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EXPERIMENTAL INVESTIGATION ON GENERATION MECHANISM OF EXPLOSIVE STRESS WAVES①

Xu Guoyuan and Gu Desheng
College of Resources, Environment and Civil Engineering, Central South University of Technology, Changsha 410083, P. R. China

ABSTRACT In order to investigate how shock energy (E_s) and bubble energy (E_b) play role in the generation of explosive stress waves, instrumented tests were conducted in concrete models with explosion loading of different column charges containing RDX. Experimental results showed that, as a coupling charge was exploded, the transducer, embedded in model at a relative radius $r = 20$, sequentially recorded two different radial stress waves; the former consisted of a compressive phase and a tensile phase, and the latter had only a compressive phase; the lasting time of the former was much less than that of the latter, but the compressive stress peak of the former was greater than that of the latter. The relation between the loading of both E_s and E_b against media surrounding a charge and the generation of explosive stress waves have been investigated. It was pointed out that the former is generated from impact of E_s and the latter is generated from dynamical loading of E_b against media surrounding a charge.

Key words generation mechanism of explosive stress waves shock energy bubble energy

1 INTRODUCTION

Explosive stress waves are quite important in rock fragmentation process. Many scholars have investigated the generation and propagation of stress waves in rock produced by the detonation of high explosives placed in a small cavity in the rock. Hundreds of radial stress waves have been recorded under different conditions[1-6]. Analyses of these records have shown that, for relatively short distances between charge and gage, the typical radial stress wave has only a compressive stress phase that decreases slowly to zero. A possible explanation of the above result could be that close to the charge the rock is in nonelastic state[1,2]. Besides the above explanation, authors believe that either the memories[2,3] or the amplifiers[4,5] with very limited frequency band, adversely affects the records. According to these typical radial stress waves, it is impossible to distinguish how E_s and E_b play role in the generation of radial stress waves. Perhaps, it is the records that are one of main roots evoking much controversy over the mechanism to rock fragmentation. The controversy focuses mainly on how E_s and E_b play role in rock fragmentation[6]. In some recent researches[7,8], some radial stress waves with more complicated waveshape have been recorded. These radial stress waves indicate that investigation on how E_s and E_b contribute to the generation of radial stress waves could be carried out by means of stress wave test systems with a wider frequency band.

In this work, instrumented tests have been conducted, and the relation between the loading of both E_s and E_b against media surrounding a charge and the generation of explosive stress waves has been investigated.

2 EXPERIMENTAL

Experimental setups for testing radial stress waves, generated at a relative radius $r = 20$,

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were shown in Fig.1. The concrete model, with the density $\rho_c = 2.23$ g/cm^3, longitudinal wave velocity $v_p = 4104$ m/s, transverse wave velocity $v_s = 2\,200$ m/s, dynamic Poisson's ratio $\mu_d = 0.3$ and dynamic elastic module $E_d = 27.9$ GPa, was 1 200 mm in length, 800 mm in width, and 350 mm in height. The transducer was similar to a stress brick, in which a sensor with standard resistance 120 Ω was stuck in cement paste bed. The sensor was 5 mm in length and 3 mm in width. The transducer was embedded in the model at a relative radius $r = 20$, and oriented to read horizontal strain component in a direction radial to the borehole. DE-6 amplifier had a band of 1 Hz ~ 1 MHz. BC-6 digital memory had a band of 1 Hz ~ 2 MHz and a recording length of 2 kb (b—byte). Sampling speed was set at 0.2 μs/b. The charge, which was either a cylindrical solid charge (A) or a cylindrical charge with an axial cavity (B), was couplingly buried in an 8 mm diameter borehole. The parameters of both charges are listed in Table 1. In the table, d, d_c and l represent outer diameter, inner diameter and length of the charge, respectively; ρ and m represent the density and mass of the charge respectively; D represents the charge's detonation velocity.

Comparison between charges A and B, found that m of charge A relatively decreased by about 10%, but D of charge A relatively increased by 38.9%. Change in D of the charges resulted from the explosive's internal channel effect. In this paper, the amount of general explosive energy (E) released from explosion of charge A was hypothetically equal to that of charge B. The E_s amount of charge A was reasonably more than that of charge B. The E_b amount of charge A was reasonably less than that of charge B. Under the experimental, the impact level E_s of charge A against borehole's wall was higher than that of charge B. The dynamically loading level of E_b of charge A against borehole's wall would be lower than that of charge B so long as E_b exerted dynamically on borehole's wall.

Fig.1 Scheme of experimental setups for testing radial stress waves (unit: mm)
1 —Charge; 2 —Stemming; 3 —Transducer; 4 —Concrete model; 5 —Computer; 6 — Memory; 7 —Amplifier

3 RESULTS AND DISCUSSION

3.1 Measurement of radial stress waves

Under the experimental shown in Fig.1, radial explosive stress at any given time was determined by[7]:

$$\alpha = \mathrm{arctg}(c_p / D) \qquad (1)$$

$$\sigma_r(t) = E_d K_b \varepsilon_s(t) / \cos\alpha \qquad (2)$$

where α is the angle between the axial of charge and stress wave front at the transducer; K_b is the calibration constant of testing system; $\varepsilon_s(t)$ and $\sigma_r(t)$ represent the digital value of horizontal strain component and radial stress at the transducer at any given time, respectively; Meanings of others above-mentioned are not changed.

The typical stress waves, generated from

Table 1 The parameters of charges

Charge	Explosive	d/mm	d_c/mm	l/mm	ρ/(g·cm^{-3})	m/g	D/(m·s^{-1})
A	RDX	8	2.56	120	0.91	5.49	7 500
B	RDX	8	0	120	0.91	4.93	5 400

explosion of charge A, are shown in Fig.2. The typical stress waves of charge B are shown in Fig.3. Since logarithmic time coordinate was used in the figures, the waves became more distinguishable. The figures show that, as a charge was exploded, the transducer sequentially sensed two different stress waves. The former consists of a compressive phase and a tensile phase, and the latter has only a compressive phase. The lasting time of the former is much lesser than that of the latter, but the compressive stress peak of the former is greater than that

Fig.2 Stress waves generated from charge A at $r = 20$

Fig.3 Stress waves generated from charge B at $r = 20$

of the latter. During the period between the end point of the former and the starting point of the latter, $\sigma_r(t)$ is almost equal to zero. The shape of stress waves, shown in Fig.2 and Fig.3, is more complicated than that of stress waves recorded by the scholars[2-5], but was similar to that of stress waves recently recorded by Dick *et al*[8]. The stress waves with complicated wave shape could objectively reflect the loading of E_s and E_b against media surrounding a charge.

The compressive stress peaks of the waves, shown in Fig.2 and Fig.3, are listed in Table 2. Analysis of the tendency between σ_{rfc} and σ_{rsc} with a change in E_s or E_b indicates that, with increase in E_s or decrease in E_b, σ_{rfc} rose while σ_{rsc} decrease. But with decrease in E_s or increase in E_b, σ_{rfc} decrease while σ_{rsc} rises.

Table 2 Compressive stress's peak of two waves

Charge	Serial No	σ_{rfc} / MPa	σ_{rsc} / MPa
A	10	51.95	14.22
A	18	40.28	10.17
B	8	26.77	17.69
B	24	24.16	21.75

3.2 Generation mechanism of stress waves

On the generation mechanism of the two different stress waves sequentially recorded at $r = 20$, the authors formulate following hypotheses.

Hypothesis One: The former and the latter, which are generated in rock simultaneously from impact of E_s against media surrounding a charge, are the longitudinal stress wave and transverse stress wave, respectively. This is because the longitudinal wave travels faster than transverse wave does through the model.

Hypothesis Two: The former and the latter are generated in rock from loading of E_s and E_b against media surrounding a charge, respectively. The former is evolved from the transmitted stress wave, which is generated in media by detonation wave striking borehole's wall with incidence. The latter is evolved from the combined action between the detonation products expansion and rebound of compressed media adjacent to the borehole. The former and the latter are related to the action of E_s and E_b, respectively. To some extent, there could be an inverse tendency between σ_{rfc} and σ_{rsc} with a change in either E_s or E_b under condition that E keeps constant.

Under the experimental, the calculated propagating interval (t_1) between the longitudinal and transverse waves from a charge center to the transducer is less than 20 μs. Analysis of the waves, shown in Fig.2 and Fig.3, finds that the starting point interval (t_2) between the latter and the former, which are in the same Figure, is about 130 ~ 194.8 μs. The fact of t_2 much greater than t_1 does not support Hypothesis One; Nor does the above-mentioned inverse tendency between σ_{rfc} and σ_{rsc} with a change in either E_s or E_b. Thus, Hypothesis One is untenable.

However, the above-mentioned results show that, under the experimental, there is the inverse tendency between σ_{rfc} and σ_{rsc} with a change in either E_s or E_b. The tendency gives support to Hypothesis Two. Moreover, Hypothesis Two could get support from other different experiment results. One is that the shock wave and bubble oscillation emerging in water are related to the action of E_s and E_b, respectively[9]. The other is that the explosion loading of a charge, which is couplingly embedded in soil or rock mass, results in the oscillation in borehole's radius[10]. The oscillation in borehole's radius provides a chance for the combined action between the detonation products expansion and rebound of compressed media adjacent to the borehole. Thus, these could verify that Hypothesis Two could be tenable.

In a word, the former and the latter, sequentially recorded at $r = 20$, could be generated from loading of E_s and E_b against media surrounding a charge, respectively. In rock fragmentation, E_b could be similar in dynamically loading or impacting against media surrounding a charge to E_s.

4 CONCLUSIONS

(1) As a charge, couplingly embedded in borehole, is exploded, the former stress wave and the latter stress wave could be sequentially generated in rock from E_s impact and E_b dynamically loading against media surrounding a charge, respectively.

(2) As E of a charge keeps constant, there could be an inverse tendency between σ_{rfc} and σ_{rsc} with a change in either E_s or E_b.

(3) Existence of the latter stress wave indicates that E_b could play an important role in rock fragmentation with dynamically loading against media surrounding a charge.

REFERENCES

1 Duvall W I. Geophysics, 1953, 18(2): 310 - 323.

2 Khanukaev A N. Stress Wave Energy in Rock Blasting by Explosion, (in Russian). Moscow, 1964: 40 - 68.

3 Borovikov V A *et al*. Soviet Mining Science, 1985, 21(6): 505 - 509.

4 Yang Xialin. J of China Coal Society, (in Chinese), 1991, 16(1): 89 - 95.

5 Liao Xiankui *et al*. Mining R & D, (in Chinese), 1997, 17(Supp): 1 - 3.

6 Atlas Power Company. Explosives and Blasting. Dallas, USA, 1987: 157 - 203.

7 Xu Guoyuan. PhD Thesis, (in Chinese). Central South University of Technology, 1995.

8 Dick R D *et al*. In: Rossmanith H P ed. Rock Fragmentation by Blasting. Balkema, Rotterdam, 1993: 47 - 54.

9 Persson P A *et al*. Rock Blasting & Explosives Eng. CRC Press Inc, 1994: 125 - 126.

10 Cherepanov G P. Mechanics of Brittle Fracture. (in Chinese). Beijing: Science Press, 1990: 360 - 376.

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