Engineering Failure Analysis 94 (2018) 469–479

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Effect of pressure and defects on the pipe flattening factor

W. Edjeou, G. Pluvinage*, J. Capelle, Z. Azari

École Nationale d'Ingénieurs de Metz (ENIM), Université de Lorraine, France

ARTICLE INFO

Keywords:
Pipe
Ovalization
Flattened factor
Working pressure

ABSTRACT

Starting from an actual case of an oil pipe exhibiting significant ovalization, maximum admissible flattened factor f_{ad} proposed by codes (3%) is discussed. The weak point of this rule is its geometric character. It is shown that the f_{ad} decreases with pressure and with geometrical defects. It is not very sensitive to the bent shape of the pipe, or the location between ovalization and orientation supports. A simple elastic model based on a safety factor of two (2) is proposed

1. Introduction

During service, pipes are subjected to deformations. There are two types of deformation which occur in the operating service, one of them is a curvature deformation. The other one is the ovalization which can be like a vertical or an horizontal deformation of initially circular section that takes an oval shape. For example when a curved pipe is subjected to an internal pressure, a resultant outward force tends to straighten this curvature according to its rigidity. Due to the difference in area between the extrados and the intrados in pipe curvature, a resultant force acts by outwardly attempting to straighten the bend and deforms the cross section into an oval shape, resulting in stress levels higher than in a straight pipe. This phenomenon is known as the “Bourdon” effect.

Abdulhameed [1] has shown that in-plane bending moments cause ovalization. Depending on the direction of the moment, the shape of the ovality is different. When the curved pipe is subjected to opening bending moment, the resulting axial forces are tensile forces below the neutral axis and compression forces above. The situation is opposite for a closing bending moment. The stress intensification factor k_A is defined as the ratio between the stress for a curved and a straight pipe in service.

According to Abdulhameed [1], the internal pressure causes an increase in the pipe stress up to 33% higher than the CSA-Z662 code [2] estimated values because the code does not consider the Bourdon effect in evaluating the hoop and the longitudinal stresses of the pipe elbow. The closing bending moment results in higher stresses for unpressurized pipe bends than the opening bending moment. However, for pressurized pipes, opening bending moments result in higher stresses than closing bending moment. This depends on the level of applied internal pressure. The internal pressure has a reduction effect in the case of pipe bends subjected to closing bending moment. However, in the case of pipe bends subjected to in-plane opening bending moment, the internal pressure tends to increase the pipe stresses. The stresses on the pipe elbow are affected by the bend angle. Therefore, the bend angle should be one of the parameters considered in the stress intensification factor.

Orynyak et al. [3] have proposed analytical solutions for determining stresses and strains in curved pipe by taking into account the conditions of clamping and connections between straight and curved pipes subjected to internal pressure and a bending moment. Orynyak et al.'s work [3] is based on Kirchhoff-Love's assumptions for thin shells. The analytical method is based on simplifying hypotheses and the approximate solution is written in the form of Krylov functions. To check the analytical solution and its applicability, numerical solutions were proposed based on the finite difference method. The unknown parameters were developed in Fourier series.

* Corresponding author.
E-mail address: pluvinage@sfr.fr (G. Pluvinage).

https://doi.org/10.1016/j.engfailanal.2018.08.017
Received 19 July 2018; Received in revised form 17 August 2018; Accepted 17 August 2018
Available online 28 August 2018
1350-6307/ Published by Elsevier Ltd.

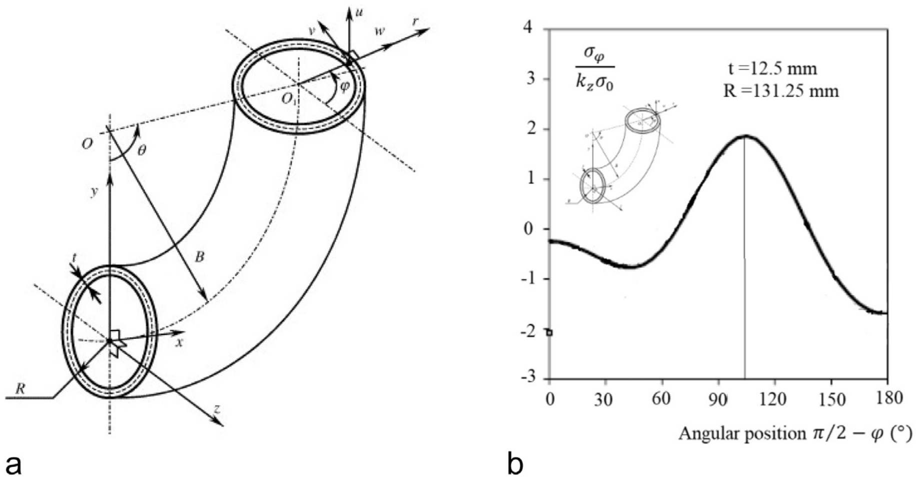

Fig. 1. a: Geometrical dimensions of a curved pipe. b non-dimensional hoop stress $\frac{\sigma_\varphi}{k_z\sigma_0}$ versus angular position

The in-plane bending moment M_z has the following form:

$$M_z = k_z\sigma_0\pi tR^2 \tag{1}$$

Where k_z is a parameter to estimate the order of magnitude of the bending moment, σ_0 is the flow stress, 2R the pipe diameter and t the wall thickness.

Fig.1b: non-dimensional hoop stress $\frac{\sigma_\varphi}{k_z\sigma_0}$ distribution on the outer surface of the bend at the point θ = 45° (half of the curvature) for a curvature B = 250 mm over the angular position $\pi/2 - \varphi$ (°). The pipe diameter is 2R = 262.5 mm and wall thickness is t = 12.5 mm [2].

Starting from the equilibrium equations for a toroidal shell in a nonlinear geometric formulation, they established the equilibrium equations for stresses and strains. In analysis of thin shells, for the expression of the flexural deformations, the linear displacements are often neglected; this makes it possible to simplify the procedure to find the solution. Fig. 1 gives the non-dimensional hoop stress $\sigma_\varphi/k_z\sigma_0$ distribution on the outer surface of the bend at the point θ = 45° (half of the curvature) versus the angular position$\pi/2 - \varphi$ (°). The curvature is equal to B = 250 mm. The pipe diameter is 2R = 262.5 mm and wall thickness is t = 12.5 mm. One notes that the stress intensification is significant.

Numerous codes take into account ovalization such as API 579-1/ASME FFS-1 2007 Fitness-For-Service sample code, [4]. Section distortion is also an element to consider for the functionality of the pipeline. A simple way of measuring this distortion is the flattening factor f = D_{max}-D_{min}/D where D is the initial diameter, ovalization is this factor multiply by 100? Fig. 2.

Table 1 summarizes the different boundary values of this factor considered in some codes. This paper starts from an inspection report concerning a major oil pipeline which conveys oil from western Canada to eastern Canada via the Great Lakes states. This pipe exhibits an important ovalization (8.8%).

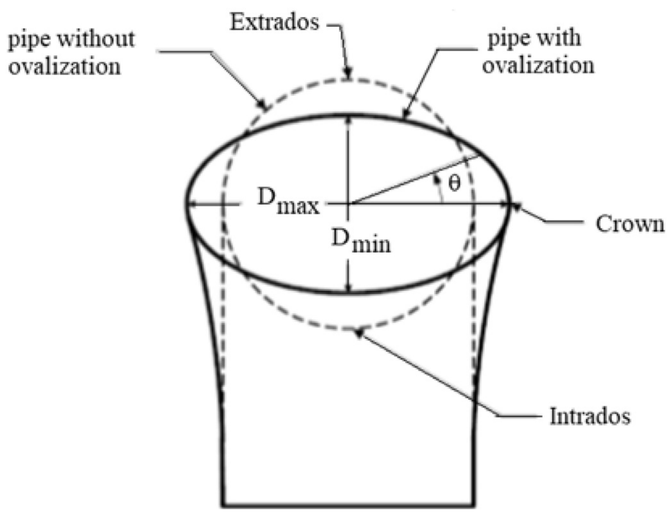

Fig. 2. Definition of minimum and maximum diameter for the flattening parameter.