IMPROVED IMPACT RESISTANCE OF LAYERED STEEL FIBER REINFORCED CONCRTE BEAM

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ABSTRACT

In this study, impact behaviors of layered concrete beams with more steel fibers in the tensile zone (0.75% of 30mm by volume) were assessed. This analysis was achieved using LS-DYNA, an explicit finite element analysis program. And the material tests were performed to obtain the material properties. These results were used as a basic input data of material models in LS-DYNA. The results indicated that the impact resistances, flexural strength, ductility, etc., increased steeply when higher steel fiber volume fractions were applied. In the case of the layered concrete beams, the higher impact resistances were obtained than those of the normal steel fiber reinforced concrete beam with an equivalent steel fiber volume fraction. The analysis results were also corroborated with the impact test results, which had similar in terms of maximum deflection.

Keywords: Impact load, Strain-rate, Steel fiber reinforced concrete, Layered concrete beam, LS-DYNA.

1. INTRODUCTION

The recent increase in terrorist attacks and natural disasters has led to increased requirements for concrete structures to be impact resistant. Concrete normally has excellent impact resistance to such extreme loads in comparison with other construction materials. Nevertheless, existing concrete structures designed without consideration of the impact or blast load with high strain rate are endangered by those unexpected extreme loads.

There are many methods to increase the impact resistance of concrete under extreme loads. Above all, adding fiber in concrete is recommended by many researchers as a method that can increase ductility of concrete(Park et al. 2010; Shin et al. 2007; Shen et al. 2008; Zhang et al. 2005). Through adding fiber in concrete, flexure-tensile capacity of structure can be increased. In this situation, many studies of steel fiber reinforce concrete (SFRC) and FRP sheet reinforced concrete

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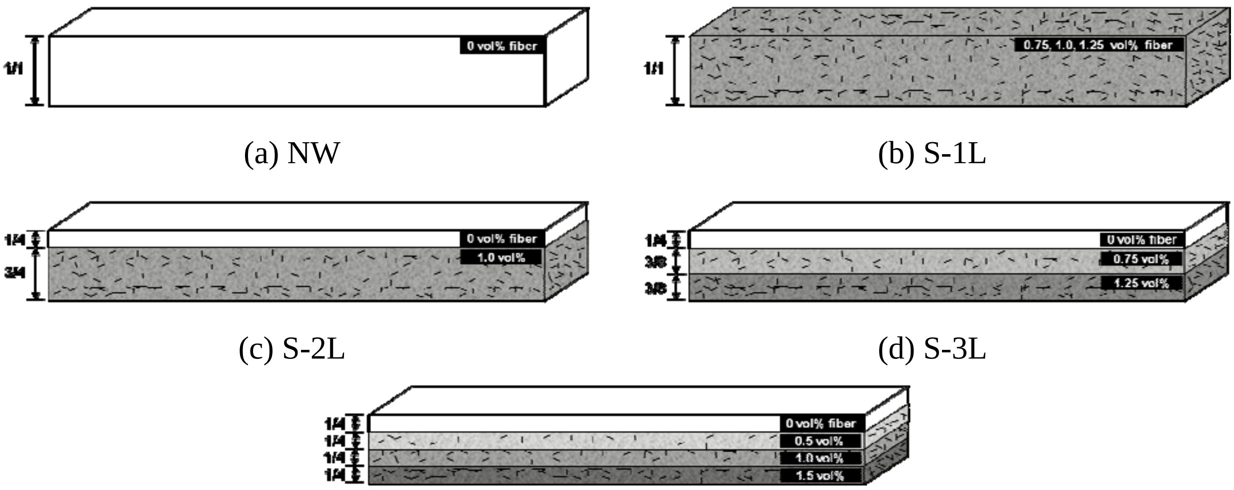
have been conducted. However, the studies are not enough to understand the structural behavior under impact loading. Therefore, this research presents the impact analysis of steel fiber reinforced layered beam using LS-DYNA, an explicit finite element analysis program. The material properties used in this analysis were obtained from material tests. The analysis results were corroborated with the drop-weight impact tests.

2. FINITE ELEMENT ANAYLSIS OF LAYERED BEAM

2.1. Introduction of analysis



(a) NW (b) S-1L

(c) S-2L (d) S-3L

(e) S-4L

Figure 1: Details of the specimens

Figure 1 shows the specimens are 120×180×1230 mm beams of normal concrete and SFRC(steel fiber reinforced concrete). All of specimens are reinforced with 0.75% of equivalent steel fiber(by volume), except NW. S-1L is one-layered beam with 0.75% of SFRC, S-2L is two-layered beam with 0.75, 1.25% of SFRC, S-3L is three-layered beam with 0%, 0.5%, 1.0% of SFRC, and S-4L is four-layered beam with 0%, 0.5%, 1.0%, 1.5% of SFRC.

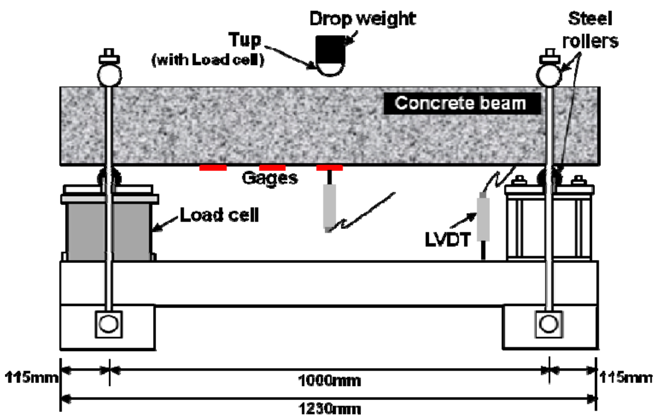


Figure 2: Impact test and analysis apparatus

Figure 2 shows the impact test and analysis apparatus of the specimens. In the impact analysis, the impact energy was about 127J with 12.97kg of drop weight. The drop height was 1.0m and velocity of the drop weight at the moment of impact was 4.5m/s.

2.2. Material models

The material properties used in analysis are shown in Table 1.

Table 1: Mechanical properties of NC and SFRC

Specimen	V_f (%)	Compressive strength (MPa)	Flexural strength (MPa)
NC	0.00	53.20	6.02
SFRC	0.50	52.43	6.03
	0.75	50.41	6.33
	1.00	49.59	6.38
	1.25	46.49	7.03
	1.50	50.00	7.49

Where, V_f =volume fraction of steel fiber

2.2.1. Normal concrete model

LS-DYNA provides the material models as concrete models which are Winfirith Concrete Model, Pseudo Tensor Concrete / Geological Model, Concrete Damage Model, Brittle Damage Model and Soil-Concrete Model. Among them, the some materials are known to be inaccurate in predicting the plastic behavior of concrete under dynamic load. In the present research, therefore, Concrete Damage Model Rel3 (MAT_72R3) was used to model normal concrete. This model was verified that could properly predict the concrete behavior under impact load. It has been developed to consider the DIF and accumulative damage. In addition, the Concrete damage model is a linear, isotropic, hyper elastic-plastic model that considered tri-axial stress (Hallquist 2006; LSTC 2007).

$$F_i(p) = a_{0i} + \frac{p}{a_{1i} + a_{2i} \cdot p} \tag{1}$$

Where $F_i(p)$ is failure surface for the deviatoric stresses, p is pressure converted from concrete stresses and a_{0i}, a_{1i}, a_{2i} are parameters for three surfaces. In this model, DIF is used based on CEB equation.

2.2.2. Steel fiber reinforced concrete model

Elastic Plastic Hydro Model (Mat_10) was adopted as steel fiber reinforced concrete (SFRC) material model to describe the strain softening behavior. The characteristics of strain softening behavior of SFRC were noted by the following equations about the effective trial stress.

$$^{*}\overline{\sigma}^{n+1} = \left(\frac{3}{2} \cdot {}^{*}s_{ij}^{\;n+1} \cdot {}^{*}s_{ij}^{\;n+1} \right)^{1/2} \tag{2}$$

Where the left superscript, *, denotes a trial stress value, S_{ij} is the deviatoric stress, and n is the number of calculation cycles.

If the effective trial stress $\bar{\sigma}$ exceeds yield stress σ_y, the Von Mises flow rule

$$\phi = \frac{1}{2} S_{ij} S_{ij} - \frac{\sigma_{ij}{}^2}{3} \leq 0 \tag{3}$$

is violated and the trial stresses will be scaled back to the yield surface, i.e., a radial return.

$$S_{ij}{}^{n+1} = m \cdot {}^* s_{ij}{}^{n+1} \tag{4}$$

If the effective trial stress is less than the yield stress, the material falls into elastic state and thus the scale factor m in equation (4) equals to 1.0 (Wang et al. 2009).

2.2.3. Dynamic increase factor

It was considered that the effect of strain rate of normal concrete and SFRC material model by applying DIF equation proposed by CEB(Commite Euro international du Beton).

3. RESULTS AND DISCUSSION

Figure 3 and Table 2 present the analysis results of layered beam. In this study, maximum deflection and dissipated energy were investigated to understand the impact resistance of layered beam. The maximum deflection and dissipate energy can be considered as index of impact resistance. Compared to maximum deflections and dissipated energy, layered beams reinforced with more steel fiber in tensile zone showed superior impact resistance. Among them, S-3L showed the greatest impact resistance. S-4L showed smaller impact resistance than S-3L, although it was placed with higher portion of steel fiber in tensile zone. The reason is that S-4L couldn't have enough layer depth.

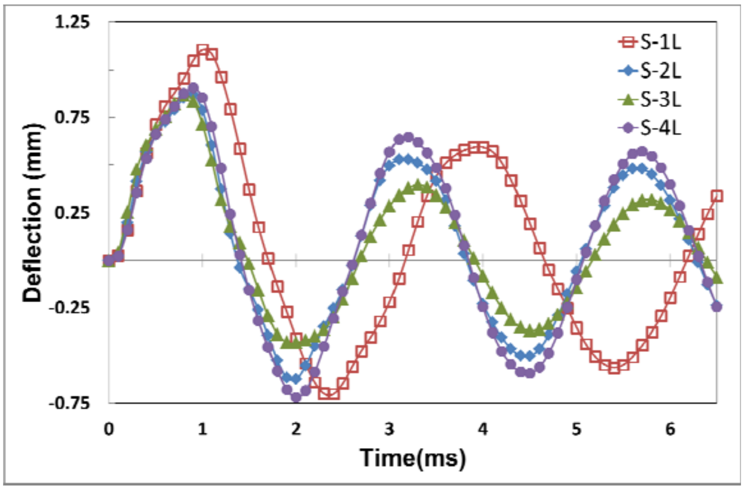


Figure 3: Time-deflection curve of layered beam

In addition, Table 3 shows the results of drop-weight impact test. It presents the maximum deflection of specimens, maximum force, and strain rate. Compared to the analytical results, it showed similar behavior. From these comparisons this analysis procedure was confirmed to simulate realistic behavior of steel fiber reinforced layered beam under impact loading.

Table 2: Analysis results

Specimen	Drop weight (kg)	Impact energy (J)	Max. d (mm)	Dissipated energy (J)
NW	12.97	128	-	58.2
SW-L			1.10	81.8
S-2L			0.90	90.5
S-3L			0.87	92.6
S-4L			0.90	82.9

Table 3: Impact test results

Specimen	Drop weight (kg)	Impact energy (J)	Max. d (mm)	Max. F_{DW} (kN)	Max. d_{DW} (mm)	Max. $d\varepsilon/dt$ (s^{-1})
NW	12.97	128.35	Fracture	73.52	7.23	-[a]
S-**1**L		128.58	2.41	70.63	8.41	0.133
S-2L		128.51	1.10	73.47	5.15	0.218
S-3L		128.41	1.14	61.07	5.99	0.161
S-4L		128.85	1.72	71.65	5.80	0.616

4. CONCLUSIONS

In order to evaluate the impact resistance of layered beams with more steel fibers in the tensile zone, finite element analysis was performed. The following is an outline of concluding remarks for this analytical study:

[1] Layered beam with higher portion of steel fiber in tensile zone was shown superior impact resistance in the regard of deflection and dissipated energy. However, unless the layered beam has enough layer depth, impact resistance will be decreased.

[2] The containing of steel fibers in concrete can significantly improve the impact resistance. The dissipated energy of steel fiber reinforced concrete (SFRC) was increased about 41% in comparison to the results of normal concrete beam.

[3] The material models based on the results of material tests showed sufficient reliability. And the adaption of DIF (dynamic increase factor) equation from CEB (Comite Euro international du Beton) is legitimate to consider strain rate effect.

5. ACKNOWLEDGMENTS

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