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Fracture Assessment Procedure for Structural Components Under Cyclic and Dynamic Loading

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A new fracture assessment method that includes 2 concepts is presented in this paper for structures subjected to large cyclic and dynamic loading. One is a reference temperature concept. The fracture toughness under cyclic and dynamic conditions is replaced by the static toughness without pre-strain at a reference temperature of $T - \Delta T_{PD}$, where T and ΔT_{PD} are the service temperature and the temperature shift of the fracture toughness. ΔT_{PD} is related to the flow stress elevation by pre-strain and dynamic loading. The other is a correction of CTOD (Crack Tip Opening Displacement) for constraint loss in structural components in large-scale yielding. The CTOD toughness correction is carried out with the equivalent CTOD ratio β defined on the basis of the Weibull stress criterion. These 2 concepts are implemented in the Japanese Engineering Standard, WES 2808. The procedure for determining β is standardized in the IST project in Japan, discussed below. For integrity assessments of pipelines with a high internal pressure, the effect of biaxial loading on β is addressed by 3-dimensional FE analysis.

INTRODUCTION

Fracture control design is most important for structures where the incidence of unstable fracture (brittle fracture) is of great concern. For assessing flaws or crack-like defects in metallic structures in service, fracture mechanics-based methods such as BS7910-2005 (British Standard, *Guide on Methods for Assessing the Acceptability of Flaws in Metallic Structures*), API 579-2000 (American Petroleum Institute, *Recommended Practice for Fitness-for-Service and Continued Operation of Equipment*) and WES 2805-1997 (Japan Welding Engineering Society Standard, *Method of Assessment for Flaws in Fusion Welded Joints with Respect to Brittle Fracture and Fatigue Crack Growth*) are widely used. It is noted that the European fitness-for-service procedure, FITNET, was developed in 2006 as a result of a 4-year European thematic network project. These fracture assessment procedures work mainly in a static loading condition.

On the other hand, buildings, bridges, tanks and pipelines in a seismic area are designed to be earthquake-proof structures. When an earthquake strikes, they are subjected to a large cyclic and dynamic strain. A large amount of strain due to a ground motion is also encountered for pipelines constructed on permafrost, that is, ground that stays at or below the freezing point of water for 2 or more years. When frost-heaving or frost-jacking occurs, the pipeline embedded in the ground is not properly anchored to resist such movement. For these structures, the design criteria should be associated with the strain-based fracture control, where the effects of cyclic and dynamic loading are taken into account in the event of an earthquake. However, no standards or specifications adequately address such a loading condition.

In Japan, a new fracture assessment procedure, WES 2808-2003 (*Method of Assessing Brittle Fracture in Steel Weldments Subjected to Large Cyclic and Dynamic Strain*), has been issued: It is characterized by 2 unique ideas. One is a reference temperature concept for fracture toughness evaluation in the seismic condition (Minami and Arimochi, 2001). The other is a correction of CTOD (Crack Tip Opening Displacement) fracture toughness for constraint loss in structural components in large-scale yielding (Minami et al., 1999). This paper describes these 2 ideas briefly. The procedure for constraint loss correction of CTOD has been standardized in the IST (International Standardization of Fracture Toughness Evaluation Procedure for Fracture Assessment of Steel Structure) project in Japan (Minami et al., 2006).

The major concern in this paper is an effect of biaxial loading on the fracture performance of pipeline components. Demand for high-pressure pipelines is steadily increasing in the gas transmission industries. The high internal pressure combined with tension/bending elevates the constraint state near the crack tip, which facilitates the incidence of brittle fracture. Stress fields for a through-thickness crack and a semi-elliptical surface crack subjected to biaxial tension are analyzed by 3-D FEM. Discussion follows on the biaxial load effect on the CTOD correction for constraint loss in large-scale yielding conditions.

WES 2808 FRACTURE ASSESSMENT METHOD

Key Ideas

In Japan, WES 2805 is commonly used for the fracture assessment of a crack located in the strain concentration area in steel structures. WES 2805 employs the CTOD design curve, the relationship between the CTOD δ and strain e_{local} in the form:

$$\frac{\delta}{\varepsilon_Y \bar{a}} = \begin{cases} (\pi/2)(e_{local}/\varepsilon_Y)^2, & e_{local} \le \varepsilon_Y \\ (\pi/8)[9(e_{local}/\varepsilon_Y) - 5], & e_{local} > \varepsilon_Y \end{cases} \quad (1)$$

where e_{local} is a local strain in the crack region, ε_Y is the yield strain of the material, and $\bar{a}$ is the half-length of the equivalent through-thickness crack. If the crack of concern is a surface crack or an embedded crack, it shall be converted to the through-thickness crack in an infinite plate with the equivalent stress intensity factor (Newman and Raju, 1984). It was confirmed that Eq. 1

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KEY WORDS: Fracture assessment, pre-strain, dynamic loading, biaxial loading, Weibull stress, constraint loss, CTOD toughness.