International Journal of Pressure Vessels and Piping 148 (2016) 46–58

Contents lists available at ScienceDirect

International Journal of Pressure Vessels and Piping

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

Bayesian approach for the reliability assessment of corroded interdependent pipe networks

El Hassene Ait Mokhtar [a,*], Alaa Chateauneuf [b,c], Radouane Laggoune [a]

[a] Unité de Recherche LaMOS, Faculté de Technologie, Université de Bejaia, 06000 Bejaia, Algeria
[b] Université Clermont Auvergne, Université Blaise Pascal, Institut Pascal, BP 10448, 63000 Clermont-Ferrand, France
[c] CNRS, UMR 6602, Institut Pascal, F-63171 Aubière, France

ARTICLE INFO

Article history:
Received 20 July 2015
Received in revised form
30 August 2016
Accepted 7 November 2016
Available online 9 November 2016

Keywords:
Bayesian networks
Bayesian updating
Corroded pipelines
Reliability assessment

ABSTRACT

Pipelines under corrosion are subject to various environment conditions, and consequently it becomes difficult to build realistic corrosion models. In the present work, a Bayesian methodology is proposed to allow for updating the corrosion model parameters according to the evolution of environmental conditions. For reliability assessment of dependent structures, Bayesian networks are used to provide interesting qualitative and quantitative description of the information in the system. The qualitative contribution lies in the modeling of complex system, composed by dependent pipelines, as a Bayesian network. The quantitative one lies in the evaluation of the dependencies between pipelines by the use of a new method for the generation of conditional probability tables. The effectiveness of Bayesian updating is illustrated through an application where the new reliability of degraded (corroded) pipe networks is assessed.

1. Introduction

During their operation life, underground pipelines are exposed to several degradation mechanisms due to environment aggressiveness. Material corrosion is the most common form of pipeline structural deterioration [1]. In fact, corrosion damage cost in the industrialized countries has been estimated between 3 and 5% of their gross national product [2], which explains why intensive researches have been conducted on failure assessment of corroded pipelines in the last 30 years as mentioned by Chen et al. [3].

Corrosion can be defined as the destructive attack of a material caused by electrochemical reaction between the metal and its environment. In pipelines, corrosion can be internal, external or both, simultaneously [1]. Internal corrosion occurs because of the reaction between the pipeline fluid and the inner surface of the pipeline, it occurs generally as individual or colonies of pits. However, the external corrosion is caused by the oxidation of the external surface of the pipeline by the environment (i.e. water, soil, temperature …), it is described by uniform corrosion (i.e. loss of wall thickness) or localized corrosion (i.e. pitting corrosion) [4]. The loss of material due to corrosion over the operational life of structures is generally described by probabilistic models given as function of time [5]. The remaining life of structures subject to corrosion, in its various forms, is a function of material loss. Therefore, when assessing the reliability of such structures, the choice of the corrosion model constitutes the key factor influencing the results [6].

The structural reliability estimation depends on two key groups: the loads acting on the system and the resistance of the system to support these loads [7]. The resistance of the system is affected by various factors, corrosion is one of the most common factors for pipelines. Several methods can be found in the literature for reliability assessment of corroded pipelines [4,7–9]. These methods depend mainly on the evaluation of the damage caused by corrosion since the failure of such systems occurs when the resistance affected by corrosion is less than or equal to the applied load. Therefore, the development of efficient methodologies for structural reliability assessment is conditioned by the realistic modeling of the evolution of defects. It is therefore important that: (i) the

* Corresponding author.
E-mail addresses: aitmokhtar_elhassene@hotmail.com (E.H. Ait Mokhtar), alaa.chateauneuf@univ-bpclermont.fr (A. Chateauneuf), r_laggoune@yahoo.fr (R. Laggoune).

http://dx.doi.org/10.1016/j.ijpvp.2016.11.002
0308-0161/

model takes into consideration the influence of the environment on the system and (ii) the model parameters can be updated when new data becomes available. From these perspectives, the present paper aims at developing a methodology for structural reliability assessment of complex systems affected by variable environment conditions. The corrosion model adopted herein has been given by Paik et al. [10], the model parameters are updated using Bayesian method when new data becomes available. The dependencies between the system components are considered by the use of Bayesian Network (BN). In the next section, a literature review of corrosion models is provided. Section 3 is devoted to Bayesian updating of the corrosion model using the Metropolis - Hastings (M − H) algorithm. Section 4 describes the methodology of reliability assessment of corroded pipelines by the use of Bayesian networks. In Section 5, an application to a water supply system illustrates the usefulness of the developed methodology.

2. Corrosion model

On the basis of statistical data on material loss collected from experimental tests or real structures, many corrosion models can be found in the literature. The existing models aim at predicting the metal loss over the time. These models can be classified according to many criteria; such as the coating protection. Southwell et al. [11] have proposed linear and bilinear models for data collected in various environments. On the basis of this model, Melchers [12] has developed a probabilistic linear and bilinear corrosion model, describing the mean and the standard deviation of the metal loss over the time. A trilinear model is also given by Melchers [13]. However, as stated in Qin et al. [6], the nonlinear models are more appropriate and more adapted. For this reason, Ahmed et al. [1] have suggested a power model for underground pipelines.

The above mentioned models do not take into consideration the coating protection of the studied systems. However, it is evident that the aggressiveness of the environment is affected by the coating protection which is therefore considered in recent corrosion models. Soares et al. [14] have suggested a nonlinear model which considers the coating protection by dividing the corrosion process into three stages: in the first one, the efficiency of the coating protection prevents the corrosion; the second stage begins after the deterioration of coating protection; the corrosion rate in this stage is high compared to the third one where it decreases until being null. This decreasing stage is due to the corrosion layer, which protects the system from external environment. The corrosion model of Paik et al. [10] considers also the coating protection through a formulation close to the power model proposed by Ahmed et al. [1]. The difference lies in the fact that in Paik's model, the corrosion starts after the loss of coating effectiveness. The coating life is assumed to follow the normal distribution and the corrosion rate follows the Weibull distribution. Qin et al. [6] suggested another corrosion model, which is divided into four stages. Compared to the models of Soares et al. [14] and Paik et al. [10], where the effectiveness of the coating protection is equal to 0 or 1, Qin et al. [6] divided the coating life into two stages. In the first one, the corrosion rate is null and in the second one, the pitting corrosion appears due to the partial loss of the coating effectiveness. The two other stages which come after the first two stages are similar to those in Soares model [14]. In the present paper, the corrosion behavior is modeled according to Paik et al. [10]. This choice is based on the interesting properties of this model, since it takes into account the coating protection on one hand, and it considers the corrosion rate to follow the Weibull distribution, which can take various forms, on another hand.

3. Bayesian update of the corrosion model

As stated in the above sections, the corrosion is affected by several factors related to external environment and coating protection. In most of the cases in the literature, the corrosion models are evaluated from experimental data observed over a given period. It may happen that these corrosion models will not describe the behavior of the corrosion in other environments, or after a given period. Therefore, it is crucial to update the model from observed data in order to describe the real behavior of the corrosion phenomenon in the considered system. The main aim of the present paper is to address these needs by developing an approach, which allows for updating the corrosion model according to its environment. For this purpose, we have opted for the use of Bayesian method, which is one of the most used updating methods from prior and observed information.

3.1. Proposed methodology

The main objective of the present paper is to develop a methodology for the reliability assessment of complexe systems composed by interconnected pipelines subjected to corrosion. The developed methodology can be easily updated with the evolution of the corrosion behavior by using Bayesian updating tool. In addition, thanks to the use of BN tool, the proposed methodology allows us to consider the interactions between the system components on one hand and between the environment and the system on the other hand. The main steps of the methodology shown in Fig. 1 are as following:

Step 1. Identification of the structure of the Bayesian network (BN). The BN nodes and their dependencies will be identified from the system structure and the environement to which it is exposed.
Step 2. Establishment of the corrosion model, for each node of the BN, from the loss of material due to corrosion.
Step 3. Definition of the strength model, which is based on the corrosion model, the system properties and the operating conditions.
Step 4. Creation of the prior probability tables of the root nodes of the BN from the strength model by using Monte Carlo simulations.
Step 5. Creation of the conditional probability tables of the nodes representing the dependencies between the system components from the system structure and the environement conditions.
Step 6. Assessment of the failure probability of the system by performing bayesian inference.

When new corrosion data becomes available for a given node, the Bayesian updating is performed in order to define the new corrosion model of the node in question and then the procedure is continued by going to **step 3**.