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Water hammer effects on a gray cast iron water network after adding pumps

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ABSTRACT

A numerical model was developed to simulate the propagation of pressure waves in water gray cast iron pipe systems in the presence of pumps. The pressure waves are caused by the water hammer phenomenon due to fast valve maneuvers in the pipe network. The mathematical formulation of the present model is based on a system of two partial differential equations of hyperbolic type. This system was solved by the method of characteristics. The constructed numeric algorithm permits to follow the propagation of pressure waves. It provides the damping of the water hammer waves in the network taking into account the effect of reflection and refraction phenomena to the passage of junctions, bifurcations and change of conducts characteristics. The numerical algorithm sustains the maximum pressure values and; therefore, FEM ABAQUS simulation of gray cast iron pipes with a superficial defect gives the maximum stresses in the different network pipes. The severity of a corrosion crater defect was estimated by calculating the safety factor for the stress distribution at the tip of defects. It allows the acquisition of the applied notch intensity factor. To study the effects of the geometry defects, semi-elliptical defects are deemed to exist up to half the thickness of the pipe wall. To obtain the value of the safety factor, the results were fed into the assessment procedure for the structural integrity (SINTAP) which offers a Failure Assessment Diagram (FAD). Conventionally, it is considered that the risk of failure occurs if the safety factor is less than two. The study allows concluding that the entire network, studied after the addition of pumps, does not work in the security field and, therefore, requires the installation of control and protection systems against sudden pressure variations.

1. Introduction

Water supply infrastructure maintenance is very important to sustain urban development. In this field mismanagement can have serious consequences, such as water pipe bursts, which not only lead to the interruption of service, but also to significant losses of water. Both developing and developed countries are facing the key problem of water lost from potable water distribution systems. A new challenge in water distribution management is the reduction of wastage and how to achieve effective water utilization, taking into account many different aspects, such as technical, social and environmental.

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Nomenclature

a	one-half length of elliptical crack
c	crack depth
e	wall thickness
g	acceleration of the gravity
h	oscillatory part of pressure-head
j	linear head loss by unit of length of the pipe
p	pressure
q	oscillatory part of fluid discharge
t	time
x	distance along the pipe
z	elevation
A	cross section area of the pipe
C	pressure wave celerity
C_1, C_2	integration constants
D_e	pipe outside diameter
E	Young modulus of the pipe
F_s	safety factor
H	instantaneous hydraulic pressure-head
K	fluid bulk modulus
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
L_r	non-dimensional stress or loading parameter
L_r^*	abscissa of the assessment point
P	internal pressure in the pipe
Q	instantaneous fluid discharge
R	outer radius of pipe
R_c	flow stress
Z	hydraulic impedance
Z_c	characteristic hydraulic impedance
$f(L_r)$	interpolating function
λ	friction factor
ν	Poisson's ratio
ρ	fluid density
σ_u	ultimate stress
σ_y	yield stress
$\sigma_{\theta\theta}$	hoop stress
ΔH	wave amplitude

Breaking pipes, quite frequent phenomenon in urban areas, is initiated on a defect due to corrosion or other, under the effect of stresses generated by the water hammer phenomenon. Studies on this phenomenon in branched networks of pipes are rare [1]. This occurs following a sudden closing of valves or pump failure in a pumping system [2] which causes the pressure waves traveling along the pipeline which may cause very serious damage to the pipes and the hydraulic components of the network.

In the present work, finite element stress analysis for gray cast iron pipes is performed including longitudinal external defects under high internal pressure due to water hammer phenomenon in water distribution networks. The failure assessment and structural integrity of the pipes have been compared with those of SINTAP levels. The elasto-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. Numerical solution of water hammer in pipe networks

In the case of one-dimensional flow in a cylindrical pipe of diameter $D = 2R$ and of linear elastic behavior according to Hook's law, the basic simplified relationships of water hammer calculation are obtained from motion and continuity