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Investigation into Pure Rate Effect on Dynamic Increase Factor for Concrete Compressive Strength

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Abstract

Dynamic increase factor (DIF) has been used to consider rate effect on compressive strength of concrete in both design and analysis of concrete structures loaded with high rate. Until now, a variety of DIFs have been suggested by various researchers, and these DIFs are adopted in design guidelines and model codes, e.g., ACI 349-13, ACI 370R-14, fib MC2010, and UFC 3-340-02. However, the DIFs includes the axial and radial inertia effects, which cause confining effect and resistance to deformation. Therefore, additional strength enhancement due to the inertia effects is included in the DIFs, so applying the DIFs to design and analysis can lead to nonconservative results. In this study, in consideration of the strain acceleration and geometry of a specimen, a new DIF, which is exclusive of the inertia effects, was suggested based on concrete split Hopkinson pressure bar (SHPB) test results. Furthermore, to validate the new DIF, finite element analyses to which the existing and new DIFs were applied were performed for concrete SHPB tests. The verification results indicated that the DIF proposed in this study improve predictions of the dynamic strength enhancement of concrete compared with the existing DIFs.

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1. Introduction

Concrete is rate dependent, so its compressive strength is enhanced under higher loading rate than quasi-static loading rate. Therefore, the rate effect should be considered for economical design and accurate analysis of concrete structures under high loading rate. Dynamic increase factor (DIF), which is generally defined as the ratio of dynamic compressive strength to static compressive strength, has been widely used to consider the rate effect in the design and analysis. Until now, various DIFs have been suggested by many researchers and the DIFs are adopted in design guidelines and model codes, e.g., ACI 349-13 [1], ACI 370R-14 [2], fib MC2010 [3], and UFC 3-340-02 [4].

However, the existing DIFs have a limitation that the DIFs include the axial and radial inertia effects. Because material properties of a specimen are unknown before a test, it is impossible to figure out a desirable load profile which eliminates the inertia effects in the specimen. For this reason, results of dynamic material test include unavoidably the resistance forces due to the axial and radial inertia effects, and the confining effect due to the radial inertia effect.

To overcome the limitation, many research on the inertia effects in dynamic material test has been conducted. Many analytical studies [5-7] revealed that strain acceleration, density and geometry of the specimen cause the inertia effects in the specimen during split Hopkinson pressure bar (SHPB) test which is widely performed to evaluate dynamic material properties of various materials.

Accordingly, a new apparent DIF, which is inclusive of the inertia effects, is formulated by considering strain acceleration, density and geometry of the specimen. Then, the effect due to each factor is quantified based on concrete SHPB test results, and DIF due to pure rate effect, which exclusive of the inertia effects, is suggested. Lastly, to validate the new DIF due to pure rate effect, finite element analyses to which the existing and new DIFs were applied are performed for concrete SHPB tests, and the result of each DIF is compared to one another.

2. Suggestion of DIF considering the pure rate effect

2.1. Apparent DIF formulation

Analytical studies [5-7] showed that the axial and radial inertia effects in SHPB test are caused by strain acceleration, density, and geometry of a specimen. Therefore, the inertia effects in concrete SHPB test can be assumed as Eq. (1), as follows:

$$\Delta f_{inertia} = k_2 \rho_s d_s^2 \ddot{\epsilon}_s + k_3 \rho_s l_s^2 \ddot{\epsilon}_s \quad (1)$$

where, $\Delta f_{inertia}$, $\ddot{\epsilon}_s$, ρ_s , d_s , l_s , k_2 , and k_3 denote the axial and radial inertia effects in SHPB test, strain acceleration, density, diameter, length of a specimen, and coefficients for each inertia effect, respectively.

Also, DIF due to the pure rate effect can be assumed as a power function of strain rate, as shown in Eq. (2), as fib MC2010 assumes DIF as the power function [3].

$$DIF_{rate} = \left(\frac{\dot{\epsilon}_s}{\dot{\epsilon}_{s,static}} \right)^{k_1} \quad (2)$$

where, $\dot{\epsilon}_s$ and $\dot{\epsilon}_{s,static}$ denote strain rate and quasi-static strain rate, respectively. Strain rate in quasi-static test was determined as 10^{-5} s^{-1} by referring ASTM C39/C39M-16b [8].

Meanwhile, apparent DIF can be expressed using Eq. (3), as follows:

$$DIF_{apparent} = DIF_{rate} + \frac{\Delta f_{inertia}}{f_{c,static}} \quad (3)$$

By substituting Eq. (3) with Eqs. (1) and (2), the apparent DIF is expressed using Eq. (4), as follows:

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