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Low-cycle Fatigue Modelling of Steel Beam-column Connections Based on Lumped Damage Mechanics

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1. Introduction

In Northridge earthquake 1994 and Hyogoken-Nanbu earthquake 1995, brittle fractures were observed at welded beam-to-column connections of steel moment-resisting frame buildings. Such damage significantly reduced capacity of beams to resist against earthquake loading, which in turn triggered damage in columns and collapse of buildings. This paper introduces a novel method to simulate beam fractures using Lumped Damage Mechanics (LDM), which can directly represent damage consequences, i.e. stiffness and strength reduction, by a single damage variable integrated in a material constitutive model.

2. Concept of lumped damage mechanics

In LDM, a frame element is assumed as the assemblage of an elastic beam and two inelastic hinges located at its ends as shown in Fig. 1. Plastic deformations (ϕ_i^p and ϕ_j^p) and damage variables (d_i and d_j) are introduced in the inelastic hinges.

The damage evolution law for simulating fracture is defined based on the Coffin-Manson law for low-cycle fatigue (LCF) where the number of cycles to fracture, N, in a uniaxial test with constant plastic strain amplitude is expressed as:

$$N = \left(\frac{\Delta \varepsilon_p}{\varepsilon_f} \right)^{\beta} \quad (1)$$

where $\Delta\varepsilon_p$ is the plastic strain amplitude, ε_f and β are material parameters. In particular, ε_f indicates the plastic strain amplitude that produces fracture in one cycle and β represents sensitivity of plastic strain amplitude with the number of cycles to initiate fracture.

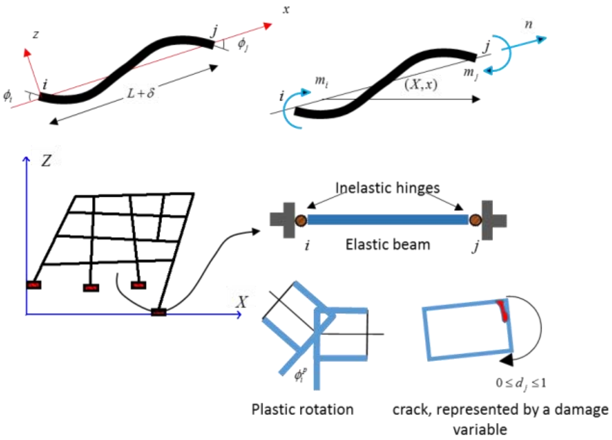

Fig. 1 Frame work of lumped damage mechanics

3. Numerical simulation of low-cycle fatigue

The lumped damage model requires the computation of conventional parameters in a frame element with plastic hinges (EI, AE, M_y, C) and three non-conventional ones for this kind of structures: α, β and ϕ_{cr}. Fig. 2 shows the simulation results of low-cycle fatigue fractures of two beam-column connection specimens under constant loading amplitude. It is noted that the ST-1 and ST-2 specimens experienced significant strength degradation accompanying with the increasing of the number of loading cycle. The proposed lumped damage model achieved high accuracy for simulating LCF fracture of steel beam-column connections.

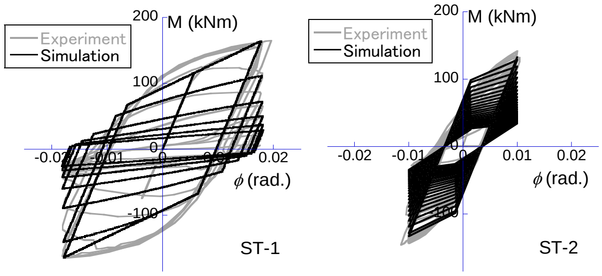

Fig. 2 Simulation results of low-cycle fatigue fracture