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Development of Surface Flaw Interaction Rules for Strain-Based Pipelines

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

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KEY WORDS: Strain-based design, strain capacity, flaw interaction rule, full-scale tests.

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.

The ability of a welded pipeline to sustain finite longitudinal tensile plastic deformation while maintaining pressure containment integrity is characterized as tensile strain capacity (TSC). Prediction of the TSC of welded pipelines is an important topic for SBD and has been a subject of ExxonMobil research (Minnaar et al., 2007; Kibey et al., 2008, 2009, 2010; Fairchild et al., 2011, 2012; Wang et al., 2009, 2010). The previous studies on TSC prediction were focused on a single surface flaw. However, the occurrence of multiple flaws in a pipe girth weld is not uncommon and mainly results from pipeline construction (welding). The effects of multiple interacting flaws on TSC have not been completely understood. An overly conservative prediction of TSC in the presence of multiple flaws can increase unnecessary weld rejection and repair rate. On the other hand, a nonconservative prediction increases the risk of potential pipeline failure under the design environmental loading conditions. Accurate and reliable prediction of TSC in the presence of multiple flaws is beneficial to efficient pipeline fabrication through engineering critical assessment and to fitness for service (FFS) assessments.

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