Development of Surface Flaw Interaction Rules for Strain-Based Pipelines

Huang Tang, Doug P. Fairchild and Wentao Cheng
ExxonMobil Upstream Research Company
Houston, Texas, USA

Wan Kan*, Mike Cook and Mario L. Macia
ExxonMobil Development Company
Houston, Texas, USA

Strain capacity prediction is important for strain-based design (SBD) of welded pipelines. Current strain capacity prediction models consider only a single flaw. Practical engineering tools are needed to assess cases in the presence of multiple defects. In the current paper, it is shown that the existing flaw interaction rules developed for allowable-stress design are not applicable for SBD, which can lead to overly conservative or nonconservative assessment. A combined numerical modeling and experimental testing investigation was performed to develop interaction rules for coplanar surface flaws specific to SBD pipelines. Advanced finite element (FE) modeling was used to simulate flaw interaction, and full-scale tests (FSTs) were conducted to study the effects of flaw spacing on pipeline strain capacity. The FE modeling was first validated against the experiments and then used to develop surface flaw interaction rules through a parametric FE study. Using the rules, multiple flaws were converted into an equivalent single flaw resulting in the same pipeline strain capacity. The developed flaw interaction rules provide a useful tool for conducting engineering critical assessment (ECA) for strain-based pipelines in the presence of multiple flaws.

NOMENCLATURE

- \( a_e \): Effective Flaw Depth
- \( \text{CTOD} \): Crack Tip Opening Displacement
- \( \text{EDM} \): Electro Discharge Machining
- \( \text{FEA} \): Finite Element Analysis
- \( \text{FST} \): Full-Scale Tests
- \( \text{ID} \): Inside Diameter
- \( K \): Strength Coefficient
- \( \text{MA} \): Misalignment
- \( N \): Strain Hardening Coefficient
- \( \text{OD} \): Outside Diameter
- \( s \): Flaw Spacing
- \( \text{SBD} \): Strain-Based Design
- \( \text{SENT} \): Single-Edge Notch Tension
- \( t \): Wall Thickness
- \( \text{TSC} \): Tensile Strain Capacity
- \( \text{UEL} \): Uniform Elongation
- \( \text{UTS} \): Ultimate Tensile Strength
- \( \text{WCL} \): Weld Center Line
- \( Y \): Yield Strength at 0.5% Engineering Strain
- \( \text{Y/T} \): Yield-to-Tensile Ratio
- \( 2c_1 \): Shorter Flaw Length
- \( 2c_2 \): Longer Flaw Length
- \( 2c_e \): Effective Flaw Length
- \( \sigma_Y \): True Yield Strength

*ISOPE Member.

INTRODUCTION

The capability of designing pipelines to safely and economically traverse regions of harsh environmental conditions plays a critical role in the development of remote energy resources. In these regions, pipelines may be potentially subjected to large plastic deformation in the longitudinal direction resulting from environmental loadings, such as earthquake fault rupture, soil liquefaction, frost heave, thaw settlement, and ice gouging (Nixon, 1991; Nobahar et al., 2007; Selvadurai, 1993). Strain-based design (SBD) is one engineering approach intended to deal with these loading conditions and ensure pipeline integrity while sustaining a finite amount of plastic deformation (Macia et al., 2010). To take full advantage of SBD, design codes generally developed for stress-based design need to be updated.

A conventional approach to deal with multiple flaws in a pipeline girth weld is to combine them into a single equivalent flaw amenable to analysis in a process known as recharacterization. The