zone almost covered the overall surface of the WHSJ. Corrosion at the WHSJ would significantly decrease the

loading capacity and seriously threaten the structural safety. The WHSJ is remarkably corroded, but the influence of the corrosion pit on its loading capacity has not been well resolved.

Studies on corrosion have mainly focused on steel plates and steel pipe [10–12]. Ok et al. [13] performed more than 256 nonlinear finite element analyses (FEAs) of panels with various locations and sizes of pitting corrosion. They adopted multivariable regression to derive new formulae to predict the ultimate strength of the unstiffened plates with localized corrosion. Nakai et al. [14] conducted a series of tests to investigate the effect of pitting corrosion on the strength of web plates subjected to patch loading. Huang et al. [15] developed an assessment formula to predict the ultimate strength of a hull plate with pitting corrosion damage under biaxial in-plane compression loading. Sultana et al. [16] performed FEA to investigate the effect of random corrosion on the compressive strength capacity of marine structural units. Saad-Eldeen [17–19] performed a series of investigations on the influence of corrosion on box girders. Yu [20] assessed the effects of local random pitting corrosion on the collapse pressure of a 2D ring under external pressure. Zhao [21] investigated the bending performance of corroded WHSJ through parametric analysis, and the FE model was validated experimentally.

The stochastic probability theory is frequently adopted to predict the reliability of a steel structure with randomly distributed corrosion. Zhao and Zhai [22] performed a comprehensive set of experiments on aluminum alloy columns under axial and eccentric compression from 1999 to 2016.

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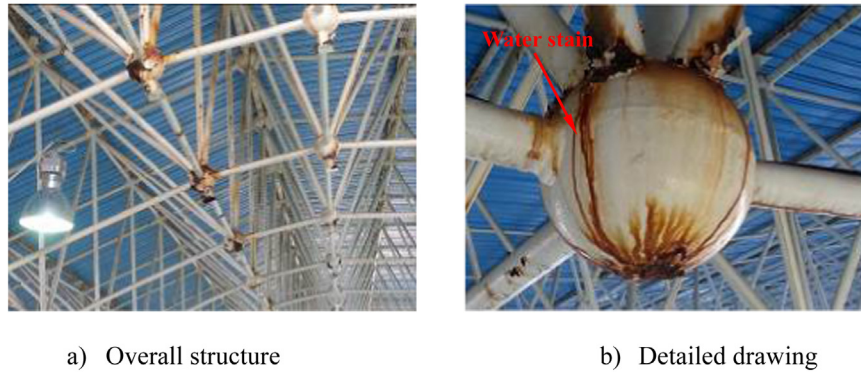


Fig. 1. Corrosion of the WHSJ.

The thickness of structural elements is reduced uniformly for general (uniform) corrosion. Then, the ultimate strength can be affected. The ultimate strength is typically calculated by excluding the loss in thickness, which will result in decreased plate slenderness and column slenderness. Many studies on the loading capacity have been conducted using empirical formulae, IACS rules, and FE method [23]. The corrosion pits in the present study were assumed to have uniform thickness.

The WHSJ is widely adopted in reticulated latticed shell structures and remarkably corroded. However, the influence of corrosion pit on loading capacity has not been well resolved. In this study, the influence of pit location on the bending capacity was systematically studied. Then, a numerical model of WHSJ with randomly distributed corrosion pit was established. A method to determine the probabilistic model was proposed. Thus, a foundation for estimating the reliability of structures connected by corroded WHSJ is provided.

2. Establishment of the FE model

A refined numerical model was established based on ANSYS code to investigate the influence of corrosion on the loading capacity on WHSJ. The element Shell 181 was adopted, and corrosion was simulated by reducing the thickness of the element [24]. Fig. 2 shows the FE model of the spherical body of a WHSJ constituted by the shell elements. The WHSJ is shear deformable and have four nodes with five independent degrees of freedom per node (three for translation and two for flexural rotation). The rigid beam option of the MPC184 element was adopted and established at both ends of the steel pipe. The loading point was established at the center of the steel pipe. The MPC184 element was used to connect the loading point and each node at the end of the steel pipe. Then, the bending moment was applied at the loading point. The transitional degree of the node at the bottom of the lower steel pipe was fixed.

The WHSJ may exhibit different patterns of corroded zones under practical condition. These patterns are categorized into latitudinal

pattern (pattern I), longitudinal pattern (pattern II), and pit corrosion (pattern III). Detailed information of the different patterns is shown in Fig. 3. The thickness of the element at the corroded zone was adjusted to model the influence of corrosion.

The reliability of the FE model was validated by comparing the model with the experimental results derived by Liu [25]. The same element and mesh scale in [21] were adopted in this study. More information on the validation can be found in [21,25]. Figs. 4 and 5 show that the FE model can accurately predict the ultimate loading capacity and the failure mode of the WHSJ.

3. Effect of corrosion parameter on bending capacity

3.1. Introduction of geometrical parameter

Several parameters are required to describe the corrosion pit at the surface of the WHSJ. Therefore, the T_c , D_c , and L_c/D are introduced to indicate the corroded thickness, diameter of corroded zone, and ratio of L_c and D . L_c indicates the specific location of the corroded zone. This parameter indicates the vertical distance between the center of the corrosion zone and the midsection of the WHSJ (Fig. 6). D indicates the diameter of the WHSJ. The detailed location between the moment and corrosion pit can be represented by the angle between the moment direction and line connect center of corrosion pit and WHSJ (Fig. 7). This angle is marked as β . The positive value of the moment indicated that the corrosion pit was located at the tension side ($0^\circ < \beta < 180^\circ$), and the negative value indicated the corrosion pit was located at the compression side ($180^\circ < \beta < 360^\circ$). Only two worst case locations were considered, namely, $\beta = 90^\circ$ and 270° , in the subsequent analysis.

The diameter of the corroded zone (D_c) indicated the size of the corrosion pit. The influence of corrosion on the loading capacity may increase with D_c . This effect was first investigated in this section. D_c values were set to 80, 160, 240, 320, 400, and 480 mm. L_c was first set to 0.25 m, and the detailed location of corrosion pit on the surface of

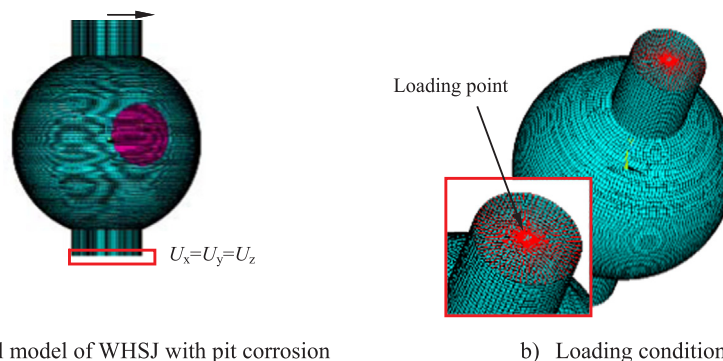


Fig. 2. Schematic of the FE model.

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