The Reliability Estimation of Pipeline Using FORM, SORM and Monte Carlo Simulation with FAD

Ouk Sub Lee
School of Mechanical Engineering, INHA University,
Incheon 402-751, Korea

Dong Hyeok Kim*
Department of Mechanical Engineering, INHA University,
Incheon 402-751, Korea

In this paper, the reliability estimation of pipelines is performed by employing the probabilistic method, which accounts for the uncertainties in the load and resistance parameters of the limit state function. The FORM (first order reliability method) and the SORM (second order reliability method) are carried out to estimate the failure probability of pipeline utilizing the FAD (failure assessment diagram). And the reliability of pipeline is assessed by using this failure probability and analyzed in accordance with a target safety level. Furthermore, the MCS (Monte Carlo Simulation) is used to verify the results of the FORM and the SORM. It is noted that the failure probability increases with the increase of dent depth, gouge depth, operating pressure, outside radius, and the decrease of wall thickness. It is found that the FORM utilizing the FAD is a useful and is an efficient method to estimate the failure probability in the reliability assessment of a pipeline. Furthermore, the pipeline safety assessment technique with the deterministic procedure utilizing the FAD only is turned out more conservative than those obtained by using the probability theory together with the FAD. The probabilistic method such as the FORM, the SORM and the MCS can be used by most plant designers regarding the operating condition and design parameters.

Key Words: Reliability, Failure Probability, FAD, FORM, SORM, Monte Carlo Simulation, Pipeline

1. Introduction

The energy supply/delivery industry is advancing to cope with the rapid growth of the economy. And the structures such as gas and oil delivery pipelines and storage structures of oil and gas have been installed in greater numbers at a vast domestic area. Defects in pipeline arisen during manufacturing and usage can reduce the reliability of pipeline. These defects are produced during welding, machining and designing process in manufacturing and produced by the variations of load and temperature, various corrosion circumferences and ground subsidence in usage.

Pipelines, like other structures in industries, are usually deteriorated according to varying boundary conditions. This natural deterioration in a metallic pipeline mainly occurs as a result of the damage caused by the surrounding environment. These pipeline, however, are difficult to replace because of economic and environmental factors. Therefore, it is necessary to evaluate the reliability of pipeline, and thus many researches on this subject have been progressed accordingly (Seo et al., 1999; Lin et al., 2004; Kwak et al.,

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* Corresponding Author,
E-mail: kdonghyeok77@yahoo.co.kr
Department of Mechanical Engineering, INHA University, Incheon 402–751, Korea. (Manuscript Received May 9, 2006; Revised August 28, 2006)
The reliability of pipeline is evaluated by a universal method that uses failure pressure model, such as B31G and MB31G models, which are based on the internal pressure of the pipeline. But these models cannot consider any other loads except internal pressure. One of varying methods for evaluating the level of reliability of structures with defects like crack is the failure assessment diagram (FAD) and crack driving force. In this paper, the FAD is applied to evaluate the reliability of pipeline because of its convenience in application and simplicity in extension to another field of engineering practices (Seo et al., 1999; Lin et al., 2004; Kwak et al., 2004; Lee and Kim, 2005).

At present, design and reliability evaluation of a pipeline are usually performed by using a determination evaluation method. But this method has a limitation; it cannot account for the uncertainty of variables such as the shape factor of a pipeline, load, and material property. Therefore, the probability theory must be applied in the reliability evaluation of a pipeline with regarding all parameters as random variables to consider the characteristic of variable distribution (Kim et al., 2004; Lee and Kim, 2004).

In this paper, a limit state for assessing the reliability of the pipeline considered has been formulated by using the FAD, and the failure probability of the pipeline is estimated by using the FORM (first order reliability method) and the SORM (second order reliability method). The reliability of the pipeline is assessed by using this failure probability. And the application of these methods to reliability estimation is investigated for a case study. Furthermore, the results obtained from the FAD are compared with the failure probability obtained by using the failure pressure models, and the effects of various boundary conditions on the reliability of the pipeline are systematically investigated. And the results obtained from the FORM and the SORM are compared with those estimated by the MCS (Monte Carlo simulation) and systematically analyzed to assess the accuracy of the reliability of pipelines.

2. FAD (Failure Assessment Diagram)

The FAD is probably the most widely used methodology for elastic plastic fracture mechanics analysis of structural components. Because the damage of structure is characterized as the combination of brittle fracture and plastic collapse, the FAD is composed of the x axis, which represents the effect of plastic collapse, and the y axis, which represents the effect of brittle fracture, as shown in Fig. 1. The line between the safe region and failure region in Fig. 1 represents the failure assessment line (FAL) derived from the theory of fracture mechanic. The state of structure with a defect is expressed by a specific value of \((S_r, K_r)\) on the FAD. If this point is located inside region of the FAL, it can be assessed that the defect is an allowable defect. However, if this point is located outside region the FAL, it can be assessed that the defect is an unallowable defect (Kim et al., 2004; Anderson, 2005; Limited, 2001).

2.1 Resistance for the plastic collapse

In the Fig. 1, the x axis expressed as \(S_r\) is the resistance for the plastic collapse and defined as the Eq. (1). In the Eq. (1), \(\sigma_c\) is the flow stress of the material and \(\sigma_{ref}\) is the stress acted on the pipeline with a defect. If \(\sigma_{ref}\) increases, \(S_r\) increases and the pipeline experiences plastic collapse, if \(\sigma_{ref}\) has the same value as \(\sigma_c\) (Kim et al.,

![Fig. 1 Typical failure assessment diagram](image-url)