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Research Article

The Dynamic Performance of Concrete under Impact Loading

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Abstract: The process of concrete under symmetric impact was experimentally investigated in the case of primary gas gun and was analyzed with Lagrange method. The value-time relations of u, v, e on every lagrange position are gained. The relationship of strain-stress is also obtained. The whole process is numerical simulated by LSDYNA970. It indicate that the damage effect of concrete under impact loading can be described by the function with plasticity strain at constant volume, equivalence plasticity strain and pressure. The manganin pressure gauge is used to measure the pressure-time curves of the samples. The parameters of high-pressure equation are obtained by the numerical simulation. Numerical simulation is a necessary complement to the test. The spall phenomenon is observed by the numerical simulation.

Keywords: Concrete, lagrangian analysis, state equation, shock wave

INTRODUCTION

Concrete is suitable for bridge decks, thin shell structures, nuclear power plants and defensive facilities that may experience impact loads . But the higher strength the concrete is, the higher brittle it is. Understanding the strain rate effect is very important in assessing the structural capacity in resisting impact and blast loads. The process of symmetry impact of concrete was experimentally investigated in literature (Tang, 2004) and analyzed by Lagrange method in the present study in the case of primary gas gun. The value-time relations of u, v, e on every Lagrange position are obtained. The strain-stress relationship is also obtained. Lagrange method is largely used in the dynamic mechanics analysis (Guoping *et al*., 2011; Bonneau *et al*., 1996; Huan and Ding, 1989, 1990).

The process of symmetry impact of concrete was experimentally investigated in literature and analyzed by Lagrange method in the present study in the case of primary gas gun. The value-time relations of u, v, e on every Lagrange position are obtained. The strain-stress relationship is also obtained. The whole process is numerical simulated by LSDYNA970.Numerical simulation compared to the test of impact with the damaging effects can also save a lot of money. The meaning is obvious. (Tang, 2004; Jacques and Cete, 2004; Bonneau *et al*., 1996; Richard and Cheyrezy, 1995).

MATERIALS PREPARATION

The strength grade of cement is P·II 52.5 according to the relevant China standard. Specimens have the diameter 92 mm and 8 mm length. There are four Specimens assembled. The flyer have the same diameter and 10 mm length. Considering contact, this length is rather small and it due to the dynamic loading conditions. The analysis of the test is based on the assumption of no lateral effect, therefore long specimens compared with the diameter must be avoided.

A second point after striking, a stress wave propagate in the flyer and the specimens. When it arrives the head face of the flyer, a sparsity reflection stress wave produced. To avoid the reflection wave catch up with the specimens, the length of flyer must be long compared with the diameter.

Fabricate process of multilayer integrate circuit is adopted on the sensors, precision of superposition between cornwall foil and manganin foil is less than 0.05 mm.

THE DESIGN OF THE EXPERIMENTS

The one-stage light gas gun has been one of the main experimental setups for testing concrete and reinforced concrete specimens. The experiments are carried out in the Earthquake Research Center Laboratory of Guangzhou University in China. The

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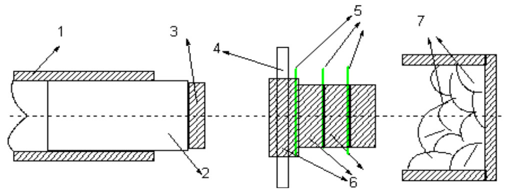

Fig. 1: Schematic diagram of the experiment
1: projectile assembly, 2: light chamber, 3: flyer, 4: target, 5: base board, 6: managanin gauges, 7: recycle bin, 8: specimen

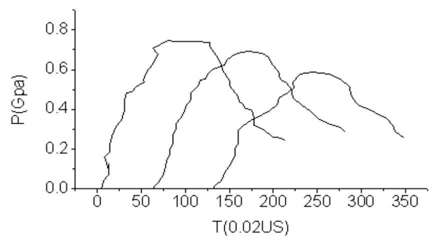

Fig. 2: The experiment results

diameter and length of the gun is 100 mm and 13 m, respectively. The range of impact velocities is from 200 m/s to 800 m/s the error of which is less than 5% and the bevel of impact is less than 10-3 rad. The responses of strain rates range from 103/s to 104/s. The one-stage light gas gun apparatus is shown in Fig. 1 and 2.

LAGRANGIAN METHOD

The record of lagrange sensor is used to calculate the flow field distributed in the tested materials. The experimental temporal curves are used to calculate the value-time relations of u, v, e on every lagrange position. The relationship of experiment, the academic model and the numerical simulation is established by the lagrange method.

Conservation equations in two-dimensions as follows (Clutter and Belk, 2002):

$$u = u_1 - \frac{1}{\rho_0}\int_{t_1}^{t_2} (\frac{l}{l_0})^2 (\frac{\partial P}{\partial h})_t dt \quad (1)$$

$$v = v_1 + \int_{t_1}^{t_2} (\frac{l}{l_0})^2 (\frac{\partial u}{\partial h})_t dt \quad (2)$$

$$E = E_1 - \int_{t_1}^{t_2} P(t)(\frac{\partial v}{\partial t})_h dt \quad (3)$$

where,

ρ_0 = The density
u = Particle velocity
u_1 = Particle velocity of shock front
v = Relatively specific volume
v_1 = Relatively specific volume of shock front
E = Internal energy per unit volume

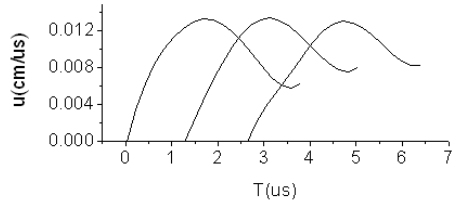

Fig. 3: Histories of u-time calculated

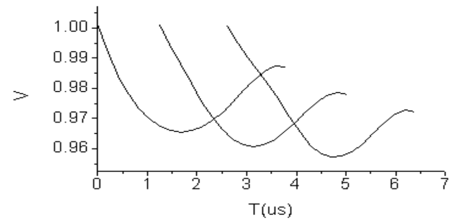

Fig. 4: Histories of v-time calculated

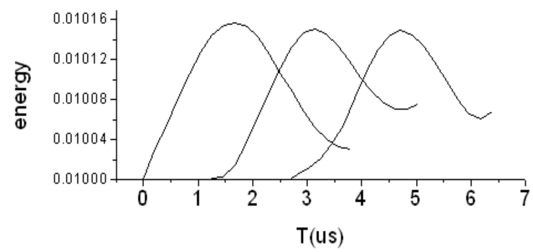

Fig. 5: Histories of e -time calculated

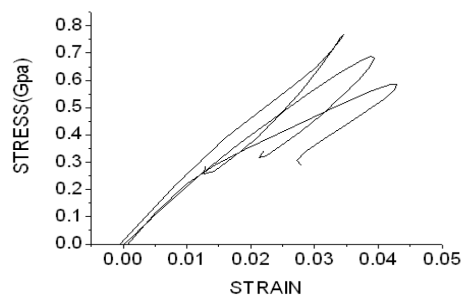

Fig. 6: Histories of strain-stress calculated

E_1 = Internal energy per unit volume of shock front and
t_1, t_2 = Start time and end time, respectively
h = Lagrangian position
l = Radial displacement
l_0 = The length of sensitive part
l/l_0 = Relatively radial displacement

The path and trace lines are adopted to prevent the useful information lost in integral along the isochrone lines. The analogical points(the characteristic points on the waves such as the end point of elastic wave, the peak point of plastic wave etc.) in the pressure-time curves are connected to establish the path lines.

On the assumption, the tested concrete and the lagrange sensors move with the same speeds because of the lagrange sensors are in the tested concretes. The trace lines are the curves of the parameters varied with the time recorded by the lagrange sensors.

The integral along isochrone lines can be changed along the path lines and particle lines:

$$(\frac{\partial p}{\partial h})_t = (\frac{dp}{dh})_j - (\frac{\partial p}{\partial t})_h (\frac{dt}{dh})_j \quad (4)$$

$$(\frac{\partial u}{\partial h})_t = (\frac{du}{dh})_j - (\frac{\partial u}{\partial t})_h (\frac{dt}{dh}) j \quad (5)$$

So, the equations (1), (2), (3) can be written as follows:

$$u = u_1 - \frac{1}{\rho_0} \int_{t_1}^{t_2} (\frac{l}{l_0})^2 [(\frac{\partial P}{\partial h})_j - (\frac{\partial P}{\partial t})_h (\frac{\partial t}{\partial h})_j] dt \quad (6)$$

$$v = v_1 + \int_{t_1}^{t_2} (\frac{l}{l_0})^2 [(\frac{\partial u}{\partial h})_j - (\frac{\partial u}{\partial t})_h (\frac{\partial t}{\partial h})_j] dt \quad (7)$$

$$E = E_1 - \int_{t_1}^{t_2} P(t) (\frac{\partial v}{\partial t})_h dt \quad (8)$$

The $u(t)$, $v(t)$ and $e(t)$ curves are all obtained from the equations (1), (2), (3) with the integral along the path and trace lines of $p(t)$ curves (Fig. 3, 4 and 5). The integral along isochrone lines changed to along the path and trace lines with no other suppose with the Eq. (4), (5). The error are mainly from the experiment and the curves fitting. The least square curves fitting method is adopted with B spline function as test function to prevent the error diffusing to the whole flow field.

The engineering strains are obtained from equation (Fig. 6):

$$\varepsilon = \frac{(v_0 - v)}{v_0} \quad (9)$$

NUMERICAL SIMULATION

The concrete subjected to large strains, high strain rates and high pressures can be described by the Johnson-Holmquist-Concrete material model. The equivalent strength is expressed as a function of pressure, strain rate and damage. The pressure is expressed as a function of the volumetric strain and includes the effect of permanent crushing. The damage is accumulated as a function of the plastic volumetric strain, the equivalent strain and pressure.

Hydrostatic-pressure p is the function of μ. Three response domains (linear elastic zone, intermediate zone, close-grained zone) are included in the relationship function of p - μ.

Three zones included in compressed domain:

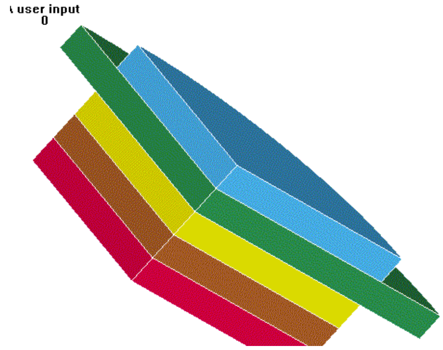

Fig. 7: The finite model

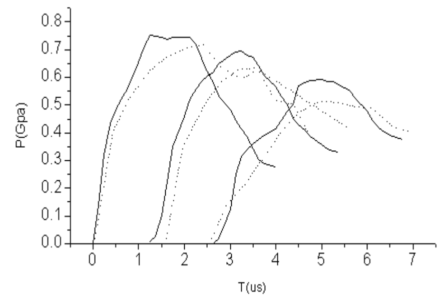

Fig. 8: The resuits of numerical simulated

$$P = \begin{cases} K_{elastic}\mu \quad p \le p_{crush} & \text{linear elastic} \\ P_{crush} + \frac{\mu_{max} - \mu_{crush}}{\mu_{lock} - \mu_{crush}}(\mu - \mu_{crush}) & \text{intermediate} \\ K_1\bar{\mu} + K_2\bar{\mu}^2 + K_3\bar{\mu}^3 \quad P_{LOCK} \le P & \text{close-grained} \end{cases}$$

In tensile domain:

$$P = \begin{cases} K_{elastic}\mu \quad p \le p_{crush} & \text{linear elastic} \\ K_1\mu & \text{intermediate} \\ \{(1-F)K_{elastic} + FK_1\}\mu & \text{close-grained} \end{cases}$$

where, F= $\mu_{max} - \mu_{crush}/\mu_{lock}$ - μ_{crush}, $K_{elastic}$ is elastic bulk modulus, K_1, K_2, K_3 are constants, P_{crush} is critical pressure and μ_{crush} is volume deformation when the voids of the concrete become clogging, $\mu_{lock} = \rho_{grain}/\rho_0 - 1$, ρ_{grain} is crystal density, ρ_0 is initial density, μ_{max} is the max volume deformation before unloading, T is tensile-strength (Fig. 7-8).

The ball has been simplified to a lumped mass on the flyer and 1/4 model adopted because of the symmetry in the numerical simulation. The calculation time is shrinked.

The symmetry impact is adopted in the experiment. The intensity of the materials is ignored to investigate the dynamic characters of materials under high pressures. The state equations or impact adiabatic equations are often adopted to describe the dynamic characters. The particle speed after and the flyer speed has exact relationship, the data processing can be easily obtained. The unsymmetrical impact need more experiments. The impact adiabatic equations should be fitted by least square function leading to the data processing obtained difficultly.

CONCLUSION

- The process of symmetry impact of concrete was experimentally investigated in literature and analyzed by Lagrange method in this study in the case of primary gas gun. The value-time relations of u, v, e on every lagrange position are obtained.
- The strain-stress relationship is obtained with the dynamic characters of materials under high pressures. The foundation has established to investigate the constitutive equations of concrete under impact loading.
- The whole process is numerical simulated by LSDYNA970. It indicate that the damage effect of concrete under impact loading can be described by the function with plasticity strain at constant volume, equivalence plasticity strain and pressure.

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