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ScienceDirect

Procedia Engineering 181 (2017) 159 – 166

Procedia Engineering

www.elsevier.com/locate/procedia

10th International Conference Interdisciplinarity in Engineering, INTER-ENG 2016

Fatigue Assessment and Behavior of a Shell Steel Element Welded Joint

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Abstract

The paper is proposing an advance research on welded joints of the shell steel elements. The assessment of the fatigue of the existing structures is a current topic in the sustainable development of the civil engineering work. Planning, manufacturing and serviceability of the steel structures under cyclic loads, involves a fatigue designing.

Simplified fatigue and fracture mechanics based assessment methods are widely used by the industry to determine the structural integrity significance of evaluate cracks, manufacturing flaws, service-induced cracking or suspected degradation of engineering components under normal and abnormal service loads. In many cases, welded joints are the areas to contain the fabrication defects or cracks initiating and growing during service operation. The welded joints are a major component that is often the cause for structure failure or for being the point at which fatigue or fracture problems initiate and propagate. Various mathematical models for various classes of welded joints are developed by analytically or by simulation software's that can be used in fatigue and fracture assessments.

Peer-review under responsibility of the organizing committee of INTER-ENG 2016

Keywords: Fatigue; steel structures; welded joints; fracture mechanics; sustainability.

1. Introduction

Fatigue is a specific case of deterioration that is of great importance in the assessment of existing steel structures (under cyclic load).

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1877-7058
Peer-review under responsibility of the organizing committee of INTER-ENG 2016
doi:10.1016/j.proeng.2017.02.423

Fatigue damage appears in the form of fatigue cracks and can occur in primary loaded or secondary elements. Since fatigue failure is depending - besides detailing or environmental conditions - on the load spectra over the service life, consequently, existing steel structures suffer more from fatigue and accumulate more damage than the older structures.

2. Linear elastic fracture mechanics approach

Stress distribution in a shell element characterized by the presence of a defect and subjected to a uniform tensile stress is influenced by it. Thus the maximum tensile stresses on the edge defect are elliptical, with value:

$$\sigma_{max} = \sigma\left(1 + \frac{2a}{b}\right), \quad \sigma_{max} = \sigma \cdot k_t \tag{1}$$

where $k_t = \sigma_{max} / \sigma$ is a stress concentration factor.

For a circular shape hole, where $a = b$, the value of the factor k_t will be 3, representing the value of the local concerted action of stress. This stress concentration is much higher for an elliptical shape hole; it tends to infinity while semi-axis b tends to zero.

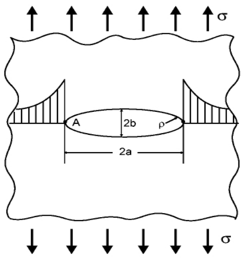

Fig. 1. Elliptical shape hole stress effect in a shell element.

Writing radius of curvature $\rho = b^2 / a$, the maximum stress will have the relation:

$$\sigma_{\max} = \sigma\left(1 + \sqrt{\frac{a}{\rho}}\right) \tag{2}$$

In case a > b, the relation is: $\sigma_{\max} = 2\sigma\sqrt{\frac{a}{\rho}}$ (3)

Thus when $\rho \to 0 \;\Leftrightarrow\; \sigma_{max} \to \infty$.

In 1957 George Rakin Irwin developed a theory based on fundamental fracture mechanics analysis of stress and strain state at crack tip. This theory shows that the stress area from the tip of a crack is determined by the factor K (as noted in honor of its employee Joseph Kies 1952-1954), known as the stress intensity factor. Analyzing the classic application and using Westergaard's theory of elasticity expressions, he characterized the elastic stress field in the proximity of a crack through the relations:

$$\sigma_x = \frac{K}{\sqrt{2\pi r}}\cos\frac{\theta}{2}\left(1 - \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right), \; \sigma_y = \frac{K}{\sqrt{2\pi r}}\cos\frac{\theta}{2}\left(1 + \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right), \; \tau_{xy} = \frac{K}{\sqrt{2\pi r}}\cos\frac{\theta}{2}\left(\sin\frac{\theta}{2}\cos\frac{3\theta}{2}\right) \tag{4}$$