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The Ultimate Capacity of Multiplanar TT- and KK-Joints: Comparison of Data to Predictions of AWS and API Design Equations

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ABSTRACT

The lack of data on multiplanar joints is reflected by the inconsistent treatment of multiplanar joints in the various design codes. Traditionally, the design codes treat multiplanar joints as a series of uniplanar joints. The interaction between the different planes is ignored, while the uncertainty about the real behavior is covered by the safety factor. Many codes such as the American Petroleum Institute Design Code API-RP2A (API, 1991) follow this traditional approach by offering guidance limited to reducing the design problem of multiplanar to uniplanar joints. Only the American Welding Institute Structural Welding Code (AWS, 1992) provides formulae applicable to the entire range of axially loaded nonoverlapping multiplanar joints, but the formulation is not based on experimental evidence of multiplanar joints, as they were not available upon the first publication. In this paper these two major codes are reviewed in the light of newly available data on multiplanar joints. The API predicts the capacity of TT- and KK-joints conservatively, while the AWS exponential formulation overpredicts the capacity of TT-joints for a number of cases. For KK-joints, the predictions are on the safe side, but the accuracy of the AWS exponential formulation can be improved by using the in-plane gap factor of Lalani and Bolt.

NOMENCLATURE

CoV : Coefficient of variation
D : Chord diameter
d : Brace diameter
g_t : Transverse (out-of-plane) gap
g : Longitudinal (in-plane) gap
$P_{u,T}$: Ultimate brace load T-joint
$P_{u,TT}$: Ultimate brace load TT-joint
$P_{u,K}$: Ultimate brace load K-joint
$P_{u,KK}$: Ultimate brace load KK-joint
Q_f : Chord stress factor (API)
Q_g : In-plane small gap factor (to be used with AWS)
Q_g : Gap factor (API)
Q_{gt} : Out-of-plane small gap factor (to be used with AWS)
Q_u : Load and geometry parameter (API)
Q_β : $= 0.3/\beta(1-0.833\beta)$ (AWS)
T : Chord wall thickness
t : Brace wall thickness
Z : Shell parameter $= L/(RT)^{1/2}$ (AWS)

α_0 : Chord ovalization factor (AWS)
β : Diameter ratio $= d/D$
θ : In-plane angle between chord and brace
γ : Chord thickness ratio $= D/(2T)$
ϕ : Out-of-plane angle between the plane's braces in which the braces lie
ζ_l : In-plane gap parameter $= g/T$
ζ_t : Out-of-plane gap parameter $= g_t/D$

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KEY WORDS: Multiplanar joints, ultimate capacity, comparison with code predictions.

INTRODUCTION

Tubular three-dimensional space frames of circular members have a history of over 40 years in application as offshore drilling or production platforms. Extending from the sea floor to just above the sea surface, they combine the reduction of drag forces with the use of the inner space of the jacket legs through which piles are driven to resist vertical gravity and lateral storm loads. The intersecting braces which are connected to the continuous chord often lie in different planes, making multiplanar joints unavoidable features of space frames. In addition to the fatigue resistance, the ultimate resistance is the most important design parameter for such joints.

Considerable research in the field of the ultimate behavior of simple uniplanar joints has been undertaken for the last three decades; research on joints under axial brace loading led the way followed by moment loading, chord loading and combinations of all preceding loadings. These efforts have resulted in sophisticated formulae for axially loaded joints and to a lesser extent for moment loaded joints or combinations and are reflected in the various codes of practice. Studies into the behavior of multiplanar joints made of circular hollow sections are scarce when compared to their uniplanar counterparts and have only recently begun, due to an increasing need for a more realistic assessment of ultimate behavior which subsequently may result in improving guidance for designing multiplanar joints. Studies by van der Vegte et al. (1991) on XX-joints, Scola et al. (1989) and Paul et al. (1991) on TT-joints, and Akiyama et al. (1974), Makino et al. (1984, 1993), Mouty and Rondal (1992) and Paul et al. (1992a) on KK-joints are the only published experimental data until now. The experiments on TT- and KK-joints are summarized by Paul (1992b) and used as input for a data base of multiplanar TT- and KK-joints under symmetrical and antisymmetrical loading. Symmetrical signifies that the out-of-plane braces are loaded in the same sense as their in-plane counterpart, while antisymmetrical signifies that