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Research on Attenuating Mechanism of Wave-eliminating Interceptor on Explosion shock wave in Tunnel Engineering

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Abstract: The research on the explosion shock wave propagation and attenuation technology in tunnel engineering had been a hot issue at home and abroad. The installation of a series of wave-eliminating interceptor in tunnel engineering was beneficial to attenuate explosion shock wave in tunnel engineering. It was rapidly achieved to attenuate the explosion shock wave. In this paper, based on the clarification of the propagation law explosion shock wave in air, explosion load in tunnel engineering was analysed. And the waveform characteristics and propagation law of explosion shock wave were revealed. Then the rectification mechanism was got. The interaction between the explosion shock wave and the interceptor was analysed. Then the reflection mechanism and the disturbing mechanism were obtained. With the numerical simulation method, the propagation law of explosion shock wave under different angles of the interceptor was studied. The attenuation law of explosion shock wave was revealed. The optimal angle of interceptor was achieved.

1 Introduction

With the improvement of precision and power of precision guided weapons, more powerful weapons would be exploded in the mouth of tunnel engineering, and the high-strength explosion shock waves would be entered the interior of tunnel engineering. It was a great threat to the facilities and personnel in the engineering. Because of the constraint of the wall surface, the attenuation and duration of the explosion shock wave were slower and longer. And the killing and damaging effect of the explosion shock wave in tunnel engineering is much larger than the free space. In order to quickly attenuate the explosion shock wave and mitigate the explosion damage effect, propagation and attenuation technology of the explosion shock wave were studied by more scholars at home and abroad.

Extending the tunnel length, excavating the T-shaped tunnel, increasing the foam aluminium buffer layer, arranging the water curtain or water spray and other explosion shock wave attenuation measures in tunnel engineering were propose, so that to attenuating the explosion shock wave. However, disadvantages and shortcomings were existed, such as high cost, high requirements for mountain conditions, unresponsiveness. In order to improve the attenuation efficiency of explosion shock wave in tunnel engineering, a new type of interceptor was developed. It was installed on the both walls of the tunnel engineering. And the interceptor was made of light high-strength material and processed into a standard component. It was usually put up and attached to the wall surface, and the normal use of the tunnel engineering could be not affected. If needed, the interceptor would be opened, and a series of prominent flats would be formed in the tunnel engineering. The explosion shock wave flow field would be reflected, disturbed and obstructed by interceptors, the explosion shock wave power would be consumed, the propagation of the explosion shock wave would be affected.

2 Explosion shock wave load in free space

When explosives exploded, huge amounts of energy in a very short time and space would be released. The substances in the explosives would be converted into high-temperature and high-pressure gases. It would be accumulated, and the surrounding air would be compressed, then explosion shock waves

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would be generated. The pressure, density, temperature and speed of air particles would be sharply increased. The typical explosion shock wave pressure-time curve in free space was shown in Figure 1.

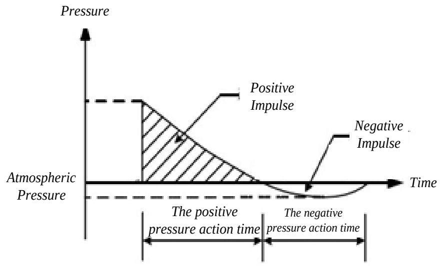

Fig.1 The typical explosion shock wave pressure-time curve

When the explosion shock wave front was reached the peak value P_{so} at time t_A, the incident wave was attenuated to the ambient atmospheric in positive action time t_0. When the reverse flow was happened, the negative pressure peak was P_{so-}, the negative action time was t_{0-}. The damage of the explosion shock wave in free space could be measured by three parameters: (1)The pressure peak of the explosion shock wave P_{so}. (2) The positive pressure action time t_0. (3) The specific impulse i_s, it could be the area enclosed by pressure-time curve in the positive pressure section.

The empirical calculation formulas were obtained by lots of scholars such as Brode, M.A.Sadovskyi, Josef Henrgeh, Baker, Chengqing&Hong Hao. In order to compare the differences of different empirical calculation formulas, the calculated results were placed in the same coordinate system, and the comparison results were shown in the Figure 2. It could be known that the deviation of the results from different formula was decreased by increasing of proportional distance R. The value of the Mills formula was higher than other formulas, and the value of the Henrych formula was lower. When the proportional distance R was greater than $1m/kg^{1/3}$, the predicted results from different formula were relatively close.

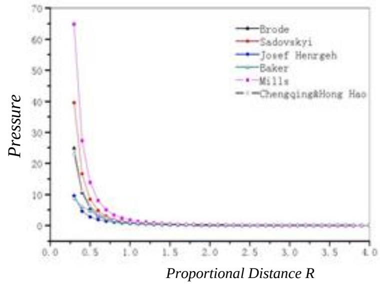

Fig.2 the relationship curve between pressure peak and proportional distance

3 Attenuating mechanism

3. 1 Integration mechanism of the tunnel engineering on explosion shock wave

The explosion effect in tunnel engineering was very different from in the free space. In the infinite space, the explosion shock wave was expanded outward in a spherical shape. The area of the wave front was added by the increasing of propagation distance. Therefore, the energy distributed per unit area of the wave front must be reduced. However, the attenuation of explosion shock wave in the tunnel engineering were mainly due to the continuous widening of the positive pressure region of the explosion shock wave with the wave propagation, and the irreversible energy loss due to the adiabatic compression of the air during its propagation.

When the explosives explode in the tunnel engineering, the pressure, impulse and heat generated by the explosion could not be spread out in time, because of the limitation of the wall surface of the tunnel engineering. The pressure action time became longer by the multiple reflection of the explosion shock wave on the tunnel wall. The personnel and equipment in the tunnel would be damaged seriously. When the same dose and the same blasting distance, the peak value of the explosion shock wave pressure, the action time and the impulse ratio in the tunnel were significantly increased, and the peak attenuation was much slower, so the damage effect was significantly enhanced.

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In the blasting center, due to the combined action of detonation products and explosion shock waves and the reflection and superposition of explosion shock waves on various surfaces in the tunnel, the distribution of the explosion shock wave flow field was complicated, the waveform was relatively disordered, and the peak value of pressure at different points on the same section of the tunnel was different. Through multiple reflections on the wall of the tunnel and the upper and lower sides, a relatively regular plane explosion shock wave waveform was generated in the distance of the blasting center (generally, when the burst distance L ≥ 6D, the blast was in the distance, and D was the equivalent diameter of the tunnel engineering). At this time, the difference about the peak value of the explosion shock wave pressure and the arrival time were gradually reduced, and the explosion shock wave gradually propagated in the form of stable fluctuation. Its pressure peak attenuation was extremely slow, and its waveform could be approximated as a regular plane explosion shock wave waveform.

3. 2 Reflection mechanism of the interceptor on the explosion shock wave

When the explosion shock wave was propagated in the tunnel engineering, the air particle behind the explosion shock wave front was moved with the wave front at a high speed. The explosion shock wave propagating toward the interceptor or the protective door installed in the tunnel engineering was the incident explosion shock wave. When the incident explosion shock wave meets the interceptor or the protective door, the movement of the air particle was blocked, and the air near the interceptor or the protective door were squeezed to increasing the pressure. The pressure and the particle velocity were changed into reverse. That was the reflected explosion shock wave.

The comparison curves of reflected explosion shock wave and incident explosion shock wave were shown in Figure 3. It could be known that the peak pressure of the reflected explosion shock wave was much larger than the peak pressure of incident explosion shock wave. And the negative pressure peak of the reflected explosion shock wave was also correspondingly larger than the incident pressure in the negative pressure section.

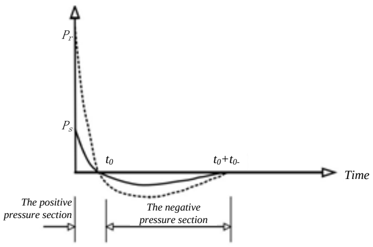

Fig.3 Comparison curves of reflected explosion shock wave and incident explosion shock wave

For the regular reflection, the ideal gas equation could be solved jointly to obtain pressure calculation formula of the reflection explosion shock wave:

$$P_r = 2P_s + \frac{6P_S^2}{P_S + 7P_0} \qquad (1)$$

In which, the reflection pressure is P_r, the incident pressure is P_s, and the atmospheric pressure of the air is P_0. It could be known that the reflection pressure was nearly twice to the incident pressure when P_r was smaller; the reflection pressure was nearly eight times to the incident pressure when P_r was lager. Even in the actual explosion process, the gas was subjected to the high temperature and high pressure of the explosion shock wave, and its state equation was no longer an ideal gas state equation, and the reflected pressure could reach several times of the incident pressure.

For regular oblique reflection, pressure calculation formula of the reflection explosion shock wave was that:

$$P_r = \left(1+\cos\theta\right)P_s + \frac{6P_S^2}{P_S + 7P_0}\cos^2\theta \qquad (2)$$

In which, the incidence angle isθ.

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3. 3 Disturbing mechanism of the interceptor on the explosion shock wave

When the explosion shock wave in the tunnel engineering was acted on the interceptor, the disturbing effect would be happened. It was shown in Figure 4.

When the incident explosion shock wave was encountered by the interceptor, oblique reflection would be occurred on the front surface of the interceptor, and the pressure of the explosion shock wave would be increased, a high-pressure region reflecting in the front surface of the interceptor would be formed.

The unobstructed incident wave was propagated forward, the pressure was not changed. And it became a low-pressure zone comparing to the front surface of the interceptor.

And a pressure difference was formed, by which the generation of air flow and sparse waves were caused. The phenomenon that the explosion wave current flows around the interceptor was the disturbing phenomenon. When the explosion shock wave was passed through the upper surface and the rear surface, an air vortex was generated and suction was generated, which would affect the pressure distribution of the upper surface and the rear surface.

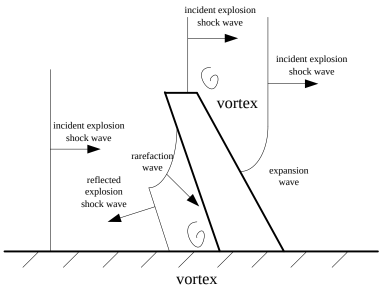


Figure 4 Disturbing effect of the interceptor on the explosion shock wave

4 Numerical simulation of attenuating explosion shock wave

The numerical simulation method was used to analyse the attenuation law of the explosion shock wave with the same explosive load in different working conditions. The peak pressure and impulse of the explosion shock wave were compared. The inclination angle θ between the interceptor and the direction of the explosion shock wave was shown in Figure 5. The distribution of the explosion shock wave flow field in the tunnel engineering was shown in Figure 6. The peak pressure and impulse of the explosion shock wave were shown in Figure 7 and Figure 8 at the different inclination angles.

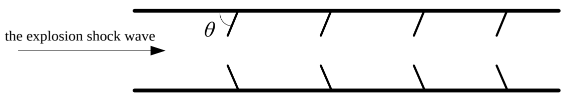


Fig. 5 The explosion shock wave propagated in the tunnel engineering

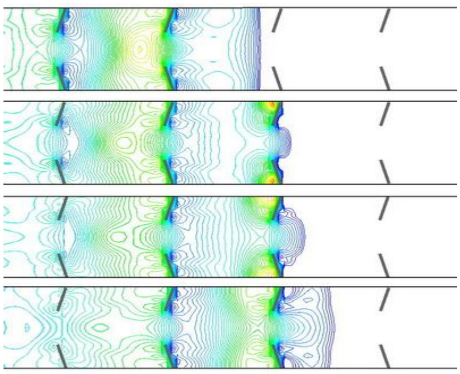
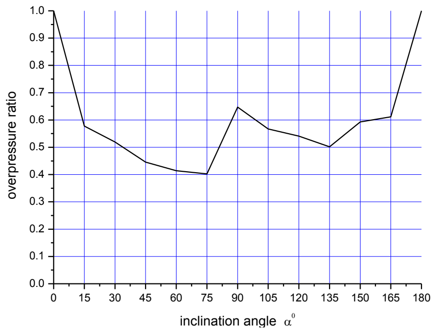


Fig. 6 The distribution of the explosion shock wave flow field



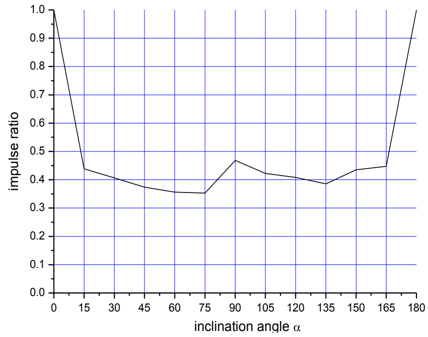


Fig. 7 The curve between inclination angle and pressure ratio Fig. 8The curve between inclination angle and impulse ratio

The schematic diagram of the numerical simulation results of the interceptor attenuating the explosion shock wave were shown in Figure 7 and Figure 8. It was shown that the explosion shock wave flow field in the tunnel engineering would be interfered by the interceptor, the propagation of the explosion shock wave would be delayed, and the pressure peak and impulse of the explosion shock wave would be effectively attenuated. According to the curves in Figure 7 and Figure 8, the optimal inclination angle of the interceptor attenuating the explosion shock wave was about 75 degrees.

5 Conclusion

Based on the clarification of the propagation law explosion shock wave in air, explosion load in tunnel engineering was analysed. The integration mechanism, reflection mechanism and disturbing mechanism were revealed. A complete mechanism of attenuating explosion shock wave by the interceptor in the tunnel engineering was obtained. With the numerical simulation method, the propagation law of explosion shock wave under different angles of the interceptor was studied. The attenuation law of explosion shock wave was revealed. The optimal angle of interceptor was achieved. There were lots of advantages, such as high wave elimination efficiency, simple structure, low cost and convenient installation. It would be significant economic benefits and wide application value.

Acknowledgements

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