Numerical simulation on explosion shock wave overpressure produced by double charges

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Abstract. The influence of the number and spatial layout of charge on the overpressure was studied using numerical simulation. The 2-D axisymmetric models were established, considering that the pressure-time history of two equal-intensity shock waves is equivalent to that of shock waves reflected from a rigid surface. At the same position, the overpressures produced by single charge and double charges, which were installed with different included angles, were measured respectively. The results show that the overpressure produced by double charges increase significantly compared to that produced by single charge. With the increase of the included angle between double charges, the overpressure increases and reaches the maximum value when the included angle is 180°.

1. Introduction
The overpressure produced in the air is one of the key factors for evaluating the damage ability of ammunition. Therefore, an effective way to increase the overpressure of the shock wave is quite necessary. In recent years, some domestic and foreign scholars have found that by interacting several shock waves with each other, the overpressure will be increased. Kmetyk [1] et al. studied the interaction of the explosive shock waves of seven hexagonally distributed ammunitions using numerical simulation method. The peak overpressure formed by multi-ammunitions is higher, compared to that formed by single ammunition whose mass is equal to the total mass of the multi-ammunitions. Hu Hongwei [2] et al. studied interaction of two and three ground shock waves experimentally. The results show that the pressure-time history of two equal-intensity explosive shock waves is equivalent to that of shock waves reflected from a rigid surface. Gu Wenbin ,Sun Bailian [3] et al. studied the shock waves produced by two explosive charges installed at the bottom of a shallow water layer using numerical simulation. The conclusion shows that the interaction of shock waves not only increases the intensity of shock waves, but magnifies the number of shock waves as well. Li Xudong [4] et al. studied the focusing phenomenon of shock waves propagating in the concrete experimentally and numerically. It was found that focusing phenomenon was caused by the interaction of multiple shock waves in the solid, so that the damage to materials and structures increased. Zhai
Hongbo [5] et al. studied the indoors explosion effects of double charges and single charge. The results show that the interaction of two shock waves will increase the impulse of the interacting area. This paper investigates the influence of the charge number and the spatial layout of the charge on the coupling effect of shock waves. It is also clarified that two equal-intensity shock waves produce same overpressure as a single shock wave reflected from a rigid surface.

2. Theoretical and simulation model

2.1. Peak overpressure of shock wave reflected from rigid surface

The peak overpressure of air shock wave reflection on rigid surface can be expressed as [6]

$$\Delta p_{rf} = \Delta p_m (1 + \frac{\cos \varphi}{B} + \frac{(\gamma + 1) \Delta p_m}{(\gamma - 1) \Delta p_m + 2B \gamma p_0} \cos^2 \varphi)$$

(1)

The formula is available when $\Delta p_m \leq 2Mpa$ . The unit of the pressure and angle are Kpa and ° respectively. $\Delta p_{rf}$ is the peak reflected overpressure; $\Delta p_m$ is the peak incident overpressure; $p_0$ is the atmospheric pressure; $\gamma$ is the adiabatic index of air; $\varphi$ is the incident angle of the shock wave; $B$ can be expressed as

$$B = \begin{cases} 
\cos \varphi & \varphi \leq \varphi_{cr} \\
\cos \varphi_{cr} & \varphi > \varphi_{cr}
\end{cases}$$

(2)

Where $\varphi_{cr}$ is the critical incident angle, $\varphi_{cr}$ can be expressed as

$$\cos \varphi_{cr} = (\frac{\gamma + 1}{4})^{1/2} (1 - \exp(-2.3 \frac{\Delta p_m}{p_0}))^{1/3}$$

(3)

Where $\gamma = 1.2~1.4$.

2.2. Simulation models

2.2.1 Equivalent model of two equal-intensity shock waves. The calculation models of two equal-intensity shock waves and single shock wave reflected from a rigid surface are shown in figure 1.

(a) two equal-intensity shock waves.  (b) shock wave reflected from rigid surface.

Figure 1. Calculation models of shock wave.

The 2-D axisymmetric simulation works were carried out using AUTODYN software. The models used in the simulation work are shown in figure 2. $r=1000$mm, $m=100g$, 150g, 200g. Spherical TNT was used. Material parameters of TNT and air were taken from the AUTODYN material library. Euler algorithm was used to describe the flow process of air and detonation product. The air areas of
The axisymmetric model and rigid surface model are 4000mm × 1000mm and 2000mm × 1000mm, respectively. The grid size in the charge area is 1mm, and the rest is 2mm.

![Figure 2. Simulation models of shock wave.](image)

By comparing the pressure fields of the two models at the same time, it can be found that the propagation processes of detonation product of two models are nearly the same. When m = 100g, the pressure fields of two models at two typical moments are shown in figure 3, the pressure-time histories of the two models recorded by observation points are shown in figure 4. At 1.2ms, the maximum pressures of axisymmetric model and rigid surface model are 505.7KPa and 505.4Kpa respectively. At 1.8ms, the maximum pressures of the two models are 298.2Kpa and 298.1Kpa respectively. It can be seen that the two models share the same pressure history from figure 4.

![Figure 3. The pressure fields of shock wave.](image)

![Figure 4. Pressure-time history.](image)

The simulation and calculation results of peak overpressures under different conditions are summarized in Table 1. The relative errors of ①-② and ②-③ are less than 2%, which indicates the rigid model can replace the axisymmetric model.

| Condition | Peak Overpressure (KPa) | Relative error(%) ①&② | Relative error(%) ②&③ |
|-----------|------------------------|------------------------|------------------------|
| m=100g    | 525.8                  | -0.330                 | 0.227                  |
| m=150g    | 779.04                 | -1.110                 | 0.397                  |
| m=200g    | 1042.7                 | -1.613                 | -1.636                 |

2.2.2. The layout of double charges. To investigate the influence of the included angle of double
charges on the shock wave overpressure, four conditions were designed as shown in figure 5. Two 100g Spherical TNT charges were installed along a circle with a radius of 1000 mm. Observation points were set at the center of the circle. The included angles(θ) of the double charges were 60 °, 90 °, 120 °, and 180 °, respectively.

![Figure 5](image-url)

Figure 5. Different layouts for two equal-quality charges.

Rigid surface model is used to simplify calculation work. The 2-D axisymmetric models of the four conditions are shown in figure 6, respectively.
2.2.3. The model of single charge. The 2-D axisymmetric model of single charge is shown in figure 7. 200g Spherical TNT charge was set at the center of the circle whose radius is 1000 mm. Observation point is set on the circle.

![Figure 7. The model of single charge.](image)

3. Results and discussion

The simulation and calculation results of peak overpressures under different layouts can be seen in Table 2. Based on the simulation results, the peak overpressure gain, which is defined as the amplification of the double charges compared to the single charge, can be calculated. As the included angle increases, the gain becomes larger. When \( \theta = 180^\circ \), the gain reaches maximum value of 120.62%.

![Figure 6. The simulation models of different included angles.](image)

| Condition                  | Peak overpressure (KPa) | Relative error(%) | Gain(%) |
|----------------------------|-------------------------|-------------------|---------|
|                            | Sim.        | Cal.       |         |         |
| 200g(single)                | 236.76      | 281.45     | -8.624  | 0       |
| 2×100g(60°)                 | 300.59      | 324.18     | -3.776  | 26.96   |
| 2×100g(90°)                 | 386.45      | 417.24     | -3.831  | 63.22   |
| 2×100g(120°)                | 415.27      | 477.95     | -7.017  | 75.40   |
| 2×100g(180°)                | 522.34      | 525.8      | -0.330  | 120.62  |

From formula (1) we can see that when \( \Delta p_m \) is constant, the partial differential of \( \Delta p_{ef} \) to \( \varphi \) can be expressed as:

\[
\frac{\partial \Delta p_{ef}}{\partial \varphi} = \begin{cases} 
\frac{(\gamma + 1)\Delta p_m^2}{(\gamma - 1)\Delta p_m + 2\gamma p_0} & \varphi \leq \varphi_{cr} \\
\frac{-\sin \varphi}{\cos \varphi_{cr}} - \frac{(\gamma + 1)\Delta p_m^2}{(\gamma - 1)\Delta p_m + 2\gamma p_0} & \varphi > \varphi_{cr}
\end{cases}
\]

(4)

Where \( 0^\circ \leq \varphi < 90^\circ, 0^\circ \leq \varphi_{cr} < 90^\circ, \gamma = 1.2 - 1.4, \Delta p_m > 0. \)
The included angles $\theta$ of the double charges can be expressed as:

$$\theta = (180^\circ - 2\varphi) \quad (5)$$

When $0^\circ \leq \varphi < 90^\circ$, $\varphi$ follows the relation of $\sin 2\varphi \geq 0$ and $\sin \varphi \geq 0$. From (4)~(5) we can see that when $0^\circ \leq \varphi < 90^\circ$, $\frac{\partial \Delta P_{ef}}{\partial \varphi} \leq 0$ and $\theta$ decreases as $\varphi$ increases. Therefore, when $\Delta P_m$ is constant, $\Delta P_{ef}$ increases with the increase of $\theta$. The maximum value of $\theta$ is $180^\circ$, as a result, when $\theta = 180^\circ$, $\Delta P_{ef}$ reaches maximum value.

4. Conclusions

According to the simulation results following conclusions were drawn:

(1) The pressure-time history of two equal-intensity shock waves is equivalent to that of shock waves reflected from a rigid surface. The relative errors of the peak overpressure calculated from two models are less than 2%.

(2) The interaction of two equal-intensity shock waves increases the peak overpressure. As the included angle ($\theta$) of the double charges increases, the peak overpressure gain becomes larger. When $\theta = 180^\circ$, the gain reaches the maximum value.

References

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