PROLOCA 7.1 A Probabilistic Framework for Fatigue Analysis of Aluminum and Weld Steel Structures

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Abstract
PROLOCA 7.1 is a probabilistic fracture mechanics (PFM) cods developed for the analysis of damage initiation and growth up to the point of structural failure. The PROLOCA (PRObability of Loss Of Coolant Accident) code was formulated to address nuclear piping and was based on past probabilistic analyses of fatigue in aircraft. These methods were integrated into a code, PROLOCA 2.0 originally developed under NRC contract [1], which was developed for nuclear piping analyses. Since that time, PROLOCA was continually improved under contract to an international team of regulators and operators. In this paper we examine some of the key differences between PROLOCA and other frameworks for fatigue analyses. Examples of the application of PROLOCA to dissimilar metal welds and aircraft damage tolerance are given to demonstrate the extremely low risk of failure with and without inspections and leak detection.

Introduction

In 1992, the probabilistic framework for the PROLOCA code was started. This work was performed under contract to NASA [2]. In 1999, a program to expand this framework was performed for the FAA to address widespread fatigue damage [3]. In 2002 the analysis of fracture in nuclear piping was brought into the framework, where the framework was officially labeled PROLOCA. In 2008, the Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research signed a memorandum of understanding addendum with the Electric Power Research Institute (EPRI) to cooperatively develop a PFM code to analyze risks associated with nuclear power plant piping systems subject to active degradation mechanisms. The resultant PFM code was called “xLPR” [4]. This code, presented in a separate paper, is the primary analysis tool for nuclear power plants. However, it has only a single fatigue mode that is focused on degradation in welded steel pipe, as is expected because one of the primary sponsors is NRC. Also, the piping degradation due to fatigue is of secondary concern for large diameter pipes in comparison to corrosion. Therefore, not many fatigue analyses have been done to date with xLPR. Given the combined resources of US NRC and EPRI were focused on xLPR funding, the development and application of PROLOCA was undertaken by an international consortium (e.g., [5])

PROLOCA Framework for Fatigue Applications

Previous studies have demonstrated that the PROLOCA probabilistic framework performed well in predicting the damage behavior in aluminum, one blind test for NASA [2] where the crack growth was predicted for a full scale test within 2% and another full scale blind test for the FAA predicted the experimental result within 1% [6], [7]. These analyses were for aluminum structures. Since 1998 the focus for the PROLOCA 7.1 framework has been on steel pipelines, primarily in the nuclear industry. One of the key differences in the aeronautical industry is the use of damage tolerance analysis, i.e., an existing crack is assumed, and two (or 4 in the case of NASA) inspections are required before structural failure is predicted. Including crack initiation leads to greatly increased uncertainty because of widely varying predictions of when a crack initiates. Also, many PFM codes assume that transient events occur at fixed times (e.g., xLPR). Finally, it is usually the case that a regulator, or operator, assumes a single fatigue deterministic model.

The PROLOCA 7.1 uses the following key concepts for fatigue analysis: (1) Four transient types which include vibration, start-up/shutdown, thermal stratification and a “generic” transient type; (2) A safe shutdown earthquake event; (3) random occurrence of transients except for the vibration and safe shutdown earthquake. The corrosion of the material can be included with the fatigue modeling. However, for this paper we will examine cases in which only fatigue is modeled. This is because stress corrosion cracking (SCC) mechanisms almost always require an initiation process while many fatigue studies assume an initial crack. This is because the growth rate of fatigue cracks is usually slower than SCC cracks so that the impact of fatigue on structural risk is many times masked by SCC.

For this paper we examine three cases: (1) fatigue crack growth in a 737 wing structure and comparison to experimental results; (2) Fatigue crack growth in a nuclear pipe weld; and (3) Combined fatigue and SCC growth in a pipe weld.

Conclusions

The results of the three analyses show a very low probability of failure in the two structures when combined with an inspection program. For the aircraft, there is a high probability of maintaining damage tolerance. For the nuclear power pipe weld there is a very low probability of a rupture when there are inspection and leak detection programs employed.

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