

SPH Simulations of High Velocity Impacts on Concrete Plate

Dr. Tatsuo Sakakibara, Dr. Toru Tsuda and Ryo Ohtagaki

ITOCHU Techno-Solutions Corporation

4-1-3, Kyutaro-machi, Chuo-ku, Osaka, Japan

Summary:

The local damages of the concrete plate are produced by high velocity impact of rigid projectile. In order to represent the cracking or perforation behaviours of the concrete, SPH is appropriate method because of completely mesh free. In this paper, SPH simulations for the local damage of the concrete plate due to high velocity impacts are performed to study the effects of the impact velocity and the strength of the concrete plate. To represent the nonlinear failure behaviour of concrete, MAT_PSEUDO_TENSOR is used as constitutive model in LS-DYNA. The strain rate effects of concrete are also take into account. The numerical results of the local damage of concrete plates are discussed through comparing with experimental results.

Keywords:

SPH, high velocity impact, concrete plate, local damage, strain rate

1 Introduction

SPH is recently well-known particle method as Lagrangian mesh free and it is applicable to high velocity and large deformation analysis like impact and penetration behaviours. SPH has some advantages; one is that it is easy to build up simulation model even though very complicated geometry and another advantage is that SPH is not need to take into account any distortion so that SPH is applicable to analyze large deformation and fracture behaviours[1].

In this paper, SPH simulations for the local damage of the concrete plate due to high velocity impacts are performed to study the effects of the impact velocity and the strength of the concrete plate. To represent the nonlinear failure behaviour of concrete, MAT_PSEUDO_TENSOR is used as constitutive model in LS-DYNA. The strain rate effects of concrete are also take into account. The numerical results of the local damage of concrete plates are discussed through comparing with experimental results. LS-DYNA Ver.971 was used for this study.

2 Model Geometry and Analytical Conditions

In this paper, the experimental specimens by Beppu et al. [2] are used for analytical object. The dimensions of the specimen are 500mm width, 500mm height and 80mm depth. A quarter size of the model with symmetric conditions is modeled in this analysis as shown in Figure 1. In order to reduce calculation time, the center region of the specimen is modeled using SPH particles and the outer region is modeled using lagrangian solid elements. SPH element and Lagrangian solid elements are connected by using "CONTACT_TIED_NODES_TO_SURFACE_CONSTRAINED_OFFSET". A distance of next SPH particles is 1.25 mm. The mass of the entire projectile is 50g. Figure 1 shows model geometry and close up view of the area around rigid projectile. The total number of elements was shown in Table 1.

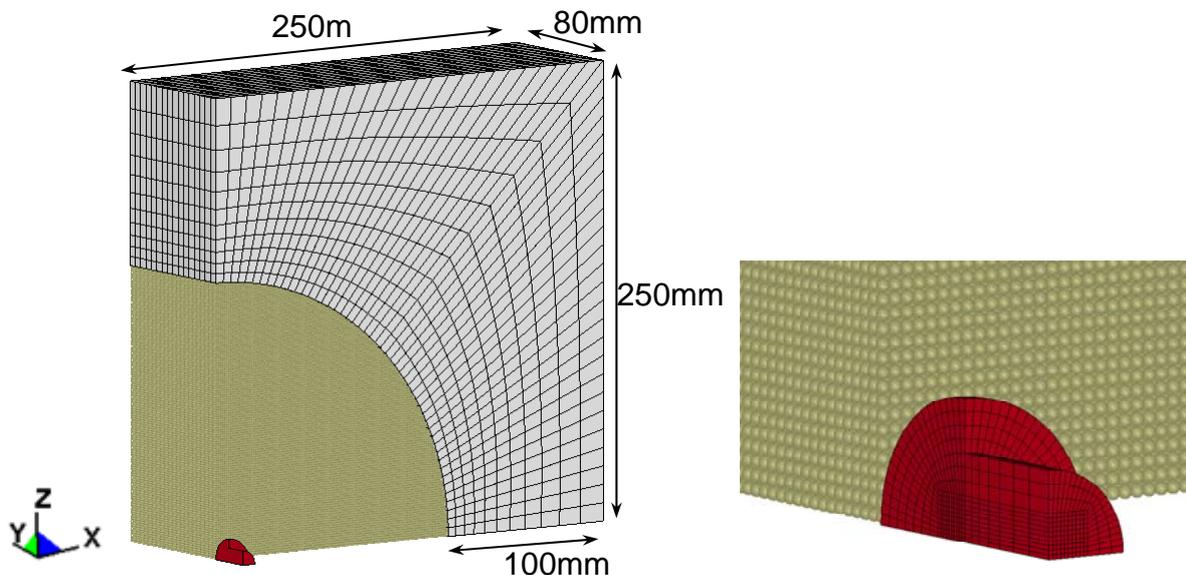


Figure 1: Model Geometry and Close up view of rigid projectile

Table 1 Number of Elements

	Elements	Nodes
Concrete (SPH)	739252	
Concrete (Solid)	8800	10404
Rigid Projectile	4220	4936

In this study, the projectile is modeled as rigid material and the concrete is modeled as elasto- plastic material with Drucker-Prager yield criteria. Two kinds of concrete are prepared as moderate strength and high strength. In order to consider the strain rate effects of the concrete, following Eq.(1) has been proposed by Fujikake et al.[3] to increase the dynamic compressive strength.

$$\frac{f'_{cd}}{f'_{cs}} = \left(\frac{\dot{\epsilon}}{\dot{\epsilon}_s} \right)^{0.006 \left[\text{Log} \left(\frac{\dot{\epsilon}}{\dot{\epsilon}_s} \right) \right]^{1.05}} \quad (1)$$

Where, $\dot{\epsilon}$ is the dynamic strain rate, $\dot{\epsilon}_s$ is the static strain rate, f'_{cd} is the dynamic compressive strength of concrete and f'_{cs} is the static compressive strength of concrete. Figure 2 shows the shear failure surfaces of the moderate strength concrete which are taken into account the strain rate effects. The dynamic compressive strength of the each element is evaluated from the each strain rate at every time step. The tensile strength of the concrete assume constant as the magnitude value of 1/10 of the uniaxial compressive strength. The material properties of the concrete plate are summarized as shown in Table 2.

The particles on the upper surface are fixed as boundary conditions as well as the experimental. The left and the bottom side are applied as symmetric boundaries. Three cases of the velocities of the rigid projectile shown in Table 3 are simulated with moderate strength and high strength concrete respectively.

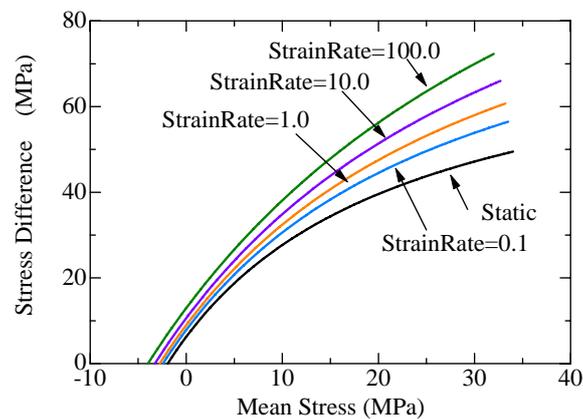


Figure 2: Shear failure surface

Table 2 Concrete Materials

Common	Elastic Modulus	MPa	25500
	Poisson's ratio		0.15
	Density	g/cm ³	2.5
Moderate Strength	Uni-axial	MPa	25.0
	Tensile Strength	MPa	2.5
High Strength	Uni-axial	MPa	100.0
	Tensile Strength	MPa	10.0

Table 3 Calculation Cases

Moderate Strength			High Strength		
NO.	Plate Thickness	Impact Velocity	NO.	Plate Thickness	Impact Velocity
1	8 cm	210 m/sec	4	8 cm	210 m/sec
2	8 cm	310 m/sec	5	8 cm	310 m/sec
3	8 cm	415 m/sec	6	8 cm	415 m/sec

3 Simulation Results and Discussions

Figure 3 and Figure 4 show effective plastic strain distributions in the center cross section, the front surface and the back surface respectively at time=0.69 msec after impact of the rigid projectile. In case of the moderate strength concrete, a large amount of fragments from the front surface scatters backward as well as the experimental results. SPH method does not need to consider any numerical technique such as erosion to avoid numerical error due to large deformation and distortion. Failure areas on the front surface of the moderate strength concrete are expanding with increasing the impact velocities. The projectile with impact velocity of 415 m/sec perforates the concrete panel of moderate strength. On the other hand, the projectiles never perforate and the size of the failure area on the surface are not so different among all cases with high strength. In case of the velocity of 415 m/sec with the high strength concrete, the failure pattern on the front surface is similar to the other cases, but the spalling on the back surface can be seen. In addition, several radial cracking are recognized on the back surface. They are corresponding to the experiment results by Beppu et al.[2].

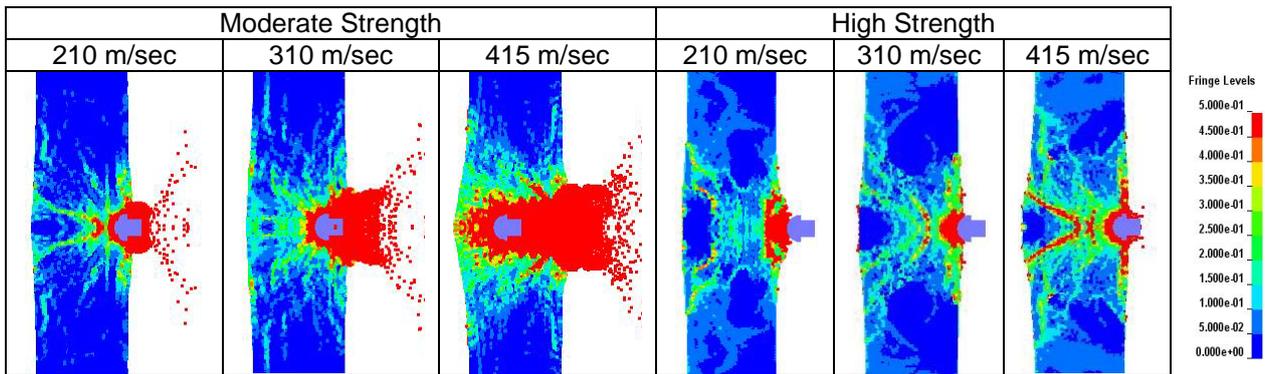


Figure 3: Fringe of effective plastic strain on cross section at time=0.69 msec

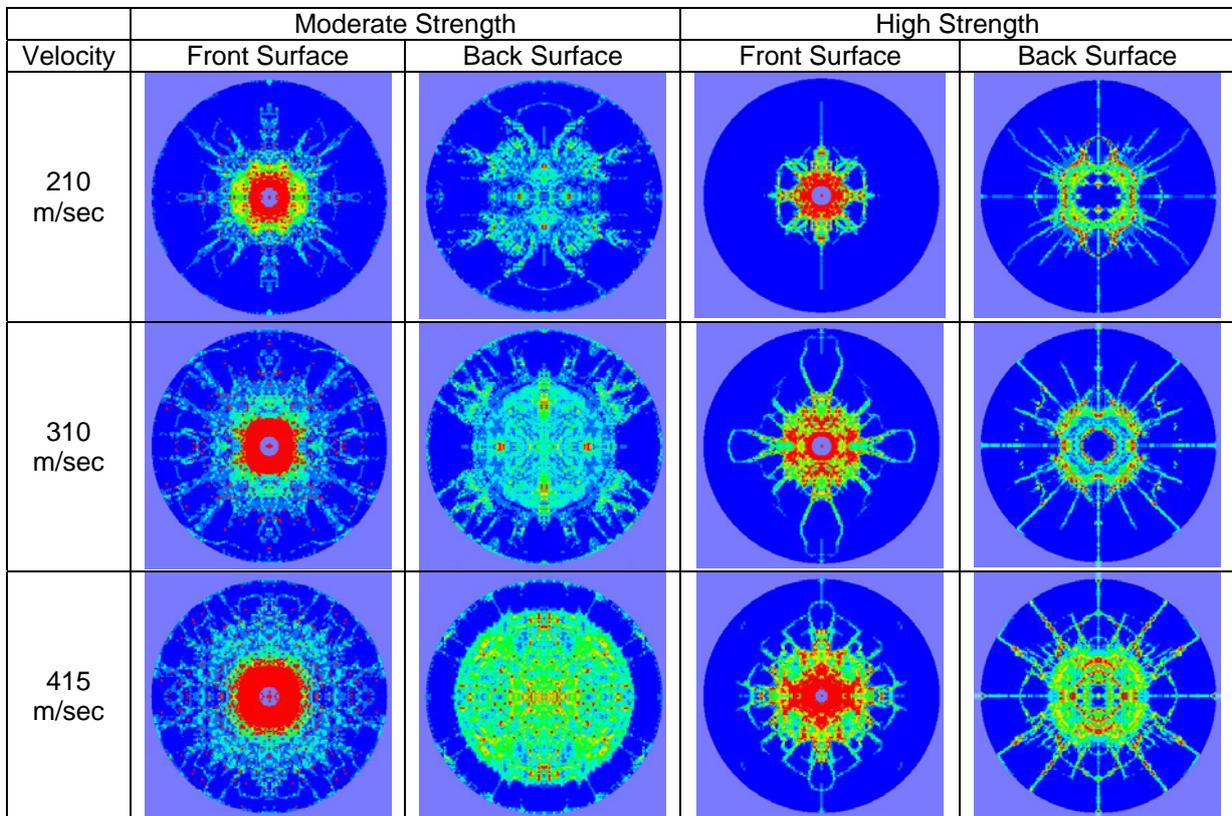


Figure 4: Fringe of effective plastic strain on the surface(Front and Back) at time=0.69 msec

Figure 5 shows the time histories of velocity of the rigid projectile. From this figure, the velocities of the moderate strength concrete gradually decrease and the projectile perforates in the case of the impact velocity of 415 m/sec. The velocities of the high strength concrete rapidly decrease and rebound can be seen in all cases.

Figure 6 shows the time histories of energy of entire model in the case of impact velocity of 415 m/sec. Figure 6 is a case with impact velocity of 415m/sec and an increase of the kinetic energy by the dispersion after the projectile collides with an increase of the strain energy of the specimen can be seen in the moderate strength concrete. Moreover, it can be understood that most of the kinetic energy of the fragments are consumed as strain energy in the high strength concrete. The effectiveness to the high speed collision of the high-strength concrete is confirmed.

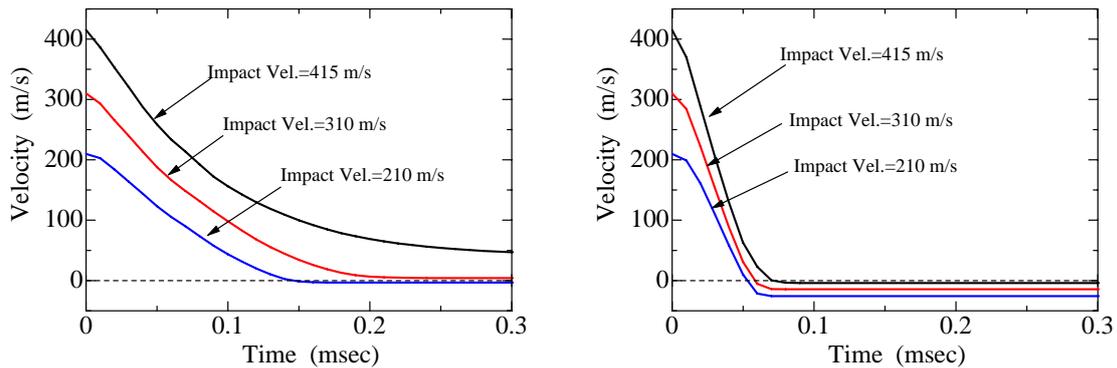


Figure 5: Rigid projectile velocity histories for moderate strength (left) and high strength (right)

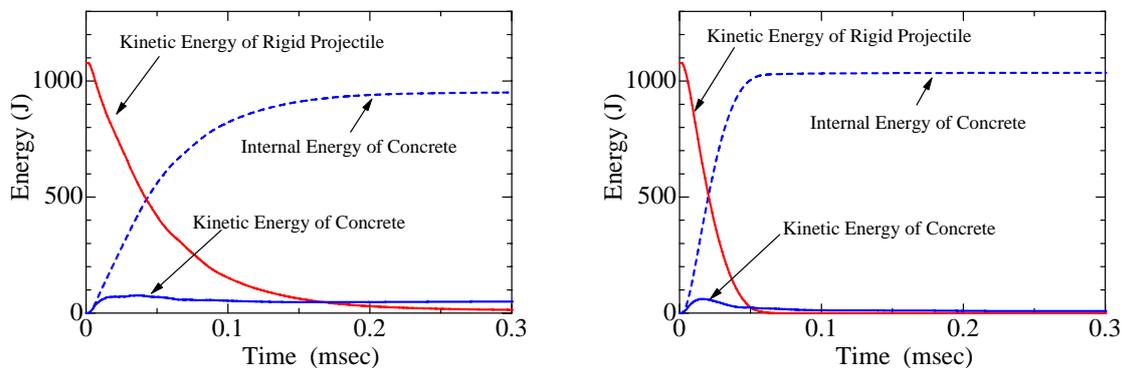


Figure 6: Energy histories for moderate strength (left) and high strength (right) with impact velocity of 415 m/sec

The correlation between fracture depth and impact velocity are shown in Figure 7. The results of the SPH simulation in this study are compared with experimental results by Beppu et al.[2]. Maximum fracture depth of the specimen in SPH results was assumed to be the penetration depth of rigid projectile. The results of the moderate strength have good agreement with the experimental results. However, the results of high strength concrete were smaller than the experimental value. It is thought that a momentary strain speed in the high strength concrete causes an overestimation of the strain rate effects.

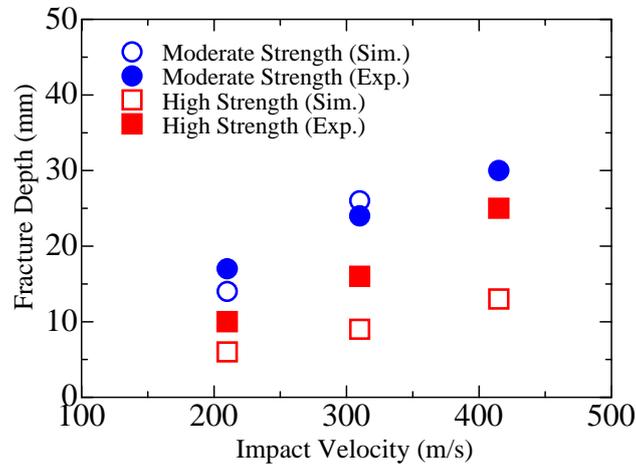


Figure 7: Correlation between fracture depth and impact velocity

4 Conclusion

The local damage of the concrete plate due to high velocity impacts were examined by SPH method. In this analytical result, it was confirmed as follows.

1. The fracture patterns are different in the moderate strength concrete according to an increase of impact velocity.
2. The effect of the decrease of the cratering on the front surface and the spalling on the back surface can be expected with the high strength concrete.

We wish to express our gratitude to Dr. M. Beppu of National Defense Academy of Japan for helpful suggestions related to the experimental results of the high velocity impact to the concrete specimens.

5 Literature

- [1] Leonard E Schwer: "Simple Input Concrete Constitutive Models: An Illustration of Brick Wall & Concrete Cylinder Perforation", 10th International LS-DYNA Users Conference, pp.20.39-20.50, 2008.
- [2] Beppu, M., Miwa, K., Itoh, M., Katayama, M. and Ohno, T.,: "Damage evaluation of concrete plates by high-velocity impact", International Journal of Impact Engineering, Vol.35, 2008, pp.1419-1426.
- [3] Fujikake, K., Uebayashi, K., Ohno, T., Mizuno, J. and Suzuki, A.: "FORMULATION OF ORTHOTROPIC CONSTITUTIVE MODEL FOR CONCRETE MATERIALS UNDER HIGH STRAIN-RATES AND TRIAXIAL STRESS STATES", Jounl of Geotech. Eng., JSCE, 53A, 2007, pp.110-123. (in Japanese)