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Characterisation and simulation of X60 elbow pipes in case of ULCF loading

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A general problem for the design of buildings and line pipe structures is the lack of economic and safe rules in case of ultra-low-cycle-fatigue loads (ULCF). In general, the design of steel structures is related to stress limit demands. By ULCF loading the design has to be based on strain limits because of significant value of plastic deformation. Common situations of ULCF are, for example, seismic loads. Especially during the devastating earthquakes in Northridge (USA) and Kobe (Japan), it was observed that many structures designed according to existing rules were unable to resist the extraordinary seismic loads.

To ensure safe plastic design, precise description of plasticity and accurate strain limit criteria are required. The determination of local plastic strains, especially in case of complex geometries under strong cyclic loading conditions, is possible solely by means of numerical analysis. In doing so, the accuracy of the results is significantly dependent upon the utilised plasticity model.

For development of an approved design layout, experimental investigations are needed as basis. Therefore large-scale tests on elbow pipes (16" diameter, 9.5mm thickness, X60 grade) have been conducted. The tests include specimens with elbow angles of 45° and 90°. The elbows were tested at internal pressure with increasing cyclic bending acc. to the recommended ECCS testing procedure [1]. The tests were performed till the complete fracture of the pipe. During the experiments the actuator stroke, reaction force, local strains, inner pressure and the ovalization of the midsection have been measured.

In many cases the plasticity parameters defined on small scale samples have a restricted application field. If these parameters were used in the material model on large scale structures, the discrepancy between results would be high. Therefore, two different approaches have been followed for the numerical simulation of the large-scale tests. The first approach was to determine the cyclic properties with small-scale smooth and notched samples. The achieved experimental results were interpreted in the framework of the non-linear kinematic hardening plasticity model provided by Armstrong-Frederick [2]. In addition the required material parameters for the plasticity model have been estimated by an inverse analysis of the experimental results. From this analysis the plasticity model parameters were estimated to fit force displacement curves of large scale tests. The obtained plastic parameters provide good approximation of material data in wide range of loading amplitudes.

Beside the problem of plastic description of steel structures, the future aim for numerical investigations is the implementation of an accurate damage criterion. The definition of such a damage criterion can be done in terms of CDM (continuums damage mechanics) models. For the verification of CDM model material characterisation in terms of Manson-Coffin curves is needed. In case of ULCF loading, this characterisation can be done on small-scale notched samples with subsequent analysis of experimental results.

Finally the large scale tests were modelled by using a combined continuum damage model. The material models used here are based on combination of two damage models with some modifications [3] [4]. The combined material model is named as MBWOT-model, MBWOT stands for Modified Bai-Wierzbicki-Ohata-Toyoda model.

The comparison of experimental and simulated results shows good agreement in case of plastic deformation and prediction of damage.

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