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Structural integrity evaluation of X52 gas pipes subjected to external corrosion defects using the SINTAP procedure

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Abstract

In the present study, the SINTAP procedure has been proposed as a general structural integrity tool for semi-spherical, semi-elliptical and long blunt notch defects. The notch stress intensity factor concept and SINTAP structural integrity procedure are employed to assess gas pipelines integrity. The external longitudinal defects have been investigated via elastic–plastic finite element method results. The notch stress intensity concept is implemented into SINTAP procedure. The safety factor is calculated via SINTAP procedure levels 0B and 1B. The extracted evaluations are compared with the limit load analysis based on ASME B31G, modified ASME B31G, DNV RP-F101 and recent proposed formulation [Choi JB, Goo BK, Kim JC, Kim YJ, Kim WS. Development of limit load solutions for corroded gas pipelines. Int J Pressure Vessel Piping 2003;80(2):121–128]. The comparison among extracted safety factors exhibits that SINTAP predictions are located between lower and upper safety factor bounds. The SINTAP procedure including notch-based assessment diagram or so-called 'NFAD' involves wide range of defect geometries with low, moderate and high stress concentrations and relative stress gradients. Finally, some inspired and advanced viewpoints have been investigated.

Keywords: Gas pipeline; External corrosion defects; SINTAP; Notch stress intensity

1. Introduction

Pipelines have been employed as one of the most practical and low cost methods for oil and gas transmission since 1950. Pipeline installation for oil and gas transmission has drastically increased in the last three decades. The economical and environmental considerations involve structural integrity and safety. Therefore, reliable structural integrity and safety of oil and gas pipelines under various service pressure events including defects should be warily evaluated. The external defects, e.g. corrosion defects, gouges, foreign object scratches and pipeline erection activities are major failure reasons of gas pipelines. In the present work, finite element stress analysis for API X52 is performed including longitudinal external defects under high internal pressure. The failure assessment and structural integrity of the gas pipeline have been compared with SINTAP failure assessment levels (levels 0B and 1B) [2] and limit load analysis (ASME B31G, modified ASME B31G, DNV RP-F101 and Choi et al. [1]). The elastic–plastic finite element analysis is utilized and the SINTAP procedure is applied to the notch problem for calculating the structural integrity of the considered pipelines.

2. Assessment of corrosion defects

In Fig. 1, a list of methods available for corrosion defect assessment is presented. The methods are grouped vertically by their type, codified methods or others, and horizontally by their applicability, pressure or combined loading, etc. The structural integrity of corrosion defects is substantially studied and the outcomes for gas pipelines are classified in ASME B31G [3] and DNV RP-F101. In Fig. 1, the coded methods, i.e. ASME B31G, modified ASME B31G [4,5] and DNV RP-F101 are taken into account.

Moreover, the SINTAP procedure is also considered to be investigated for the structural integrity assessment of corroded pipelines. In the present study, corroded pipes under pressure excluding combined loading and external force are addressed.

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Nomenclature

D	outside diameter	ε_{ref}	reference strain
t	wall thickness	σ_{ref}	reference stress
L	longitudinal corrosion defect length	K_{ρ}	notch stress intensity factor
d	corrosion depth	σ_{eff}	effective stress
P_f	failure pressure	σ_{max}	maximum stress
M	bulging factor	X_{eff}	effective distance
σ_Y	yield stress	X_n	distance at the end of zone III
σ_f	flow stress	$\chi(r)$	relative stress gradient
σ_U	ultimate tensile stress	$\sigma_{yy}(r)$	maximum principal stress
Q	corrector factor	$\Phi(r)$	weight function
R	outside radius	$\delta(x)$	Dirac's delta function
D_i	inside diameter	$A\%$	relative elongation
k_r	non-dimensional stress intensity parameter	n	hardening exponent
L_r	non-dimensional loading based parameter	K	hardening coefficient
L_r^{max}	maximum of L_r	K_C^*	fracture toughness
SF	safety factor	k_t	elastic stress concentration factor
$f(L_r)$	interpolating function	k_{σ}	elastic–plastic stress factor
μ	first correction factor	σ_g	applied circumferential stress
N	second correction factor	P_{app}	applied internal gage pressure
E	modulus of elasticity	F_s	safety factor using SINTAP procedure
ν	Poisson's ratio	F_S	security factor using SINTAP procedure

2.1. ASME B31G and modified ASME B31G

ASME B31G is a code for evaluating the remaining strength of corroded pipelines. It is a supplement to the ASME B31 code for pressure piping. The code was developed in the late 1960s and early 1970s at Battelle Memorial Institute and provides a semi-empirical procedure for the assessment of corroded pipes. Based on an extensive series of full-scale tests on corroded pipe sections, it was concluded that pipeline steels have adequate toughness and the toughness is not a significant factor. The failure of blunt corrosion flaws is controlled by their size and the flow stress or yield stress of the material. The input parameters include pipe outer diameter (D) and wall thickness (t), the specified minimum yield strength (σ_Y), the maximum allowable operating pressure (MAOP), longitudinal extent of corrosion (L_c) and defect depth (d).

According to the ASME B31G code, a failure equation for corroded pipelines was proposed by means of data of burst experiments and expressed with consideration of two conditions below.

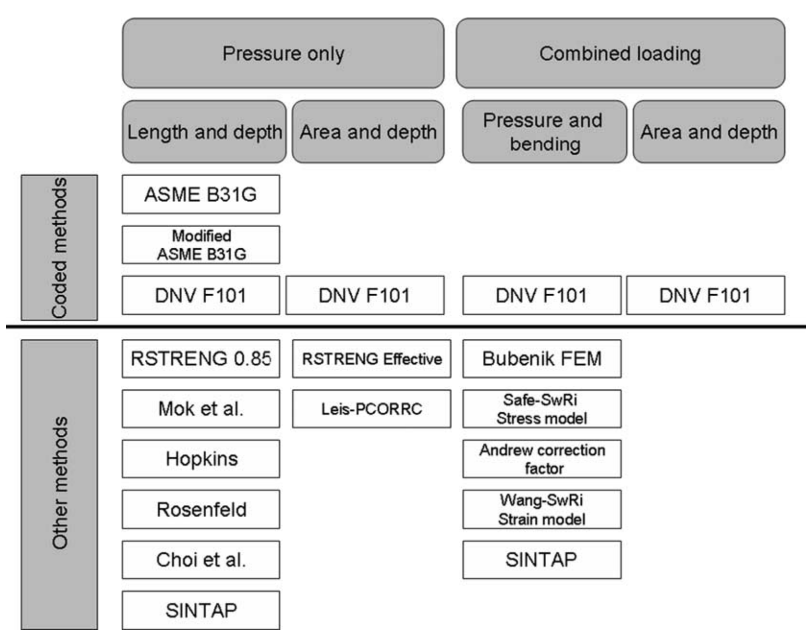

Fig. 1. Methods for corrosion assessment including codified and other methods.