Digital twin, CAE design, Steel structures, Life extension/retrofit

Advanced life extension technology based on digital twins for steel structures: Highly accurate prediction of cyclic elastoplastic deformation and fatigue damage process against earthquake and traffic loads

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Abstract

It is said that nearly 80% of the damage that occurs to machines, devices, and structures of all sizes around us is caused by “fatigue” that occurs as a result of repeated force and deformation. Therefore, it is important to establish a method that can accurately evaluate and predict the fatigue process of structures made of various materials to prevent fatigue damage and related accidents. This is an extremely important issue for conducting social activities and increasing international competitiveness in various industrial fields. Fatigue damage process has been discussed in terms of the fatigue crack initiation process and the subsequent growth process, and many predictive models have been proposed that span multiple theoretical systems, such as plasticity theory and fracture mechanics. We have developed a numerical simulation (digital twin) technology that can predict the deformation and stress states of structures with high precision and efficiency. Also, the method can evaluate fatigue cracks from initiation to propagation and rupture.

Background & Results

By utilizing the digital twin/numerical simulation technology that we are developing that targets deformation and fatigue failure phenomena in structures, we will be able to, for example, streamline the treatment of various types of existing infrastructure steel structures that are aging rapidly. We are working to solve many social issues, such as formulating new repair and reinforcement plans, proposing new structures/materials that can reduce maintenance costs, and developing new life extension technologies for steel structures.

Significance of the research and Future perspective

Many cases of fatigue damage originating from welds have been reported in various weld structures, and the development of various life extension techniques and remaining life diagnosis techniques necessary for their evaluation is progressing. The main causes of this fatigue damage are: a) high stress occurs due to the alignment of the weld and the structural discontinuity, and the presence of weld excess and sometimes defects; b) damage to the base metal due to welding heat input. Depending on the welding process conditions, such as weld metal dilution and subsequent cooling rate, resulting in non-uniform material structure/shape/strength distribution and residual stresses/residual deformations, and c) the complex stresses/strains experienced in weld structures, which is multi-axial/non-proportional/fluctuation history, so there are limits to experimental investigation. In other words, in order to improve the fatigue performance evaluation method and life extension technology for weld structures that depend on welding conditions, it is necessary to develop and implement numerical simulation technology that can appropriately take into account the influencing factors a) to c) above. Deployment of these digital twin technology to mechanical design is vitally important, and we are conducting research with the aim of developing technology with high engineering impact that is essential to solving these problems.

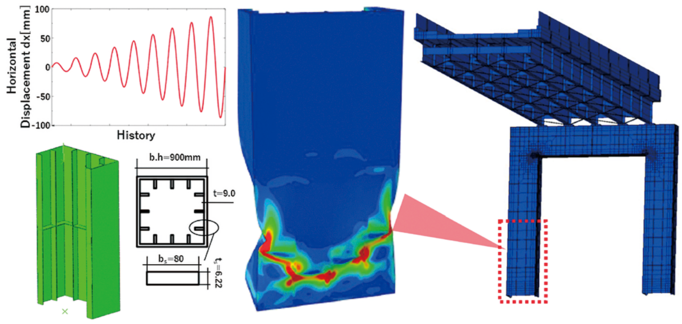

Fig 1 Digital Twin of Bridge pier (Cyclic elasto-plasticity FEM simulation)

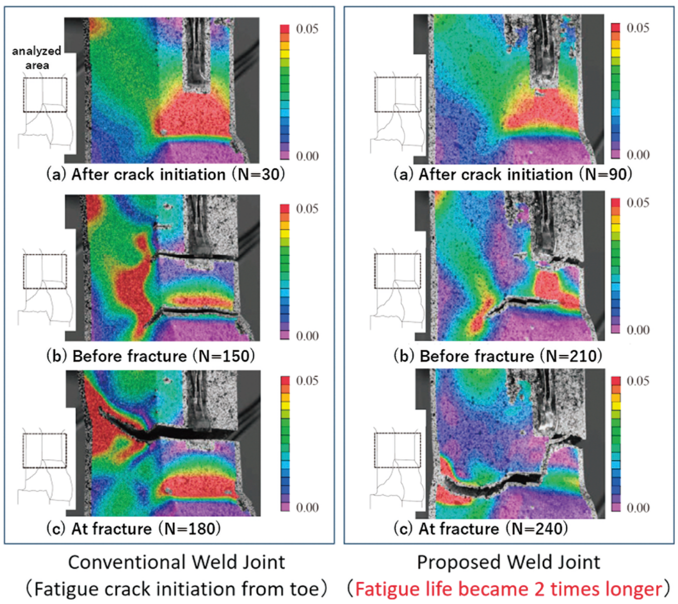

Fig 2 Max. strain distribution measured by DIC (Low-cycle fatigue test of weld joint)

Patent

Treatise

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Keyword cyclic plasticity, material model, FEM, fatigue, crack initiation/propagation