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NUMERICAL MODELLING OF STEEL PIPELINES SUBJECTED TO SEVERE MONOTONIC AND CYCLIC STRAINING

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Most of the existing pipeline design codes are based on limiting stress criteria, which is considered acceptable for steel with a well-defined yield point, ductility and strength. Nevertheless, in certain cases such as earthquakes, landslides, during the laying of submarine pipelines and other displacement control loads, the stress in pipelines may exceed the limit under some loads, therefore the strength design criteria based on stress are no longer valid. Stress-based design criteria are based on the minimum yield stress of a pipeline, while strain-based design criteria are based on limit state design and displacement-controlled load. If the safe operation can be ensured under displacement-controlled loads, the pipeline strain is allowed to be more than the specified yield strain.

The primary areas where strain-based design is adopted are the design of reeled laying of offshore pipelines, in thermal design of arctic pipelines, in design of types of offshore pipe lay systems, in the assessment of pipelines in areas with significant expected ground movement, and in HT/HP applications. In the strain-based design of pipelines, there may be also some applications where cyclic loads cause occasional peak stresses above the pipe yield strength. In these cases, the cyclic lifetime assessment is improved by using strain ranges instead of stress ranges for the description of the load effects of each cycle. Moreover, design of pipelines to resist ratcheting has become more important recently because of the thermal cycle effects on high-temperature pipelines and flowlines. As for other types of cyclic loading, the currently available design methods are relatively conservative, but have been shifting to allow more cycles of plastic strain.

Both for monotonic and cyclic loading, codes propose some advanced procedures which imply the extensive use of numerical modelling (i.e. by means of the finite element method). In this case a greater effort is needed in extending the material behavior knowledge, which should be followed by a proper modelling description within the numerical codes. Despite the fact that significant efforts have been put in the codes to take into account for complex loading scenarios, the need for advanced material modelling techniques and limit state criteria is still a fundamental issue. In the present paper a contribution towards the development of material modelling best practices is given. Modelling issues, both under monotonic and cyclic loading conditions, are discussed. In addition, material strain limit state conditions are presented and a comparison with available design codes recommendations is attempted.

Under monotonic loading, a new isotropic criterion able to capture the influence of the third invariant of the deviatoric stress tensor on plasticity and fracture has been developed. A nonlinear damage accumulation rule, also applicable under non proportional loading paths, is used to predict the material strain limits under complex stress states. Accordingly to the above modelling framework, a comparison with the existing codes is presented, evidencing possible improvements.

Under cyclic loading conditions, a mixed nonlinear kinematic hardening/isotropic rule is adopted for the description of the material elastic-plastic behavior. In addition, a damage accumulation rule based on the evolution of an effective equivalent plastic strain is utilized. A special-purpose user-subroutine has been developed for the incorporation of the combined cyclic plasticity and damage model into a commercial finite element code and it has been employed for the simulation of a cyclic loading material test. The simulation results are found to be in good agreement with the experimental findings. Finally, for the example under consideration, a prediction of the number of cycles to crack initiation is attempted. The prediction is found to be on the safe side with respect to the experimentally defined number of cycles to failure of the specimen.

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