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Limit loads and fracture mechanics parameters for thick-walled pipes

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ABSTRACT

In this paper, information on plastic limit loads and both elastic and elastic-plastic fracture mechanics parameters is given for cracked thick-walled pipes with mean radius-to-thickness ratios ranging from two to five. It is found that existing limit load expressions for thin-walled pipes can be applied to thick-walled pipes, provided that they are normalized with respect to the corresponding un-cracked thick-walled pipe values. For elastic fracture mechanics parameters, FE values of the influence functions for the stress intensity factor and the crack opening displacement are tabulated. For elastic-plastic J, it is shown that existing reference stress based J estimates can be applied, provided that a proper limit load for thick-walled pipes is used.

1. Introduction

The assessment of crack-like defects in pipes is an important issue in design and maintenance of power plant components. Accordingly, numerous works have been published up to the present, and reviewing the literature in detail would be too lengthy. Interested readers can refer, for instance, to Refs. [1–8]. However, it should be noted that existing works mainly cover the cases of cracked pipes having mean radius-to-thickness ratios greater than five. Recently, in the design of critical piping components, the pipe thickness tends to be larger due to the requirement of longer service life, and thus the mean radius-to-thickness ratio tends to be smaller. Furthermore, overlay welding of critical piping components (such as pressurizer nozzle components in pressurized water nuclear reactors) for either repair or mitigation purposes also tends to make the mean radius-to-thickness ratio smaller. Another example is the use of polyethylene pipes in nuclear power plants. The mean radius-to-thickness ratio tends to be small in this case due to the large thickness required against seismic design. As shown in the above examples, there are several cases where the significance of a crack needs to be assessed for pipes having mean radius-to-thickness ratios less than five, which in turn requires a method for defect assessment. Such a method includes, for instance, the need for stress intensity factor solutions for elastic fracture mechanics analysis, limit load solutions for fully plastic fracture mechanics analysis and J-estimation methods for elastic-plastic fracture mechanics analysis. For thick-walled pipes, stress intensity factor solutions for through-wall and semi-elliptical surface cracks are given in [3,5,7,9–16]. Although solutions for semi-elliptical surface cracks are useful for practical information, those for constant-depth surface cracks would be also of interest. For limit loads, limited solutions for thick-walled pipes are given in Refs. [3,17,18].

This paper presents plastic limit loads and both elastic and elastic-plastic fracture mechanics parameters for thick-walled pipes where the mean radius-to-thickness ratio is less than five. Both axial and circumferential surface cracks are considered, together with the limiting through-wall crack cases. Internal pressure, axial tension and global bending loads are considered. Section 2 summarizes finite element (FE) analyses performed in this work. Section 3 presents plastic limit load results. Elastic and elastic-plastic fracture mechanics parameters are presented in Section 4 and Section 5, respectively. The present work is concluded in Section 6.

2. Finite element analysis

2.1. Geometry

Consider a cracked pipe with mean radius r and thickness t subject either to internal pressure P, axial tension N or global

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