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Plasticity model for directional nonlocality by tension cracks in concrete planar members

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ABSTRACT

The concept of directional nonlocality is defined to describe the inherent characteristics of concrete tensile cracks affecting the compressive behavior as well as the tensile behavior of concrete. In the cracked concrete, the crack damage in one direction is influenced by damages from other directions. In the present study, a material model was developed to describe the directional nonlocal effect by tension cracks in concrete planar members. For nonlinear numerical analysis of concrete, the proposed directionality parameter was employed in the plasticity model with multiple failure criteria, and an identical tension crack parameter was used for both the tensile behavior and compressive behavior of the concrete. In the proposed plasticity model, tensile and compressive micro failure surfaces defined in the prescribed multiple fixed orientations were used to describe the directional nonlocality in the micro-structure of concrete, and the overall failure surface of the concrete was calculated by averaging the multi-oriented micro-surfaces. The proposed plasticity model was used for nonlinear finite element analysis of reinforced concrete shear panels, and the analysis results were compared with test results.

1. Introduction

Due to the anisotropic property of concrete, which consists of aggregates and cement paste, tensile cracking occurs not only in the direction perpendicular to the principal tensile stress axis, but also in the adjacent directions. Particularly in reinforced concrete which shows ductile behavior after tensile cracking, tensile cracks are more directionally distributed by the effect of reinforcing steel bars. In plain concretes, a tensile crack is oriented as a small number of large cracks and causes an immediate failure of the member. But, in reinforced concretes, the tensile crack does not result in an immediate failure by the bridge effects of reinforcing steel bars, and more scattered (in aspects of directions as well as area) micro-cracks originate. Thus, the overall tensile crack effect of concrete is caused by the propagation of numerous multi-directional micro-cracks (Fig. 1). To describe the influences of micro-cracks, the concept of "directional nonlocality" needs to be addressed. In general, the "nonlocal" continuum is defined as a continuum in which the stress at a given point depends not only on the strain at that point but on the deformation of a certain neighborhood [1–3]. Similar to this concept, in the present study, the directional nonlocality is defined: The stress at a given orientation depends not only on the strain in that orientation but on the strain of neighborhood orientations, and the damage in one orientation is influenced by damages from other orientations. After tension cracking in concrete, due to the effect of micro-cracks, the crack damage exists in the neighbored orientations as well as in the macro-crack orientation. In other words, the effect of tension crack is distributed throughout the nonlocalized orientations. Therefore, considering the directional nonlocality by tensile cracking, the post-cracking stress at a given direction is represented depending not only on the cracking damage in that orientation but on the cracking damages in certain neighbored orientations. The directional nonlocality by tension crack may significantly affect the structural capacity of reinforced concrete.

In reinforced concrete subjected to tension–compression (or shear), after initial tensile cracking, the principal stress axis rotates from its original orientation when the reinforcing bars were asymmetrically arranged or when the internal force distribution of the member changes due to tensile cracking. However, even when the principal stress axis rotates significantly, new initial tensile cracking does not develop independently from the existing tensile cracks. Instead, the overall tensile crack damage is caused by a combination of the existing multi-directional micro-cracks and new micro-cracks additionally developed by the rotation of the principal tensile stress axis. Due to the influence of such directional nonlocality by tension crack, the tensile stress–strain relationship

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