

論文 Effect of Strain Gradient on Confinement of Reinforced Concrete Columns

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ABSTRACT: Three-dimensional finite element analysis, which incorporating three-dimensional elasto-plastic and continuum fracture model, was utilized to study the effect of strain gradient on confinement of reinforced concrete columns. Section capacity was calculated based on stress-strain relationship for each local fiber in concrete section. For section with strain gradient, the capacity of reinforced concrete section increases significantly for the case of higher axial load, while ductility increases for lower axial load.

KEYWORDS: confinement, strain gradient, reinforced concrete columns, finite element analysis

1. INTRODUCTION

Nowadays, there are two general approaches to calculate the section capacity of reinforced concrete. The first approach is based on plain concrete stress-strain relationship as suggested by ACI Building Code [1]. This approach will give a conservative value, especially for reinforced concrete section heavily confined by lateral ties. The second approach is based on confined concrete stress-strain relationship under uniaxial compression as suggested by New Zealand Code [2].

Many stress-strain curves for plain and confined concrete have been proposed. Most of these models were derived empirically from experimental data of reinforced concrete columns loaded in uniaxial compression. Sheikh and Yeh [3] has extended the model to include the effect of flexural strain gradient. In calculating section capacity, this curve was used to represent stress-strain relationship for all fiber in the concrete section, regardless the location of the fiber. In fact, the amount of confinement across the concrete section under combined axial load and flexure is different. It causes stress-strain relationship across the section be different. The difference can be traced from the stress field and local inelasticity inside the concrete. For this purpose, analytical approach utilizing three-dimensional elasto-plastic and continuum fracture model was applied to understand the confinement mechanism for the section under combined axial load and flexure.

The aim of this study is to computationally investigate the effect of strain gradient on the confinement of reinforced concrete columns. To study the effect on section capacity, interaction diagram of axial load and bending moment for both unconfined and confined concrete section were calculated and compared. The effect on ductility was considered from the stress-strain curves of extreme fiber of concrete section. Local fiber stress-strain relationship along the depth of section was also studied to understand the effect of strain gradient on the confinement of reinforced concrete columns.

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2. THREE-DIMENSIONAL ELASTO-PLASTIC AND CONTINUUM FRACTURE MODEL

Nonlinear behavior of concrete is indicated by internal damage and plasticity. Internal damage represents the loss of elastic shear stiffness induced by the occurrence of micro-defects and the internal stress intensity, while plasticity denotes residual deformation. Micro defects were found not to affect the volumetric elastic energy capacity of concrete but elastic energy capacity in shear mode. Maekawa et al.[4] introduced fracture parameter K to indicate continuum damage occurring in the shear elasticity of concrete. Second invariant of elastic strains J_{2e} was proposed as a primary indicator of internal stress intensity, which evolves the continuum damage associated with the assembly of micro-defects. The damage is formulated of being suppressed by the three-dimensional confinement denoted by I_{1e} as well. Thus, the following indicators of concrete nonlinearity are used [4]:

Indicator of fracturing damage,

$$K = \frac{J_2}{2G_o J_{2e}} \quad (1)$$

Indicator of plasticity,

$$J_{2p} = \int \frac{\partial J_{2e}}{\partial \epsilon_{eij}} d\epsilon_{pij} \quad (2)$$

Indicator of internal shear stress,

$$J_{2e} = \sqrt{\frac{1}{2} e_{eij} e_{eij}} \quad (3)$$

Indicator of internal confinement,

$$I_{1e} = \frac{\epsilon_{ekk}}{3} \quad (4)$$

Indicator of total shear stress,

$$J_2 = \sqrt{\frac{1}{2} s_{ij} s_{ij}} \quad (5)$$

Fracture parameter K represents continuum damage of concrete in terms of elastic shear strain energy. The smaller the value of K , the smaller the capacity of the concrete to absorb and release the elastic shear strain energy due to the induced micro defects. G_o is defined as the initial elastic shear modulus. Plastic indicator J_{2p} represents induced permanent deformation in shear mode and isotropic plastic indicator $I_{1p}(=\epsilon_{pkk}/3)$ represents inelastic dilatancy. Notations ϵ_{eij} and ϵ_{pij} mean elastic and plastic strain tensors, respectively. The values of K and J_{2e} are related to the strength gain of confined columns and J_{2p} to the ductility. Constitutive laws were proposed incorporating the above nonlinear indicators. Details are discussed in reference [4].

3. SECTION ANALYSIS

Study of strain gradient effect on the confinement of reinforced concrete column was carried out by using section analysis. In this analysis, the local fiber stress-strain relationship along the height of section is needed to calculate the capacity of the section. Three dimensional finite element analysis, which is formulated based on constitutive laws described in previous chapter, was utilized to obtain the stress-strain relationship of confined concrete subjected to combined axial load and flexure across the section. Half of the spacing was taken as finite element domain. In this domain, neutral axis was determined and a linear displacement was enforced to the compression part of the section as shown in