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Study of the influence of dent depth on the critical pressure of pipeline

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ABSTRACT

The origin of more than 90% in service pipeline failures is attributed to the presence of stress concentration areas such as defects in forms of gouges, dents, or when these defects are present together. These defects are provoked by external factors interferences, for instance by excavation machines. The influence of the dent depth on the burst pressure of the pipeline was evaluated. An approach based on a simple local strain criterion has been proposed to predict the damage and the failure of evaluated dented pipe. To validate a purely empirical rule, which specifies that a critical depth dent is equal to 10% of outside diameter of the pipeline, a series of mechanical tests (denting tests and burst tests) were conducted. Finite element analysis used in order to compare the numerical and experimental results. Experimental results showed that a single dent did not affect the burst pressure of the investigated specimens; therefore the rule of a critical depth of dent equal to 10% was found very conservative.

1. Introduction

Over the last 50 years, gas transmission pipelines have become significant networks to transmit high energy quantities on long distances from gas deposits to consumption areas. Considering European Transmission Pipelines only, the onshore network mileage has been multiplied by more than three times between 1970 and 2007. But, despite the growth of the gas transmission pipeline mileage, the failure frequencies by leak or rupture have been reduced by five in Europe at the same time. According to the European Gas pipeline Incident data Group report (EGIG report [1]) which has collected incident data along 129,719 km since 1970, the primary failure frequency over the entire period (1970–2007) was equal to 0.37 per (1000 km year) and was over the last five years in 2007 equal to 0.14 per (1000 km year).

The pipeline safe operation and high reliability depend on various factors: mechanical damages or external interference, fatigue cracks, material defects, weld cracks, improper welding, internal or external corrosion and most of all on the ageing of the physical state of the pipeline metal and welded joints. The damage caused by human error or vandalism are not infrequent either.

Six different causes of incidents have been identified and are given in Table 1 with their percentage of occurrence.

It can be noted that mechanical damage (external interference) is the major cause of transmission pipeline failures in Europe. These types of damage can be classified into gouges and dents. Defect assessment in pipeline is made using different tools according to defect types and fracture modes.

In Western Europe, weather patterns are such that the pipe steels remain ductile. Consequently limit analysis is generally used for non severe defects such as corrosion defect [2], gouges [3] or dents [4]. For severe defects such as crack in welds [5], sharp gouges [6] or a combination of a dent and a gouge [7], a fracture mechanics approach is generally used.

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Nomenclature

H	dent depth in the non pressurized condition
H_0	depth of the dent in the pressurized condition
D_e	pipe outside diameter
R	outer radius of pipe
t	wall thickness
V	curvature radius of dent
c	half length of dent
α	pipe strength reduction factor
γ	relative length of defect (dent)
σ_u	ultimate stress
σ_m	hydrostatic stress
$\overline{\sigma}$	equivalent stress
P	internal pressure
P_L	limit pressure
$P_{L,O}$	Orynyak limit pressure
$\overline{\varepsilon}$	equivalent strain
$\overline{\varepsilon_f}$	equivalent strain at which the fracture occurs
I	Oyane integrate
C_1, C_2	material constants
K	hardening material constant
n	work-hardening exponent

This paper deals with the behaviour of pipes under pressure containing a plain dent. The main objective is to examine the influence of dent depth on burst pressure of pipes. For that, comparison of experimental and numerically results are compared with the plastic collapse model by Orynyak et al. [4] and a simple local strain criterion [8].

2. Background dents

A dent in a pipeline is a permanent plastic deformation of the circular cross-section of the pipe (Fig. 1). A dent causes a local stress and strain concentration and a local reduction in the pipe diameter. Dent depth is defined as the maximum reduction in the diameter of the pipe compared to the original diameter. There are different types of pipeline dents defined according to their impact on pipeline wall dimensions and geometry [9], these dents are listed bellow:

- *Smooth dent:* is a dent that causes a smooth change in curvature of the pipe wall.
- *Kinked dent:* is a dent that causes an abrupt change in curvature of the pipe wall.
- *Plain dent:* is a smooth dent that contains no wall thickness reduction.
- *Unconstrained dent:* is a dent that is free to rebound elastically when the indenter is removed.
- *Constrained dent:* is a dent that is not free to rebound because the indenter is not removed.

In this paper, only the impact of plain dent on pipeline performance was investigated. The critical variables relating to plain dents are [9]:

- Dent depth (H): distance between undamaged cross section and damaged cross section.
- Pipe geometry (ratio of diameter to wall thickness).
- Curvature profile of the dent.
- Service pressure.
- Applied cyclic pressure range.

The dent depth, Fig. 2, is the most significant factor affecting the burst strength and the fatigue life of a plain dent.

Table 1
Causes of incidents and percentage of occurrence.

External interference (%)	Construction defect/material failure (%)	Corrosion (%)	Ground movement (%)	Hot-tap made by error (%)	Other or unknown (%)
49.6	16.5	15.3	7.3	4.6	6.7