The 2016 World Congress on
The 2016 Structures Congress (Structures16)
Jeju Island, Korea, August 28-September 1, 2016

Numerical Analysis of Behavior of UHPC Panels under High Velocity Impact Loading

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ABSTRACT

Given the lack of the study of the relationship between the strain history and behavior of UHPC panels under high velocity impact loading, the numerical analysis and experiment test were conducted to find out the relationship. When a projectile collides with a UHPC panel, compression pulse is generated from the front face and that pulse is transferred to the rear face of a UHPC panel. In order to resist the compression wave that reaches the rear surface, the tensile wave is generated. This tension wave caused the scabbing from the rear side, as the strain histories on the rear face showed three different regions as compression region, steady region and tension region.

1. INTRODUCTION

In general, exterior plates first of all add the aesthetic beauty to buildings and also helps buttress the external loads. By using existing types of exterior plates such as bricks, granite, marble, or glass, it is not easy to materialize the various forms required by the rapidly advancing and modernizing buildings in this era. Moreover, because of the recent increase in irregular shaped buildings, and high rise and special buildings, the need for various types of exterior plates is rising. As an alternative for new exterior plates, the use of high-strength concrete has been widely accepted and has gained popularity as shown in Fig. 1.This paper studies to find out the relationship between the strain history and behavior of UHPC panels under high velocity impact loading through LS-DYNA and experiment tests.

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Fig. 1 Application of UHPC exterior (Musée des Civilisations de l'Europe et de la Méditerranée, France (http://www.mucem.org))

2. EXPERIMENTAL and ANALYSIS PLAN

2.1 Experiment Plan

An experiment was planned in order to assess collision damage prevention of high-strength concrete plates. A specified compressive strength of 180 MPa concrete was used to manufacture the exterior plates, because it was thought that it would help lighten the weight of plates. The concrete mix was based on the mix proportion, mixer process, and the curing methods of high-strength concrete (Koh et al., 2012) that was developed by the Korea Institute of Civil Engineering and Building Technology (KICT). The high-strength concrete does not use coarse aggregates and it is concrete with narrowed particle space between the hydrate and filler which increases its density. Considering its purpose, the specimen was manufactured with a dimension of 400×400 mm and thickness of 30 mm. The specimen was named as SC180-30-No. based on the concrete compressive strength and its thickness.

The impact energy at which the specimen would collide was set up at a similar level to the kinetic energy of the bullet from a gun. In this experiment, a spherical steel ball was created with a diameter of 20 mm and weight of 32 g to produce a similar level of muzzle energy of the bullet, and it was shot at a speed of around 180 m/s.

Table 1 Concrete mixture

Material		Value	**Water**	150 kg/m^3
Specified Compressive Strength (f'_c)		180 MPa	**Premixing of binder constitutions**[c]	400 kg/m^3
W/B (%)[a]		20	**Fine aggregate**	867.4 kg/m^3
V_f (%)[b]	ϕ0.2 × 16 mm	0.5%	**Antifoaming agent**	0.5 kg/m^3
	ϕ0.2 × 20 mm	1.0%	**Superplasticizer**	18.1 kg/m^3

a. W/B = water-binder ratio,

b. V_f = steel fiber volume fraction,

c. Premixing of binder constitutions is consisted of cement, expansive admixture for cement mixture, zirconia silica fume, Shrinkage Reducing Admixtures, and Filler.

2.2. Numerical analysis using LS-DYNA

In this paper, LS-DYNA was used for the numerical analysis. Choosing a material model is a significant factor in numerical analysis, and for the numerical analysis of this paper, the Holmquist-Johnson-Cook (HJC) model (Holmquist et al., 1993) was used in order to apply the large strain, high strain rate, and high pressure. The HJC model is composed of the pressure, strain rate, and high pressure. The HJC model used the strain value when a damage occurred and the damage was calculated by the incremental equivalent plastic strain and the incremental equivalent volumetric strain (see Eqs. (1) to (4)).

$$\sigma^* = \frac{\sigma}{f_c^{'}} \tag{1}$$

$$P^{*N} = \frac{P}{f_c^{'}} \tag{2}$$

$$\sigma^* = [A(1-D) \rightarrow BP^{*N}][1 + C\ln(\dot{\varepsilon}^*)] \tag{3}$$

$$D = \sum \frac{\Delta\varepsilon_p + \Delta\mu_p}{D_1(P^* + T^*)^{D_2}} \tag{4}$$

where σ^* is the normalized equivalent stress; σ is the actual equivalent stress; $f_c^{'}$ is the quasi-static uniaxial compressive strength; P^{*N} is the normalized pressure; *P* is the actual hydrostatic pressure; *A* is the normalized cohesive strength; *B* is the Normalized pressure hardening; *C* is the strain rate coefficient; *D* is the damage parameter; *N* is the pressure hardening exponent; $\dot{\varepsilon}^*$ is the dimensionless strain rate; $\Delta\varepsilon_p$ and $\Delta\mu_p$ are the equivalent plastic strain and plastic volumetric strain, respectively; D_1 and D_2 are the material constants; and T^* is the normalized maximum tensile hydrostatic pressure.

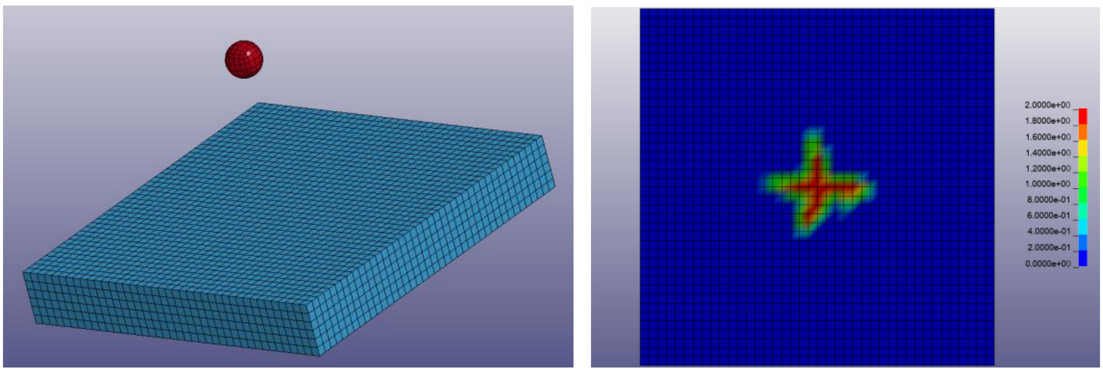

Fig. 3 Modeling (Left) and contours of strain on rear face of UHPC (Right)

3. STRAIN HISTORY

The strain value occurs roughly at a 20μs value compression in the beginning in Fig. 4, while the strain value soon returned to 0. Afterwards, a tensile occurred. Summarizing such a strain history, it can be divided into three regions as seen in Fig. 5. The region 1 is a compression region where the compression wave was applied onto the rear face by the impact load, and then offset by the reflection of tension pulse. The region 2 is a steady region where a compression on the rear face is mainly applied by the tensile force of the free point outside the rear face of the panel, and the strain is maintained as 0. The region 3 is a stage where there is tension and if there is tensile force that exceeds that of the tensile force of the concrete it becomes a tension region where the scabbing occurs. According to the results, it can be argued that there is a failure on the rear where the tensile stress exceeds that of the concrete fracture strength.

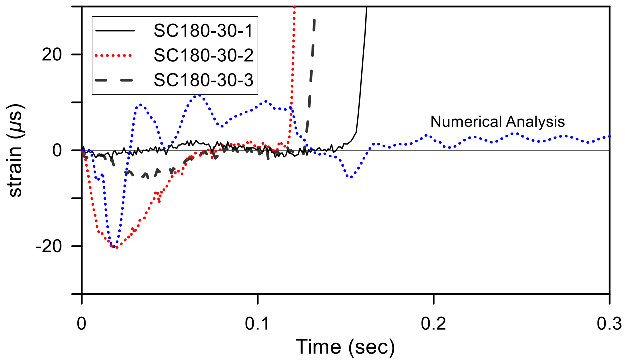

Fig. 4 Strain histories of experiment and numerical analysis

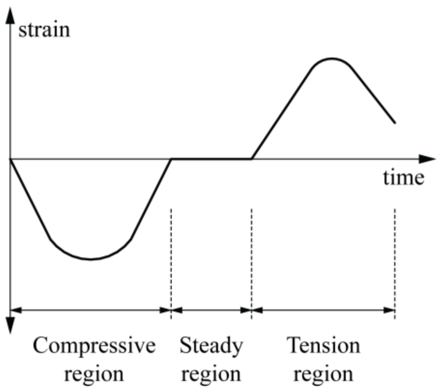

Fig. 5 Generalized strain history theory under impact

4. CONCLUSIONS

In this study, numerical analysis and experiment test were conducted to find out the relationship between the strain history and behavior of UHPC panels under high velocity impact loading. The strain history at the center of the rear face can be generally divided into three regions: the compressive region, steady region, and tension region. The compressive region seems to have been created as the compression pulse of a specimen reaches the rear side from its interior. Afterwards, a tension pulse occurs at the free point outside the rear face of the panel. A region where the compressive pulse and tension pulse becomes similar after the offsetting; in other words, a steady region occurs. Then, after the impact energy of the projectile is exhausted, the tension force that occurs centered around the free point exceeds the concrete fracture strength leading to a creation of a scabbing.

REFERENCES

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