(12) NUMERICAL STUDY OF IMPACT RESPONSE ON REINFORCED MORTAR BEAM

Shahrul Niza Mokhatar*, Jin Fukazawa*, Soichiro Tokumaru**, Yoshimi Sonoda***

*M. of Eng, Student, Dept of Civil Engineering. Kyushu University（〒819-0395 744, Motooka, Nishi-ku Fukuoka ）
**B. of Eng, Student, Dept of Civil Engineering. Kyushu University（〒819-0395 744, Motooka, Nishi-ku Fukuoka ）
***Dr. of Eng, Prof, Dept of Civil Engineering. Kyushu University （〒819-0395 744, Motooka, Nishi-ku Fukuoka ）

Key Words :(ASPH, Impact response, Reinforced mortar Beam)

1. Introduction

Numerous numerical techniques have been developed in order to predict the impact response of reinforced concrete elements. Furthermore, many researchers have done the study of reinforced concrete under low-velocity impact using computational technique such as FEM, FDM etc. However, some of the techniques have certain inherent advantages and disadvantages, which depend, to a large extent on their particular application.

Nowadays, the developments of mesh-free particles method such as Smoothed Particle Hydrodynamics (SPH) become a new trend as a valuable computational tool other than FEM. Previous application of SPH has been widely used for simulating the impact problems and many researchers have also been successfully applied this kind of mesh-free method to the problems of solids mechanics. The nonexistence of a mesh and the calculation of relations among particles based on their separation alone means that the bending deformation and cracking of an RC elements can be computed without difficulty by using SPH. However, the new theory of SPH that so-called Adaptive Smoothed Particle Hydrodynamics (ASPH) method has been introduced that can extensively improve the accuracy and the ability of general SPH methods. The research led to an ASPH application has been implementing and Shapiro et al. have identified the following common problems with SPH in a year 1994 on simulating the galaxy and large-scale structure formation.

Therefore, in this study, an attempt has been made to examine the accuracy and ability of ASPH method with regards to assessing the response of reinforced mortar beam in term of shear cracking and bending failure during the application of impact forces.

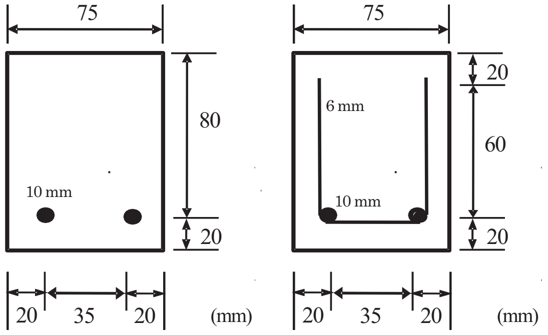
2. Experimental Work

2.1 Introduction to experimental work

The experimental work has shown that the impact results in the beam realizing a peak loading followed by cracking and bending failure of the mortar/concrete structure. The shear crack pattern and bending failure of the beam are most important for further analysis and comparison to the results of the numerical simulation. Of particular interest is the tensile side and bottom region of reinforced mortar beam.

2.2 Setup

The practical test was carried out in Kyushu University that investigating the low velocity impact behaviour and the failure of the beams. Several specimens were tested under drop-weight loads. The total size of the beam is 100mm and 75mm in depth and width, 500mm in length for short beam specimen. For the long beam specimen, 900mm length mortar beam were used. The beam is reinforced with 10mm diameter steel bars and 20mm length for mortar cover between main reinforcement bars to the edge of the beam. In order to prevent the excessive spreading of shear cracking associated with complete failure of long beam specimens. Thus, the stirrups of 6mm were placed along the long beam specimens that spaced at 100mm intervals. In addition, the impact mass 100kg is used as a drop weight. The details of reinforcement arrangement and test set-up used in practical tests are shown in Figure-1 and Figure-2.



(a) Short beam (b) Long beam

Figure - 1 Cross section of the mortar beam

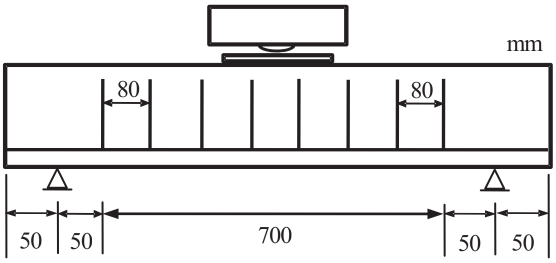


Figure - 2 Schematic diagrams of the beam specimen

2.3 Test set-up

To provide high quality information about the transient development of the failure mechanism of the specimens, the following data systems were used and as shown in Figure 3:

1) The displacement of beam has been measured by displacement measurement (laser displacement meter)

2) The reinforcement had strain gauges placed inside the beam as well as the strain of the mortar beam has been recorded by attaching strain measurement.

3) In order to investigate the failure mechanism, high-speed video camera was used.

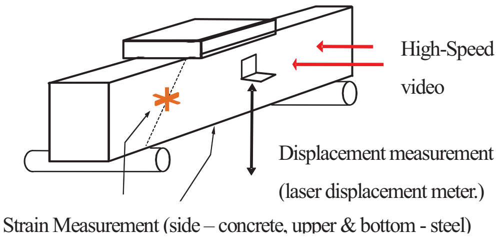
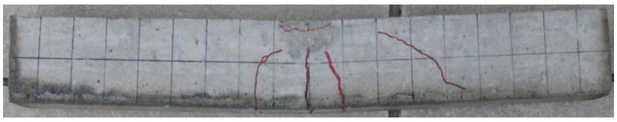


Figure – 3 Details of the position for measurement equipment

2.4 Practical test results

The projectile mass 100kg was dropped and struck the beam directly. Different drop height is applied in this experimental test, where, 0.1m (1m/s) for short beam and 0.25m (2.5m/s) height for long beam specimen. As a result, the shear tension failure, shear compression tension failure as well as bending failure of the short and long beam subsequent to impact process could be investigated. The loss of bond between mortar and steel due to crack could be observed on short beam model. Meanwhile, for the long beam specimen, bending cracking and shear compression tension due to the crushing of mortar is obtained. Both results is shown in Figure 4.

(a) Short beam specimen



(b) Long beam specimen

Figure – 4 Experimental results

3. Numerical Simulation

In this part, ASPH technique was utilized to investigate the shear cracking as well as the bending failure of the mortar beam. Generally, the procedure of ASPH calculations is similar to the conventional SPH. However, in this study some modification has been made to the kernel function and to the isotropic constitutive equation. The ASPH method implemented three independent smoothing kernel functions on the orthogonal three coordinates, in which considering anisotropic kernel function instead isotropic kernel function. Therefore, the shear cracking mechanism could be calculated closely to the experiment result. The first derivative of an ASPH method as shown in equation (1) and the B-spline function as the smoothing function can be seen in the following equation (2). The factor one-dimensional space 1/h was utilized in this calculation due to the independent three coordinates.

$$\nabla W = \left(\frac{\partial W_x}{\partial_x} W_y W_z , W_x \frac{\partial W_y}{\partial_y} W_z , W_x W_y \frac{\partial W_z}{\partial_z} \right) \tag{1}$$

$$W(q,h) = factor* \begin{cases} \frac{2}{3} - q^2 + \frac{1}{2} q^3 & 0 \le q < 1 \\ \frac{1}{6}(2-q)^3 & 1 \le q < 2 \\ 0 & q \ge 2 \end{cases} \tag{2}$$

In general, the performance of ASPH calculation can be summarized by:

1) The interactive particle in the influence area should be defined prior updating the time increment.

2) Calculate the kernel function or integral approximation. For impact calculation, the contact forces should be calculated by using kernel function.

3) The momentum equation that replacing the gradient of stress to the kernel approximation was computed under the force thread. In this formulation, the artificial viscosity of Monaghan as equation (3) has been used in order to prevent the unnecessary penetration for particle during impact.

$$\Pi_{ij} = \left\{ \frac{-\alpha_{\Pi}\bar{c}_{ij}\phi_{ij} + \beta_{\Pi}\phi_{ij}^{2}}{\bar{\rho}_{ij}} \quad v_{ij} < 0 \right. \tag{3}$$

4) Compute the strain rate by replacing the velocity gradient to the kernel approximation. Therefore, the strain rate equation can be obtained by following equation:

$$\varepsilon_{ij} = \frac{1}{2}\sum_{J=1}^{N}\left(\frac{m^J}{\rho^J}v_i^{JI}\frac{\partial W}{\partial x_j^I} + \frac{m^J}{\rho^J}v_j^{JI}\frac{\partial W}{\partial x_i^I}\right) \tag{4}$$

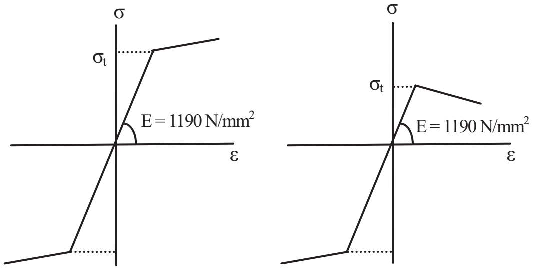
where,

$$v_i^{JI} = \left(v_i^J - v_i^I\right), v_j^{JI}\left(v_j^J - v_j^I\right) \tag{5}$$

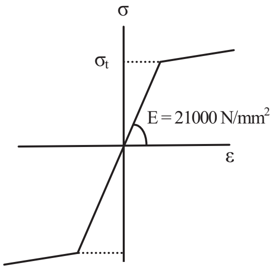
5) Update the strain due to the time increment and update the stress by applying the constitutive equation.

3.1 Reinforced mortar beam modelling

The steel reinforcement and projectile was modelled by yield stress of 30 N/mm^2 for both compressive and tensile side. In addition, an elastic-plastic strain hardening behaviour at 1/100 of the initial stiffness, 21000 N/mm^2 is also applied in the both side. Poisson's ratio for steel and mortar are 0.3 and 0.22 respectively. In order to calculate precise cracking pattern of the beam, Von Mises' with tensile softening and without tensile softening has been applied in the tensile side of the mortar. Furthermore, Young's Modulus for mortar is 1190 N/mm^2 and yield stress for modified Von Mises' is 17 N/mm^2 and 1.7 N/mm^2 for both compression and tension side of mortar. In addition, yield stress 17 N/mm^2 is applied for conventional Von Mises'. The stress-strain curve for both materials could be seen in the Figure 5.



Mortar



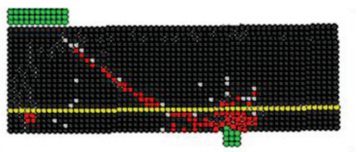
Steel

Figure - 5 The stress-strain curves of steel and mortar

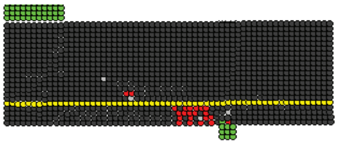
4. Analysis Result

4.1 Comparisons between ASPH and SPH

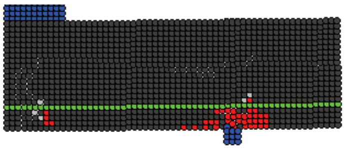
In order to investigate the tensile softening criteria that applied in this calculation. ASPH without tensile softening was also compared with the SPH as shown in Figure 6. It can be seen that the ASPH method with tensile softening could give similar shear crack pattern with the experiment results instead of ASPH without softening criteria and SPH. In practical results, inclined cracking width propagates from top to bottom region approximately about 5 to 15mm. This mechanism appeared closely as in softening criteria used in ASPH models. On the other hand, for the SPH results, the isotropic kernel function used in the SPH calculations could not simulate the shear cracking perfectly. This is regard to the local mean inter-particle spacing in SPH could only changes in time and space instead of ASPH could varies in direction as well. Therefore, the large shear stress in local area only could be calculated precisely using ASPH method.



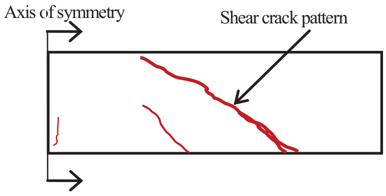
(a) ASPH result with tensile softening



(b) ASPH result without tensile softening



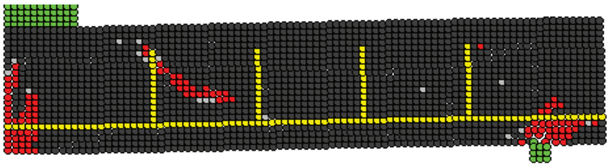
(c) SPH result



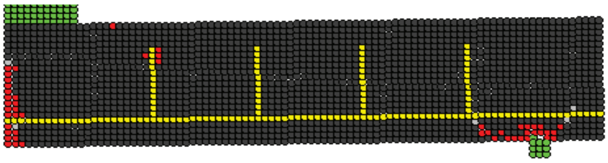
(c) Practical result

Figure – 6 Shear cracking propagation results.

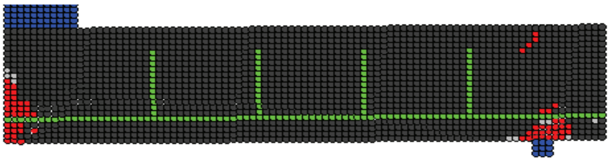
For the long beam models analysis, the same mass with 2.5m/s velocity is applied in this numerical simulation. In this part, bending failure mechanism is the main point of investigation to verify the ability of an ASPH method. Again, both ASPH and conventional SPH calculation has been compared in order to calculate the precise bending cracking. Both ASPH model shows the bending crack distribution and crack pattern that correspond well to the experimental one instead of SPH model. However, APSH method with softening could give more close results in term of inclined cracking pattern.



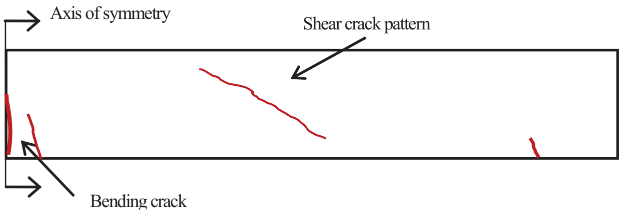
(a) ASPH with tensile softening



(b) ASPH without tensile softening



(c) SPH



(c) Practical result

Figure – 7 Cracking propagation results.

5 Conclusions

According to the numerical simulation result in the previous paragraphs, ASPH can be a reliable method to calculate both shear cracking and bending cracking for reinforced mortar beam. Moreover, numerical simulation using Von Mises model with tensile softening criteria in tension side could produce as closed as an experimental results.

However, to obtain more reasonable and realistic estimations in order to investigate the possible tensile and compressive failure of reinforced concrete elements, further study on ASPH calculations should be done numerously.

References

1) Liu G. R. and Liu M. B., : Smoothed Particle Hydrodynamics, World Scientific Pub. Co. Inc, 2003.
2) Randles, P. W and Libersky, L. D : Smoothed particle hydrodynamics (SPH) method: Some recent improvements and applications, Comput. Methods Appl. Mech. Engrg., Vol.139, pp.375-408, 1996.
3) Owen J.M., Villumsen J. V., Shapiro P. R., and Martel H., : Adaptive smoothed particle hydrodynamics, with application to cosmology: methodology II, Astrophysical Journal Supplement Series, 116, 155-209, 1998.
4) T. Yu, J.G. Teng, Y.L. Wong, and S.L. Dong., : Finite element modeling of confined concrete-I: Drucker Prager type plasticity model, Engineering Struct., Vol.32, pp.665-679, 2010.