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The Static Strength and Stiffness of Multiplanar Tubular Steel X-Joints

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ABSTRACT

Current design codes, used to predict the ultimate static load of uniplanar and multiplanar X-joints in circular hollow sections, are mainly based on extensive tests on simple uniplanar joints. Very few test results on multiplanar joints are available for verification. Therefore, a test series, consisting of 3 uniplanar and 9 multiplanar X-joints in circular hollow sections, has been carried out for determination of stiffness, ultimate static load and deformation capacity. The objective of this study is to investigate the influence of loaded and unloaded out-of-plane braces on the behaviour of statically loaded X-joints under axial load, in-plane bending or out-of-plane bending. A clear multiplanar effect is observed for the stiffness, strength and deformation capacity of multiplanar X-joints in comparison to uniplanar X-joints. Finally, the test results are compared with the values of the ultimate loads obtained from several design codes and recommendations. It appeared that the AWS code, which is the only code taking into account the multiplanar effects, gives conservative values for ultimate loads for axially loaded multiplanar joints.

NOMENCLATURE

d_0 : outer diameter of the chord
t_0 : wall thickness of the chord
d_1 : outer diameter of the in-plane brace
d_2 : outer diameter of the out-of-plane brace
$f_{y0,L}$: measured yield stress of the chord member (in longitudinal direction)
$f_{y0,c}$: measured yield stress of the chord member (in circumferential direction)
$f_{u0,L}$: measured ultimate tensile stress of the chord member (in longitudinal direction)
$f_{u0,c}$: measured ultimate tensile stress of the chord member (in circumferential direction)
l_0 : length of the chord
t_1 : wall thickness of the in-plane brace
t_2 : wall thickness of the out-of-plane brace
F : axial force in the in-plane braces
F_H : axial force (pre-load) in the out-of-plane braces
$F_{u,up}$: ultimate axial load of a uniplanar joint
$F'_{u,up}$: ultimate axial load of the joint according to the modified formula of Kurobane (1980, 1981). The pre-load on the out-of-plane braces is equal to 60% of $F'_{u,up}$.
$F_{u,mp}$: ultimate axial load of a multiplanar joint
M_{ipb} : in-plane bending moment
M_{opb} : out-of-plane bending moment
$M_{u,ipb}$: ultimate in-plane bending moment
$M_{u,opb}$: ultimate out-of-plane bending moment
M_p : full plastic moment of the brace(s)
N_p : squash load of the brace(s)
α : the geometric chord length parameter $2 * l_0 / d_0$
β : diameter ratio d_1 / d_0 and d_2 / d_0
γ : chord radius to thickness ratio $d_0 / 2 * t_0$
τ : the wall thickness ratio t_1 / t_0

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INTRODUCTION

In offshore structures it is common practice to analyse and design multiplanar joints with braces in different planes as being uniplanar.

Initial investigations (Paul, 1989; van der Vegte, 1989) have shown that, depending on the geometry and the loading, this may result in actual strengths which are either 30% lower, or in some cases even 100% higher, than the ultimate strengths for uniplanar joints.

Furthermore, the stiffness and the deformation capacity of multiplanar joints are largely influenced by multiplanar loading effects.

Of the existing codes, only the AWS (1988) takes the multiplanar effects into account. The AWS — as well as other codes — is based on an extensive series of tests on uniplanar joints. Very few test results on multiplanar joints are available.

The influence of the multiplanar effects on strength is expected to be most severe for X-joints. Furthermore, the load transfer for this type of joint is more straightforward, and the behaviour easier to understand, than for other types of joints. Therefore, in this study, the influence of loaded and unloaded out-of-plane braces on the static strength, stiffness and deformation capacity of X-joints in circular hollow sections has been determined experi-