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Evaluation of steel fiber-reinforced concrete panel`s impact resistance using existing impact performance prediction models

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ABSTRACT

Impact performance of steel fiber-reinforced concrete is evaluated in this study using the existing prediction formulas. The authors' previous experiments (Kim et al. 2015) confirmed that several available prediction models are conservative with (*t*/*d*) ratios of 3.5 or less, where *t* is the panel thickness and *d* is the projectile diameter. Despite the conservative predictions, the modified NDRC formula and the ACE formula predict the impact resistance more consistently than the other formulas.

1. INTRODUCTION

In the recent design process, there are an increasing number of cases in which structures become damaged or collapsed because of the unexpected blast load or impact by objects with huge kinetic energy. Accordingly, the steel fiber-reinforced concrete (SFRC) with superior damage control and toughness has received attention and several researchers are currently investigating the impact resistance of SFRC (e.g., Almusallam et. al. 2013, Hrynyk and Vecchio 2014, Kim et al. 2015).

In the previous research (Kim et al. 2015), panel specimens with panel thickness (*h*) to projectile diameter (*d*) ratios of 3.5 or less were manufactured which contains variables in order to evaluate impact resistance of SFRC. A major variable was the steel fiber volume fraction, and additional variables were the size of coarse aggregates and specimen thickness. The research was intended to verify the increase of impact resistance of SFRC according to steel fiber volume fraction under various conditions.

In this study, the quantitative analysis is performed using the experimental data and existing predictions formulas suggested by previous researchers and/or codes, and the difference of impact resistance between normal concrete and SFRC is evaluated. By assessing applicability of existing prediction formulas for normal concrete to the

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evaluation of impact resistance of SFRC, this study aims to provide useful information for the impact resistance design for structures adopting SFRC.

2. LITERATURE REVIEW ON IMPACT PERFORMANCE PREDICTION MODELS

The evaluation of impact resistance of concrete has been carried out by numerous researchers (Li et al. 2006, Wang et al. 2013, Yazici 2013, Kim et al. 2015). The study about impact resistance evaluation of concrete structures goes back to approximately one hundred years ago, when Perty conducted a research for national defense (Kennedy 1976). The Perty formula (Kennedy 1976) was produced using the equation of motion based on the research about a hard missile which collides with concrete structures. The Army Corp of Engineers (ACE 1946) and the National Defense Research Committee (NDRC 1946) proceeded related studies and developed the prediction formulas as shown in the following subsections.

2.1 ACE Formula

Before 1943 the Ordnance Department of the US Army and the Ballistic Research Laboratory (BRL) operated a lot of impact experiments of concrete structures, and the ACE came up with the ACE formula based on their test results, which represents the formula for penetration depth as shown in Eq. (1).

$$\frac{x}{d} = \frac{3.5\times10^{-4}}{\sqrt{f_c}}\left(\frac{M}{d^3}\right)d^{0.2}V_o^{0.5} + 0.5 \tag{1}$$

x = penetration depth (m)
d = diameter of missile (m)
M = mass (kg)
f_c = compressive strength of concrete (Pa)
V_o = velocity of missile (m/s)

2.2 Modified NDRC Formula

The NDRC conducted additional experiments on the ground of the ACE formula, and it proposed the modified NDRC formula, which is the formula for penetration depth of rigid missile towards massive concrete targets. The modified NDRC formula suggests the nose shape factor (*N*) according to the nose of projectile in particular as shown in Eq. (2).

$$G = 3.8\times1.0^{-5}\frac{NM}{d\sqrt{f_c}}\left(\frac{V_o}{d}\right)^{1.8} \tag{2}$$

$\frac{x}{d} = 2G^{0.5}$ for $G \geq 1$ or $\frac{x}{d} = G+1$ for $G<1$

G = impact function

N = nose shape factor for the modified NDRC formula = 0.72, 0.84, 1.0 and 1.14 for flat, hemispherical, blunt and very sharp noses, respectively

2.3 Hughes Formula

The Hughes formula (Hughes 1984) considers strain rate effect on concrete tensile strength using Dynamic Increase Factor (DIF, *S*) as shown in Eq. (3).

$$\frac{x}{d} = 0.19k\frac{I}{S}; \quad I < 3500 \qquad (3)$$

I = impact factor $= (MV^2)/(f_r d^3)$

S = dynamic increase factor $= 1 + 12.3\ln(1 + 0.03I)$

k = nose shape coefficient for the Hughes formula = 1, 1.12, 1.26 and 1.39 for flat, blunt, spherical and very sharp noses, respectively

3. EVALUATION OF PENETRATION DEPTH USING PREDICTION MODELS

The predicted penetration depth and tested penetration depth dependent on steel fiber volume fraction are compared in Fig. 1, where the modified NDRC formula, ACE formula, and Hughes formula are applied. In the figure, the ratio of tested penetration depth to predicted penetration depth ($x_{test}/x_{predicted}$) was classified by steel fiber volume fraction. Before the validity of the formula for penetration in terms of steel fiber volume fraction was evaluated, it was noticed that the tested penetration depth was less than the predicted depth for the specimen with 0% steel fiber volume fraction. The average ratios were found to be 0.71, 0.81, and 0.7 when the modified NDRC formula, ACE formula, and Hughes formula are used, respectively. This might be due to the fact that bending energy absorption of the panel was not accounted for in the prediction models.

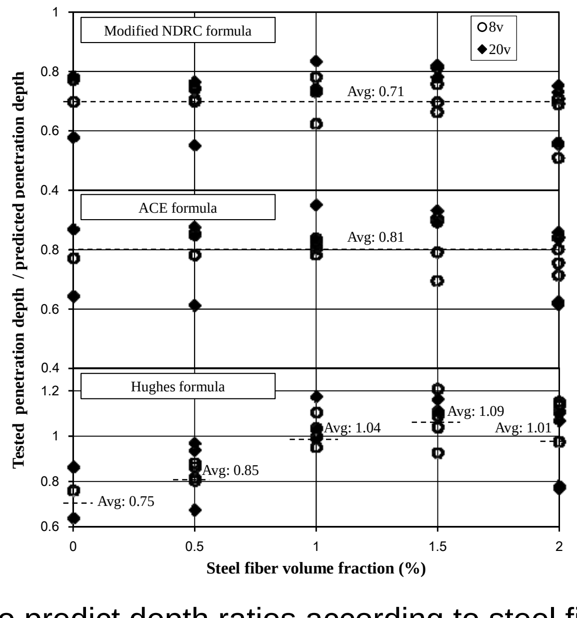

Fig. 1 Penetration depth to predict depth ratios according to steel fiber volume fraction

4. CONCLUSIONS

When the ratio of panel thickness (*h*) to diameter of projectile (*d*) is below 3.5, the predicted penetration depth by the existing impact performance prediction formulas was overestimated than the actual test results. It was because the impact performance prediction models did not reflect the absorption of kinetic energy by deformation capacity. Even so, the predicted penetration depth by the modified NDRC formula and the ACE formula seemed to reflect the effect of steel fiber volume fraction reasonably well.

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