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Bending capacity of corroded welded hollow spherical joints

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A R T I C L E I N F O

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A B S T R A C T

Welded hollow spherical joints (WHSJ) have been widely used in space lattice structures. Corrosion is inevitable in the service life of WHSJ, which significantly reduces their bending capacity and seriously threatens their structural safety. This study aims to investigate the influence of corrosion that occurred at different places on the bending stiffness and bending capacity of WHSJ. The effects of corroded location and size, corroded thickness, and diameter and thickness of spherical body were investigated through a series of nonlinear numerical analyses. Two types of corroded shape were investigated. The equation used for predicting the residual bending stiffness of corroded WHSJ was established. Results indicated that corrosions in different places had distinct influence on the bending capacity of WHSJ. Loading capacity could be significantly reduced when corrosion occurred at other areas. The derived results would provide a foundation for estimating the residual bending stiffness and strength of structures connected by corroded WHSJ.

1. Introduction

Welded hollow spherical joints (WHSJ) have been widely used in space lattice structures. In 1965, WSHJ were developed and first applied on the project of Science and Technology Hall in Tianjin [1,2]. Several researchers have studied their mechanical behavior and their influence on integral structures [3–5]. Han [6,7] studied the ultimate bearing capacity of WHSJ, and Wang [8] investigated the axial flexibility and flexural stiffness of WHSJ by finite element (FE) approach. Gu [9] studied the influence of WHSJ on single-layer latticed domes by using a refined FE analysis (FEA). Zhao [10] investigated the influence of welding residual stress on the ultimate loading capacity of WHSJ. Liu [11] examined the post-fire behavior of WHSJ through experimental work.

Corrosion is a type of fatal injury for steel structures in their service phase. However, the abovementioned studies did not consider the influence of corrosion, which reduces the loading capacity of WHSJ. Corrosion is inevitable for the service phase of steel structures, especially for swimming pools and marine structures. Corrosion that occurred at the roof structure of a swimming pool in Tianjin University is shown in Fig. 1. The corrosion constantly initially occurred at the weld of steel pipe and spherical body and then expanded to other locations. Corrosion that occurred at WHSJ would significantly reduce their loading capacity and seriously threaten their structural safety.

Numerous researchers have investigated the influence of corrosion on steel plates [12–14]. Ok et al. [15] conducted over 256 nonlinear FEAs on panels with various locations and sizes of pitting corrosion and adopted the multi-variable regression method to derive new formulas in predicting the ultimate strength of unstiffened plates with localized corrosion. Nakai et al. [16] 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. [17] developed an assessment formula for predicting the ultimate strength of hull plates with pitting corrosion damages under biaxial in-plane compression loading. Sultana et al. [18] utilized FEA to investigate the effect of random corrosion on the compressive strength capacity of marine structural units. Saad-Eldeen [19–21] performed a series of investigations on the influence of corrosion on box girders.

The thickness of structural elements is uniformly reduced in general (uniform) corrosion. Then, the bending stiffness and ultimate strength of structural elements are influenced. Several existing studies have indicated that bending stiffness has a significant influence on the mechanical behavior of structures connected by semi-rigid connections [22,23]. Thus, the influence of corrosion on bending stiffness of WHSJ should be estimated in detail. Saad-Eldeen et al. [24] investigated the effect of corrosion degradation on the ultimate strength of corroded steel box girders and observed a significant reduction in stiffness. Ultimate strength calculations are typically conducted by excluding thickness loss, which will result in the decrease of the slenderness of plate and column. A considerable amount of research on loading capacity has been conducted by using empirical formulas, IACS rules, and FE methods [25].

The present study aims to investigated the influence of corrosion on the bending capacity of WHSJ. Effects of corroded location and size,

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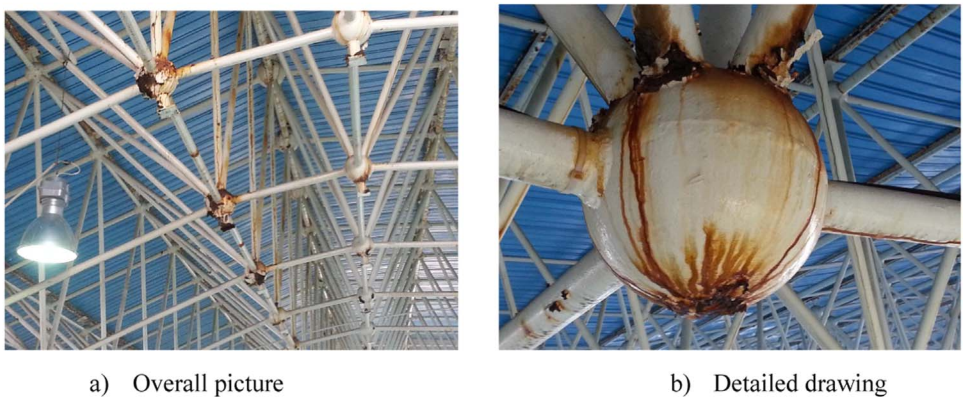

Fig. 1. Corrosion of WHSJ.

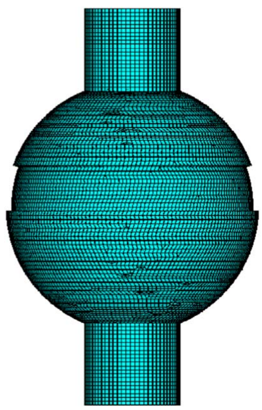

Fig. 2. Numerical model of corroded WHSJ.

corroded thickness, and diameter and thickness of spherical body were investigated through a series of nonlinear numerical analyses. FE method was adopted, and thickness loss was considered by specifying the section of shell elements. The derived results would provide a foundation for estimating the residual strength of structures connected by corroded WHSJ.

The shape of corrosion was idealized. However, the derived results revealed the influence of corrosion on the bending capacity and stiffness of WHSJ. WHSJ are the key component for reticulated shell structures. Thus, the detailed location of corrosion on WHSJ directly influences the safety of reticulated shell structures. The derived conclusions provide information on the influence of corrosion on WHSJ. These conclusions can be used as basis on estimating the residual loading capacity of overall structures. Relevant research on this aspect has yet to be conducted by researchers. The present work will thus provide an important reference for engineers in the maintenance of existing structures. Bending stiffness has a significant influence on the mechanical behavior of reticulated shell structures. Thus, the proposed calculating methods and formulas on estimating the residual stiffness of WHSJ will provide a foundation for estimating the mechanical behavior of reticulated shell structures connected by corroded WHSJ.

2. Establishment of FE model

A refined numerical model was established based on ANSYS code to investigate the influence of corrosion on the loading capacity of WHSJ. Element SHELL181 was adopted, and the corrosion was simulated by reducing the element thickness [29]. Fig. 2 shows the FE model of the spherical body of WHSJ constituted by shell elements, which is shear deformable and has four nodes with five independent degrees of freedom per node (three for translation and two for flexural rotation). The material of steel was Q345 whose yield strength, elastic modulus, Poisson ratio, and density were 345 MPa, 210 GPa, 0.3, and 7800 kg/m^3, respectively. The ideal elastoplastic model was adopted.

Corroded zones of WHSJ may exhibit different patterns under practical conditions. The distribution patterns of corroded zones were categorized into three types, namely, latitudinal pattern (Pattern I), longitudinal pattern (Pattern II), and pit corrosion. Detailed information on the different patterns is shown in Fig. 3. Symbol T_c and H_c indicate the corroded thickness and the height of corroded zone,

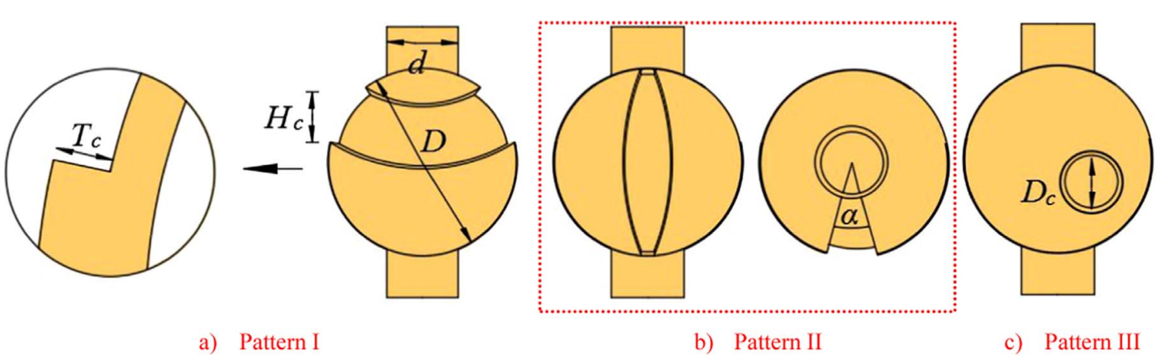

Fig. 3. Distribution patterns of corroded zone.