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Review Article

A review of stress concentration factors in tubular and non-tubular joints for design of offshore installations

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Abstract

Tubular structures are widely used in offshore installations, trusses, high rise buildings, towers for wind turbines, ski-lift installations, lightning, road pole signals etc., owing to their excellent structural performance and attractive appearance. Stress concentration, especially in the welded joints of these structures, is an important design consideration particularly for fatigue design. In the context of tubular and non-tubular joints, this paper provides a review of the experimental and numerical studies that have been carried out so far to determine the stress concentration factor (SCF). Emphasis is also placed on the complexity of capturing different types of stresses in tubular/non-tubular joints for estimation of SCF. Present code provisions for evaluation of SCF are also discussed. Further, a few issues, which require significant research effort to advance our understanding and to improve the current design guidelines, have been identified.

Keywords: Hot-spot stress; Stress concentration factor (SCF); Fatigue; Tubular joints; Non-tubular joints.

1. Introduction

Three dimensional structures fabricated from steel tubular sections are widely used these days in various structures such as trusses, high rise buildings, towers for offshore wind turbines, and offshore installations. This is because the tubular sections have inherent properties of minimizing the hydrodynamic forces, and possess high torsional rigidity as well as higher strength to weight ratio compared to the conventional steel sections. Hence, from construction cost as well as strength point of view, it is advantageous to use the tubular hollow sections for various applications, especially for offshore structures.

Typically used tubular sections in offshore platforms are circular hollow sections (CHS). However, in case of truss structures, bridges and high rise buildings, rectangular hollow sections (RHS) or square hollow sections (SHS) are commonly used. A connection between two or more tubular sections is refereed as tubular joint. For a tubular joint consisting of two pipes of different diameters, the larger diameter pipe is called the chord and the smaller one is known as the brace. Figs. 1 and 2, respectively show a few uni-planar and multi-planar tubular joints that are being used in offshore structures. Non-tubular joints are those where tubular member are connected to a non-tubular section such as tubular to a girder flange, girder flange connection to a vertical tubular leg member at ring stiffener plate and girder flange to a girder flange or flange plate. Schematic diagram showing these joints are provided in Fig. 3.

Many of these structures undergo several types of cyclic environmental/operational loading e.g., wind, wave, ice and traffic loads during their service lives. As a result, fatigue damage occurs in critical joints of these structures. Stacey and Sharp [1], Chang and Dover [2] verified the data provided by U.K.'s Health and Safety Executive and identified that the fatigue was the major cause of repair to steel offshore platforms in the North Sea. The most sensitive fatigue areas in offshore platforms are the welds in tubular joints.

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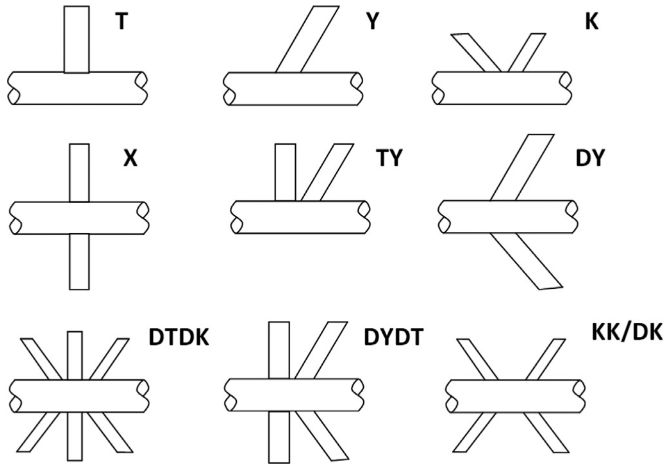

Fig. 1. Types of tubular joints along with their nomenclature.

1.1. Stress distribution in tubular and non-tubular joints

The total stress at a joint can be defined as the resultant of different stresses in the tubular/non-tubular joints as shown in Fig. 5. These are mainly due to the structural action (Nominal stress), stress arisen to maintain compatibility between different members (Geometric stress) and due to discontinuity at the joint (Local stress). A brief description of these stresses are provided as follows:

Nominal Stress: Nominal stress (σ_{nom}) can be calculated using the simple beam theory and the superposition principle without consideration of the localized weld effect and geometric discontinuity. The nominal stress can be determined as follows:

$$\sigma_{nom} = \frac{P}{A} \pm \frac{M}{I} y \tag{1}$$

where P is the applied axial compressive load, A is the cross-sectional area, M is the applied bending moment; and y is the position of the extreme fiber.

Geometric Stress: Geometric stress (σ_G) also known as the hot-spot stress/structural stress, is used to calculate the fatigue life of a tubular/non-tubular joints. Due to the difference in deformations between the brace and chord member of a joint, the tube wall tries to bend to maintain the compatibility and therefore, giving rise to geometric stress. This also results in the distribution of the membrane stress.

Local Stress: Local stress is caused mainly due to the local notch of the weld toe. It is a function of weld geometry and size. Thus, local stress is mainly dependent on the quality of welding and workmanship and it is quite difficult to incorporate such effects into formulation of stress concentration.

1.2. Stress concentration factor (SCF)

Fig. 4 illustrates the stress concentration phenomenon due to in-plane axial load. This figure clearly shows that local stress at the welded joint is several times higher than the nominal stress due to stress concentration. It may be noted that the local peak stresses are highly influenced by the weld profile.

There are different approaches for fatigue life analysis of a welded joint. These methods are distinguished mainly by the parameters used for the description of fatigue life *'N'* or fatigue strength. These approaches include nominal stress approach, structural or hot-spot stress approach, notch stress or notch intensity approach, notch strain approach, crack propagation approach, etc. Among these, hot-spot stress is the most widely used and recommended by various fatigue design guidelines (e.g., American Petroleum Institute (API) [3], CIDECT Design Guide No. 8 [4]).

The hot-spot stress method, also known as geometric stress method, considers the stress raising effect due to structural discontinuity except the stress concentration due to weld toe, i.e., without considering the localized weld notch stress. Hot-spot stress is the surface value of structural stress at hot-spots. The hot-spots are the locations at a welded joint where the initiation of cracks is possible under cyclic loading due to increased stress value. This method was developed in 1970s by the offshore platform operators with the help of research institutes. The main aim was the fatigue strength assessment

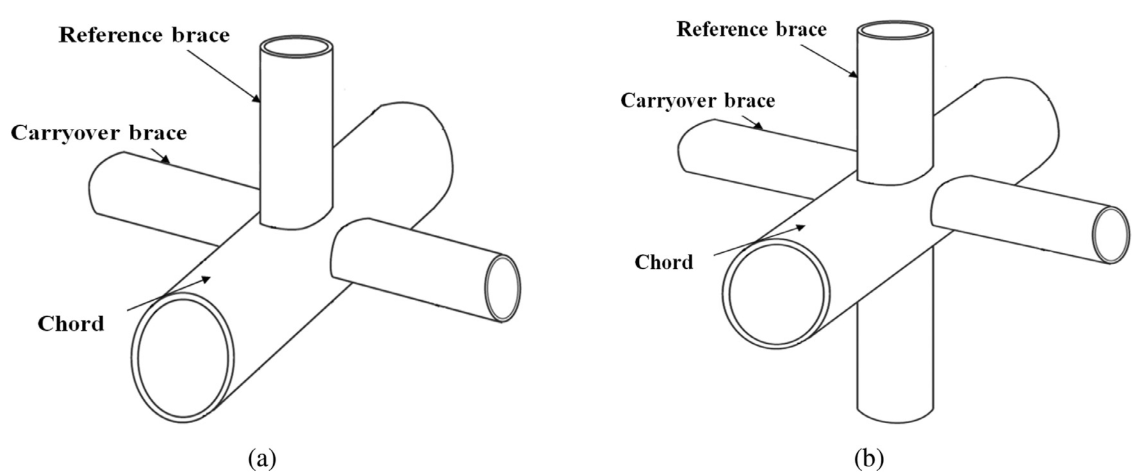

Fig. 2. Example of multi-planar joints (CIDECT Design Guide No. 8 [4]): (a) multi-planar XT joint and (b) multi-planar XX joint.