Advanced Cyclical Numerical Material Model Supports Pipeline Reel-lay

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ABSTRACT

Reel-laying rigid pipelines induce cyclic deformation that affect the section. Among other, excessive ovality may jeopardize pipe strength during installation & in-service. Previous works shown that conventional material stress-strain relation is no longer suitable for pipeline reel-lay simulations. This paper introduces an advanced model for material behaviour. The evolution of the material behavior and its variations on the cyclic loads paths is detailed. The model uses stress-strain relations and yield surface evolution from the first load curve, with Lüders plateau leading to stabilized cycle with material property variations in cycles. The model has been implemented in finite element software. This model calibration and validation are discussed in this paper. Simulation accuracy is improved compared to published results.

KEY WORDS: rigid pipeline; material model; cyclic loading; Abaqus user subroutine; reel-lay; FE simulation; tests

INTRODUCTION

The pipeline reeling installation process can be a cost-effective installation method for infield flowlines/risers and smaller diameter export lines under certain economical, logistical and technical circumstances. Saipem has acquired a recent pipeline construction vessel, Constellation, which has been designed as a high-performance construction and lay vessel, capable of performing in the world’s hardest environments and designed to meet the requirements of current deep and ultra-deep-water projects.

During offshore reeling installation, and possibly later pipeline recovery and re-reeling installation, the pipe is reeled, unreeled and straightened. During the process, part of the pipe cross-section has experienced varying levels of plastic deformation in compression and tension, in a cyclic manner. Throughout these steps, the plasticity deformation has modified the pipe material properties, while the other part remains in the elastic domain.

Materials under cyclic loading can harden both kinematically and isotropically (or anisotropically). For applications where cyclic loads stay within a single cycle, hardening process comes mainly from kinematic hardening while yield domain surface evolution is negligible. Within a single cycle, Bauschinger effect drive the model behavior, while variation of this behavior through cycles comes from isotropic hardening. The Bauschinger effect refers to a property of materials where the material's stress/strain characteristics change as a result of the microscopic stress distribution of the material. An increase in tensile yield strength occurs at the expense of compressive yield strength. After increasing the tensile yield strength, the local initial compressive yield strength is actually reduced. The greater the tensile strengthening, the lower the compressive yield strength.

Over several cycles, the material also hardens isotropically. This means the peak tension and compression stresses in a given cycle increase from one cycle to the next until saturation is achieved. This process is often called cyclic hardening, as it often occurs from cycle to cycle over many cycles. Kinematic hardening, on the other hand, occurs within each cycle. Consequently, the material property across the pipe section will change at each reeling step with the cyclic straining.

Significant efforts on material modeling has been performed and published, to predict accurately material property variation during reeling. A plasticity model (Martinez and Brown, 2005), has been presented as an Abaqus user material model (UMAT), which is based on an anisotropic Hill criterion (Abaqus User Manual Collection, 2014) and attention is paid to the hardening.

Based on small scale specimen tests performed to describe the material behavior under plastic cyclic straining, another material model has been proposed (Karjadi et al, 2013; Karjadi et al., 2015a). The non-linear kinematic hardening and Hill’s potential model (Abaqus User Manual Collection, 2014) and the Lemaitre-Chaboche material model (1990) were used in FE analysis. In Karjadi et al, 2015b, cross-hardening characteristics of material under cyclic plastic deformation modeled using “distortional plasticity” principle was implemented in a user subroutine of Abaqus FEA software as a user defined material model (UMAT).

Material evolution models are discussed in (Sriskandarajah and Rao, 2015). The material test data using the combined isotropic and kinematic hardening material model were used to develop a material model representative of the cyclic plasticity for the pipes using combined isotropic and kinematic hardening material model. The