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Elastic-Plastic Moment-Rotation Characterisation of Tubular YT-Joint Using an Energy Method for Response Prediction

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ABSTRACT

A complementary energy method is presented for the prediction of non-linear, elastic-plastic brace-end rotation responses of a simply-supported YT-joint under the action of combined T- and Y-brace in-plane moment loading histories, corresponding to radial load paths in the load space. The method is based on a series of geometrically and materially non-linear finite element analyses of the YT-joint, simulating joint response up to and beyond maximum load-carrying capacity.

KEYWORDS: tubular joint, complementary work, non-linear FE, moment-rotation prediction, radial loading.

INTRODUCTION

The non-linear static pushover analyses of steel jacket frameworks for the determination of structure collapse and other stucture reliability estimates, such as reserve strength ratio (RSR) (Banon, 1994), is conventionally based on the use of finite element (FE) idealisations consisting of three-dimensional beam elements. The behaviour of the joints under the extreme loads corresponding to the attainment of maximum load in the framework force-displacement response is highly non-linear and typical assumptions ignoring local joint behaviour may not be accurate; inelastic material behaviour typically occurs at the welded joints first, due to the associated concentration of stress. It is difficult to model the joints accurately enough to incorporate this local non-linear behaviour in the global analyses, due to the large numbers of three-dimensional (3D) shell or brick elements required, not to mention the enormous run-times that would be required for such incremental/iterative FE analyses.

A large amount of work has been done in relation to the linear, elastic local joint behaviour for axial force, in-plane bending (IPB) and out-of-plane bending (OPB), e.g. Chen (1993), UEG (1984), Fessler (1986), Ure (1993), and some work on the elastic-plastic local joint behaviour has been carried out by Ueda (1990); the method presented here adopts a fundamentally different approach and basis (i.e. an energy-based method) to that of Ueda (1990).

The present work is related to the development of a single elastic-plastic joint element to represent each joint in a typical framework model, with the joint elements being interconnected by conventional beam or beam-column elements. The authors have previously presented the basis of the 'constitutive' behaviour of such an element, in terms of generalised stress and strain (i.e. force and displacement), for the case of a simply-supported YT-joint under the action of combined axial T- and Y-brace forces, based on FE analyses (Hyde, 1997); it was shown that using the results of a set of twenty-four 'basis' loadcases (each corresponding to a non-linear FE analysis with a different T- to Y-brace applied force ratio) the displacement response for other 'non-basis' loadcases could be predicted, without necessitating additional FE analyses. The predictions were restricted to radial force paths in the two-dimensional load space of T- and Y-brace forces, i.e. proportional and monotonically increasing. With non-radial load paths a modification to the method presented is required; this issue is to be dealt with in a future publication.

In this paper the results of a series of twenty-five non-linear FE analyses of the simply-supported tubular YT-joint, under the action of combined T-/Y-brace end IPB moments, are presented; the large displacement/finite strain inelastic analyses simulate the response of the joint up to and beyond failure, which is defined as the first peak in the moment-rotation response. These results are then used to derive a set of complementary work level curves, in the two-dimensional load space of Y-/T-brace moments, for the moment-rotation response of the joint, as done by the authors for axial forces (Hyde, 1997). The non-linear evolution of brace-end rotations to collapse is then calculable from this set of level curves for any specified radial load path (i.e. proportional, no unloading of applied moments) in the moment load space, using the method of complementary energy/work (Langhaar, 1962), which is a generalisation of Castigliano's theorem, and the principle of maximum plastic work (Calladine, 1985). The prediction procedure is implemented numerically in a computer program to