Buckling Resistance of Line Pipes with Girth Weld Evaluated by New Computational Simulation and Experimental Technology for Full-Scale Pipes

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This paper deals with the buckling behavior of UOE pipes under a bending moment. Full-scale bending tests were performed to evaluate the compressive strain limit ($\varepsilon_{\text{L-limit}}$). During the numerical simulation, the pipe was modeled using the measured pipe profile and the material constitutive law newly developed to analyze the orthogonal anisotropy. The test results verified that $\varepsilon_{\text{L-limit}}$ was not degraded by aging during the anti-corrosion coating, although it declined for pipes with girth welds. The results obtained from the validated models suggest that the conventional method using the isotropic work hardening law may overestimate $\varepsilon_{\text{L-limit}}$ under high internal pressure.

NOMENCLATURE

- $C$ = circumferential
- $D$ = pipe diameter, mm
- $D_\text{av}$ = average diameter, mm
- $D_\text{min}$ = minimum diameter, mm
- $D_\text{max}$ = maximum diameter, mm
- $L$ = pipe length, mm
- $L_\alpha$ = longitudinal
- $D_\beta$ = distance between inclinometers, mm
- $P_\text{f}$ = internal pressure, MPa
- SMIP = specified minimum internal yield pressure
- SS = stress-strain
- $t$ = wall thickness, mm
- $x$ = axial position, mm
- YPE = yield point elongation
- YS = yield strength, MPa
- $w$ = radial displacement of pipe radius, mm
- $\alpha$ = geometric imperfection
- $\varepsilon_{\text{comp}}$ = compressive strain
- $\varepsilon_{\text{L-limit}}$ = compressive strain limit
- $\varepsilon_{\text{neutral}}$ = strain at neutral position
- $\varepsilon_0$ = strain just after internal pressure
- $\theta$ = angle of inclination on both sides of wrinkle, rad
- $\lambda$ = buckling wavelength, mm
- $\nu$ = Poisson’s ratio

INTRODUCTION

Design technique, or so-called strain-based design (SBD), is applied for line pipes buried in discontinuous permafrost subject to ground movement such as frost heave and subsidence, while tensile and compressive strain limits are considered into SBD, represented by the joint integrity of the girth weld and the buckling resistance of the pipe body (Glover and Rothwell, 2004; Barbas and Weir, 2007). This paper describes the buckling resistance of UOE line pipes under a bending moment with internal pressure, which is the typical loading condition in discontinuous permafrost. Generally, bending deformation is allowable up to the peak moment, since local buckling leads to excessively high strain inducing pipe burst. The early local buckling increases the maintenance cost of pipelines.

Many studies note that the major dominating factors for pipe buckling include the material characteristics and the pipe geometries (Suzuki et al., 2003; Tsuru et al., 2007). Pipe manufacturers have developed line pipes with high strength and deformability, which are mainly designed by chemical compositions and the TMCP (Thermo Mechanical Control Process) condition during the plate manufacturing process (Shinohara et al., 2005). However, the plastic working in the pipe forming, and the strain aging by heat during the anti-corrosion coating, change the mechanical properties of the plate. Both forming and aging result in significant orthogonal anisotropy, whereby the stress vs. strain (SS) curve differs between the longitudinal ($L$-) and circumferential ($C$-) directions (Liu and Wang, 2006; Treinen et al., 2008). Many attempts have been made to show the effect of the $L$-$SS$ curves on buckling resistance, although the undeveloped constituent model of the material prevents us from solving the effect of the orthogonal work-hardening anisotropy.

Regarding the pipe profile, the geometric imperfection caused by the girth weld is the most significant factor when conservatively estimating the buckling resistance. A few studies have been undertaken to investigate the harmful influence of the offset in the girth weld on the tensile strain limit (Kibey et al., 2008). Murray and Yoosef-Ghodsi reported the buckling resistance of the girth-welded line pipe in experimental and numerical approaches (Murray, 1997; Yoosef-Ghodsi et al., 2000). However, there have been few attempts to examine the combined effects of the offset and material aging on $\varepsilon_{\text{L-limit}}$.

The objectives of this study are to verify the newly developed work-hardening law, to clarify the effects of strain aging and geometric imperfections on buckling resistance, and to construct an FEA (Finite Element Analysis) model for parametric studies.

Full-scale bending tests were performed for 3 pipes (914 D $\times$ 19.8 t, X80), as received (not heated), aged, and girth-welded under 72% SMIP (Specified Minimum Internal Pressure). In the numerical simulation, the constitutive model of the material, considering orthogonal anisotropy, is innovated into the FEA model of a UOE pipe, while the geometric imperfections are modeled by reflecting the measured profile of the pipe’s outer surface. In addition, simple models are also prepared for parametric studies.