Engineering Failure Analysis 51 (2015) 69–82

Contents lists available at ScienceDirect

Engineering Failure Analysis

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

Accuracy and security analysis of transient flows in relatively long pipelines

M. Dallali [a,b], M.A. Guidara [a,b], M.A. Bouaziz [a,b], C. Schmitt [b,*], E. Haj-Taieb [a], Z. Azari [b]

[a] Laboratoire de Mécanique des Fluides Appliquée, Génie des Procédés et Environnement (MFAGPE), Ecole Nationale d'Ingénieurs de Sfax, BP 1173, 3038 Sfax, Tunisia
[b] Laboratoire de Biomécanique, Polymères et Structures (LaBPS), Ecole Nationale d'Ingénieurs de Metz, 57070 Metz, France

ARTICLE INFO

Article history:
Received 5 November 2014
Received in revised form 4 February 2015
Accepted 1 March 2015
Available online 7 March 2015

Keywords:
Water hammer
Long pipeline
Method of characteristics
Failure assessment diagram
Volumetric method

ABSTRACT

Consideration is given, in this paper, to the accurate numerical solution of transient flows in relatively long pipelines caused by the water hammer phenomenon. The governing equations for such flows are a set of two coupled non-linear hyperbolic partial differential equations where the friction factor is a very important parameter. In these equations, the gravity force is introduced to take into account the pipeline inclination. The mathematical equations are solved in the time domain by the method of characteristics using linear integration. To reproduce correctly the transient flow, very small time increments were used in the constructed computer program. This program permits to get some systematic indications on the evolution and the damping of the pressure head waves due to a fast closing valve at the downstream end of a long pipeline. The study shows that results are different from those of short pipelines and small viscous fluids. To check the validity of the numerical model, computed results have been successfully compared with those found in the relevant literature. These results show that the gravity lift may have an important effect on the maximum pressures, which may become very important near the valve and cause failure of the pipeline especially in presence of defect. The safety factor, computed at equidistant sections of the line, determines the distance between the reservoir and the defect from which the failure may happen. For the considered application, results show that the pipeline is safe near the supply upstream tank.

1. Introduction

The analysis of transient flows in relatively long pipelines is rather complex because the head losses due to friction are large compared to the instantaneous head rise caused by a sudden variation of the flow velocity that is by the water hammer phenomenon.

The mathematical one-dimensional model, for these flows, has been developed in various documents. For instance, numerical models exist in textbooks of Chaudhry [1], Streeter and Wylie [2], Wylie and Streeter [3], and Wylie et al. [4]. It is constituted of a system of two partial differential equations of first order of hyperbolic type. The numerical solution of the governing equations is obtained by the method of characteristics [5].

Some important phenomena, that exist in unsteady flows in the relatively industrial long pipelines, such as attenuation, line packing, potential surge, pyramiding, and rarefaction are mentioned. But, only few numerical results have been presented by Streeter and Wylie [2]. These results show the location and the shape of the pressure heads and the hydraulic

* Corresponding author.

http://dx.doi.org/10.1016/j.engfailanal.2015.03.001
1350-6307/

Nomenclature

a	notch depth
c	one-half length of elliptical notch
e	wall thickness
g	acceleration of the gravity
p	internal pressure in the pipeline
r	distance
t	time
$t * C/L$	dimensionless time
x	distance along the pipeline
z	elevation
$B = C/(gS)$	constant used in the method of characteristics
C	pressure wave celerity
C_P, C_M	constants used in the method of characteristics
D	pipeline diameter
E	Young modulus of the pipeline
H	hydraulic pressure head
H_0	reservoir elevation
H_{v0}	initial pressure head at the valve
J	linear head loss by unit of length of the pipeline
k_r	non dimensional stress intensity factor
K_I	applied stress intensity factor
K_{Ic}	fracture toughness of material
K_r^*	ordinate of the assessment point
K_ρ	notch stress intensity factor
$K_{\rho,c}$	critical notch stress intensity factor
L	pipeline length
L_r	non dimensional stress or loading parameter
L_r^*	abscissa of the assessment point
N	number of reaches
Q	fluid discharge
R_i	inner radius of the pipeline
R_c	flow stress
S	cross section area of the pipeline
SF	safety factor
X_{eff}	effective distance
$f(k_r, L_r)$	interpolating function
α	pipeline slope
γ	exponent of the power stress distribution
λ	friction factor
ρ	fluid density
σ_{eff}	effective stress
σ_U	ultimate stress
σ_Y	yield stress
σ_{YY}	opening stress
$\sigma_{\theta\theta}$	hoop stress
ξ	Courant number
Δp	pressure head variations at wave front

grade lines, at different instants after a sudden valve closure on a long pipeline. The authors mentioned that the pressure rise at the wave front is reduced as the wave propagates to the upstream end of the long pipeline. This reduction is known as attenuation of the wave. However, after the reflection of the attenuated wave at the upstream boundary, which is a reservoir at a constant level, the abrupt wave front is not clear and not visible. Indeed, the reflected wave amplitude is too small to be detected. Moreover, the time at which the pressure head reaches its maximum value has not been accurately determined.

These are due to the unavailability, at the time, of digital high-speed computers and thus the numerical results are not estimated accurately [6]. The lack of precision is probably due to the use of a small number of pipeline sections in the computing program and therefore a large time step.

One possibility for improving this situation is to use more little time stepping. Today, the solution for different operating conditions can be predicted accurately on high-speed digital systems.