# SIMULATION-BASED FATIGUE CRACK MANAGEMENT IN WELDED STRUCTURAL DETAILS

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## ABSTRACT

In the present paper, a simulation-based fatigue crack management is proposed based on an advanced numerical simulation system, which can predict the fatigue failure mode and the corresponding remaining life of a two-dimensional through-the-thickness curved crack propagation in a welded 3-D structure. The simulation is based on a step-by step finite element approach, and its procedure is described in the following;

- Pre-Processing: finite element mesh is automatically generated for two-dimensional crack propagating domains,
- Super-element: a super-element is introduced to model the surrounding 3-D structure which is defined outside the crack propagating domains,
- Welding residual stress: residual stress distribution is assumed for an intact condition of the crack propagating domain,
- Crack analysis: stress field parameters near a crack tip are calculated by the method of superposition of analytical and finite element solutions,
- Crack path prediction: curved crack extension is predicted by the first order perturbation method with the use of local symmetry criterion,
- Crack growth calculation: crack growth is calculated by the Paris' law,

A user-friendly system is proposed based on an improved paving method for the mesh generation with a GUI-environment for the input and output phases of the simulation. A general-purpose code "MSC-NASTRAN" is used for the calculation of the stiffness and the load-vectors of the super-element of the three-dimensional surrounding structures. Fatigue crack paths and propagation lives are investigated for several structural details at the intersection of longitudinal stiffeners and a transverse girder. It is found that final failure modes could be controlled by the local structural design, and this system can be used as an efficient simulation-based tool for the fatigue crack management of critical weld details.

## 1 INTRODUCTION

Fatigue crack propagation and remaining life assessment of welded structures have been investigated by numerical simulations focusing attention on its curved crack path, the effects of welding residual stress, applied stress distributions, and structural redundancy (Sumi *et al*. [1, 2, 3, 4]). The method is based on a step-by-step finite element analysis, where a user-friendly system is developed based on an improved paving method for the mesh generation with a GUI-environment for the input and output phases of the simulation. A general-purpose code "MSC-NASTRAN" is used for the calculation of the stiffness and the load-vectors of the super-element of the three-dimensional surrounding structures.

Fatigue crack paths and propagation lives are investigated for several weld structural details at the intersection of longitudinal stiffeners and a transverse girder. The influencing factors such as geometry of structural details, welding residual stress, structural redundancy, as well as crack paths are taken into consideration, so that realistic fatigue crack propagation can be simulated. From the results, it is found that final failure modes could be controlled by the local structural design, and this system can be used as an efficient simulation-based tool for the fatigue crack management of critical weld details.

## 2 AN ADVANCED SIMULATION SYSTEM FOR FATIGUE CRACK PROPAGATION

An advanced simulation method for fatigue crack propagation based on a step-by step finite element approach, which is named as CP-SYSTEM, is described by Sumi *et al*. [4]. A fatigue crack is modeled as a two-dimensional crack in a plate, and the simulation consists of the following steps (see Figure 1);

1. Pre-Processing: finite element mesh is automatically generated by an advanced paving method (Blacker, T.D. and Stephenson, M.B. [5], Kawamura *et al.* [6] in a crack-propagating domain, while a super-element is generated to model the 3-D structures surrounding the crack propagating zone,
2. Crack analysis: stress field parameters near a crack tip are calculated by the method of superposition of analytical and finite element solutions,
3. Crack path prediction: curved crack extension is predicted by the first order perturbation method (Sumi *et al*. [7,8]) with the use of local symmetry criterion,
4. Crack growth calculation: fatigue crack growth is calculated based on the Paris’ law,

5. Go back to step1 to continue simulation.

In each step a cracked domain is subdivided into new finite element mesh by an advanced paving method, which is specially developed for the refined smooth mesh gradation for crack analysis. The stress field parameters of the Irwin-Williams' expansion are determined by the method of superposition of analytical and finite element solutions, where not only the stress intensity factors but also the T-stress and higher order coefficients corresponding to the stress of $O$ ($r^{1/2}$) are determined. In order to consider the interactive nature of the growth of the system of cracks, the rate problems of crack growth are also solved so that the stress intensity factors at an arbitrarily extended crack tip are obtained analytically by the first order perturbation method (Sumi *et al.* [7,8]). Then the crack path is determined with the use of the local symmetry criterion. The crack propagation life is calculated by using the stress intensity range along its path, and the procedure is repeated until the final stage of the crack propagation is reached.

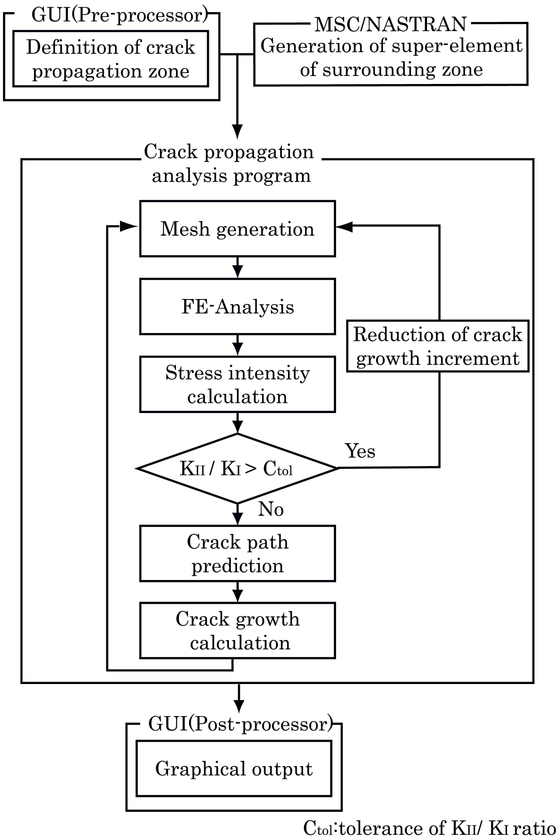


Figure 1: Flowchart of CP-System.

## 3 FATIGUE CRACK PROPAGATION AT THE INTERSECTION OF LONGITUDINAL STIFFENER AND TRANSVERSE GIRDER

Numerical simulations are carried out for fatigue cracks propagating at the intersection of the longitudinal stiffener and the transverse girder as shown in Figure 2, where the magnitude of the repeated pressure load range is 100kPa. At the both ends of the longitudinal stiffeners, they are fixed, and the lateral deflection is also restrained at the mid-span. In order to model the periodicity of the longitudinal stiffeners, symmetric conditions are prescribed along the both sides of the calculation model. The longitudinal stiffeners are connected to the transverse girder by a flat bar stiffener (see Figure 2) or a variety of brackets as illustrated in Figure 3 (a)-(d).

Figure 4 illustrates the various crack paths obtained by the CP-System. It is interesting to see that crack paths from the end of the bracket connections are gradually curved and tend to avoid the penetration into the skin plate, which may form a critical compartment boundary. The corresponding crack propagation lives are shown in Figure 5. The simulated results indicate that the present system can be employed to control fatigue crack paths, and it could be applied to the fatigue design and remaining life assessment of an actual structural detail of a welded structure.

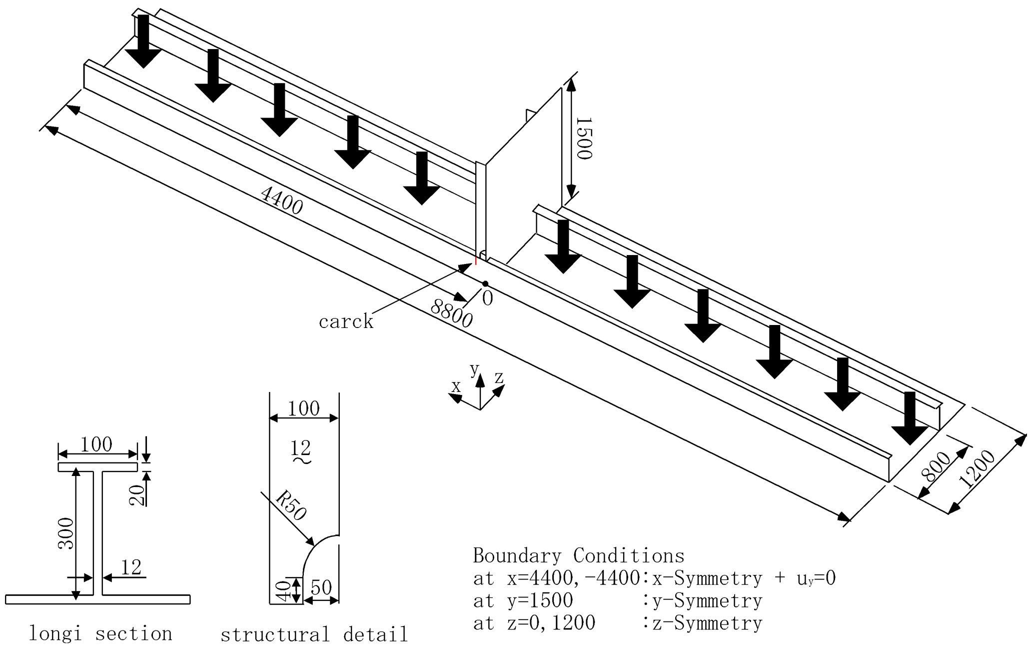


Figure 2: Calculation Model of Longitudinal Stiffener Subjected to Repeated Pressure Loading.

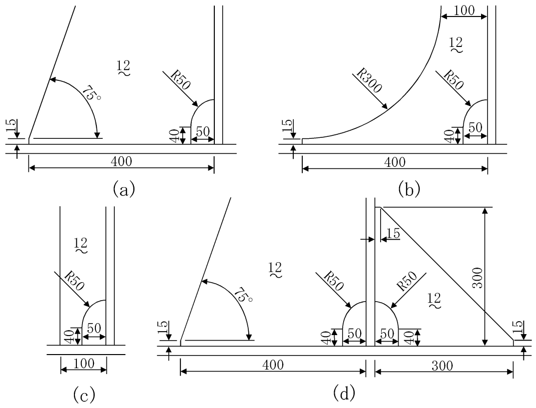


Figure 3: Brackets and Stiffeners at the Connection of Longitudinals and Transverse Girders; (a) bracket, (b) round web stiffener, (c) flat bar stiffener, (d) bracket with a back bracket.

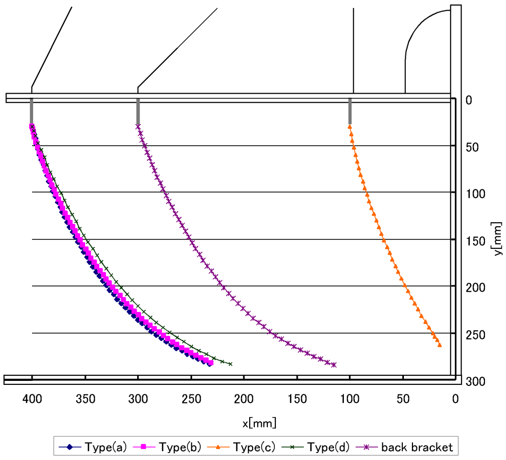


Figure 4: Simulated Crack Paths in the Web of the Longitudinal Stiffener.

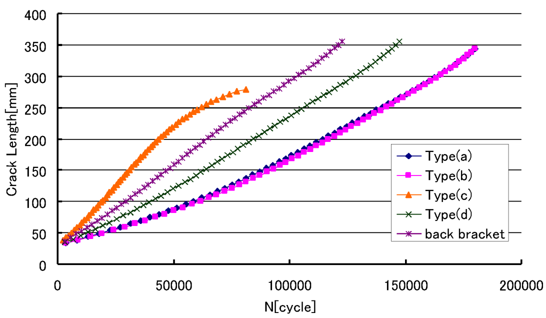


Figure 5: Various Crack Propagation Lives in the Web of the Longitudinal Stiffener.

## 4 CONCLUSIONS

An advanced simulation system is proposed for the fatigue design based on a step-by-step finite element analysis. Fatigue crack paths are predicted for welded structural details, and their crack propagation lives are investigated by considering the influencing factors such as geometry of structural details and structural redundancy. The present method may offer an efficient simulation-based tool for the design of critical weld details.

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