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The height of the three-wave point of the shock wave in the blast field will directly affect the damage effect of the ammunition on the target. Accurately obtaining the height of the three-wave point of the shock wave at different altitudes is of great significance for the design of the ammunition and the assessment of the damage power. The paper uses AUTODYN to establish a finite element numerical simulation model of the shock wave pressure distribution of the TNT bare charge explosion field at different altitudes, analyzes the three-wave point heights of the shock wave pressure at the altitudes of 198m, 1500m, 2000m and 4650m, and obtains the effect of the altitude on the shock wave. The influence relationship of the trajectory height of the pressure three-wave point provides a certain degree of guidance for the engineering installation of the free-field shock wave pressure sensor.

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I. INTRODUCTION

During the explosion of the ammunition, there will be many damage elements, such as fragments, shock waves, fireballs, etc., among which the shock wave is one of the main damage parameters. The size of the shock wave pressure directly affects the damage power of the ammunition. During the test, the influence of the three-wave point height trajectory on the shock wave pressure must be considered. It is very important to carry out the research on the relationship between the three-wave point height and the altitude in the existing test environment to accurately obtain the shock wave pressure data.

At present, there are many studies on the variation law of the three-wave point height of the blast field shock wave at home and abroad. For example, Xu Chundong et al used AUTODYN to establish a 1:1 numerical simulation model for the measured blast field environment, and carried out the explosion shock wave data under the equivalent of 10 kg TNT. Obtained, and compared and analyzed the measured data and simulation data, obtained the variation law of the height of the three-wave point, and put forward the engineering installation requirements of the free-field shock wave pressure sensor. Tang Yikang et al. studied the three-wave point trajectory in the explosion field by numerical simulation method based on AUTODYN finite element analysis software, and obtained the relationship between the height of the three-wave point trajectory and the charge quality and the detonation method. Cao Tao et al. established a specific equivalent of TNT free field and near-earth explosion models, and verified the accuracy of the numerical simulation by comparing the free field shock wave overpressure empirical formula. In the near-ground explosion model, the propagation process of the shock wave, the propagation characteristics of the air shock wave and the moving path of the three-wave point are analyzed, which can provide a reference for the arrangement and data analysis of the shock wave overpressure sensor in the thermal baking test of the ammunition. Liao Zhen et al. used the finite element analysis software AUTODYN to establish a finite element model of the near-ground air explosion of TNT charge in order to study the change law of the Mach wave shock wave parameters and the influence of the type of charge and the shape of the charge on the three-wave point trace. , carried out the numerical simulation of the near-ground air explosion for the explosives with different charge shapes and charge types, and obtained the three-wave point traces of the spherical charge and the columnar charge with an aspect ratio of 1 are almost the same. The larger the diameter ratio, the smaller the Mach wave height. Zhang Yulei et al. obtained a formula for predicting the height of the three-wave point height of TNT near-Earth explosion by extracting a large amount of data and using mathematical calculation tools to perform high-precision fitting on the basis of existing research data, and carried out literature data verification and experiments. verify. The results show that the formula prediction results are highly consistent with the literature and experimental results, which can be used for accurate prediction of the triple-wave point height of the TNT near-earth explosion shock wave, and also provides a reference for the prediction of the triple-wave point height of other high explosives. Based on LS-DYNA finite element software, Qu Yandong et al. used numerical simulation method to study the three-wave point motion trajectory of TNT explosive on concrete ground to form an explosion shock wave, and initially revealed factors such as blast height, charge and explosive shape. The effect on the height of the triple wave point. Duan Xiaoyu et al. used ANSYS/AUTODYN explicit finite element program to analyze three kinds of RDX-based aluminum-containing explosives HL-01 (RDXph), HL-02 (85%RDXph+15%Al) and HL-03 (70%RDXph) +30%Al) air explosion process was simulated, and the three-wave point heights of the three explosives were HL-03, HL-02, and HL-01 in descending order; for the same explosive, the three-wave point heights increased with the explosion. increase with decreasing height. It can be seen from the above that the research on the trajectory height of the shock wave three-wave point in the current domestic and foreign research mainly focuses on the influence of the charge quality, the detonation method and the explosion height on the three-wave point height. Therefore, it is necessary to carry out a study on the height variation of the shock wave pressure three-wave point trajectory at different altitudes.

In this paper, the explosion mechanics simulation software AUTODYN is used to establish the finite element numerical simulation model of the blast field shock wave pressure of 10kg TNT at the altitudes of 198m, 1500m, 2000m and 4650m. The effect of height on the change of the height of the three-wave point trajectory is established, and the functional relationship between the two is established.

II. THREE-WAVE POINT OF BLAST FIELD SHOCK WAVE

When the air shock wave encounters a rigid wall, the particle velocity suddenly becomes zero, and the particles at the wall continue to gather, which increases the pressure and density, so the types of reflected waves that form the incident angle of the reflected shock wave are also different.

When a plane steady shock wave is regularly reflected on an infinite absolute rigid wall, the basic relational expression of the shock wave and the shock adiabatic equation are simultaneously sorted out to get

$$\Delta P_2 = 2\Delta P_1 + \frac{(K+1)\Delta P_1^2}{(K-1)+2KP_0} \tag{1}$$

In the formula: ΔP_1 is the overpressure of the incident shock wave; ΔP_2 is the overpressure of the reflected shock wave; P_0 is the pressure of the undisturbed medium; K is the specific heat ratio of air. In general, K=1.4, it can be seen from the formula that the larger the incident overpressure is, the larger the reflected overpressure is.

With the propagation of the incident wave, reflected wave and Mach wave, the three meet in space, and the meeting point is the three-wave point. When the shock wave pressure sensor is located below the three-wave point, the measured shock wave pressure is the pressure of the Mach rod. When the shock wave pressure sensor is located above the three wave points, two wave peaks will be measured at this time. The first wave peak is the incident shock wave pressure, and the second wave peak is the reflected shock wave pressure. When testing the shock wave pressure of the ammunition explosion, more attention is paid to the pressure value of the incident shock wave. Therefore, in the actual test of the shooting range, it is necessary to arrange the free field pressure sensor as much as possible above the three wave points to accurately obtain the pressure of the incident shock wave.

III. ESTABLISHMENT OF FINITE ELEMENT NUMERICAL SIMULATION MODEL

When using ANSYS AUTODYN display dynamics simulation software for numerical simulation of blast field shock wave pressure, the charge material is TNT, the charge mass is 10kg, the charge shape is spherical, the length-diameter ratio of the charge column is calculated as 1:1, and the detonation method is the center Point detonation, the height of the detonation center from the ground is 1.5m, because the model is an axisymmetric structure, so choose two-dimensional axisymmetric in modeling, and establish a 1/4 model. The ground material in the model is sandy soil, the sandy soil structure size is $\text{length} \times \text{width} = 20000mm \times 3000mm$, and the mesh size is $10mm \times 10mm$. The established finite element numerical simulation model of blast field shock wave pressure distribution is shown in the following Figure. 2.

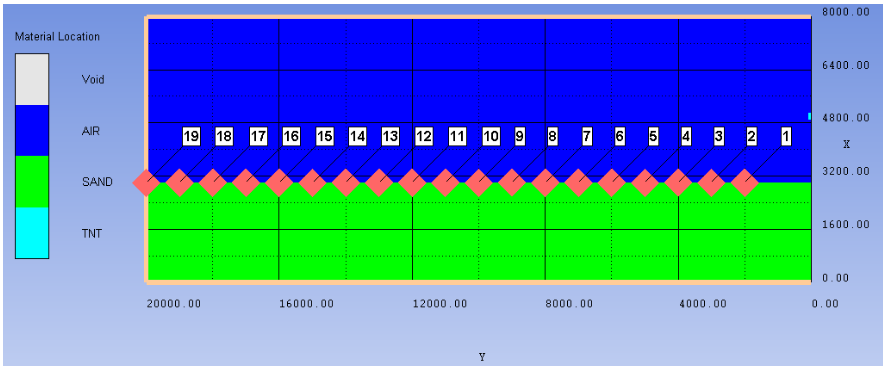


Figure. 2: Finite Element Numerical Simulation Model of Shock Wave in Explosion Field

In the above model, air is in an ideal gas state, the density is 0.001225g/cm³, $E = 4.29 \times 10^6 J/Kg$; TNT adopts the JWL state equation, and its equation is shown in the following formula (2):

$$P = A\left(1 - \frac{\omega}{R_1 V}\right)e^{-R_1 V} + B\left(1 - \frac{\omega}{R_2 V}\right)e^{-R_2 V} + \qquad (2)$$

In the above formula, P is the pressure, V is the volume, E is the internal energy, A and B are the material parameters, R_1, R_2 and ω are constants, and the specific values of the parameters are shown in Table 1.

Table 1: Parameters of JWL equation of state in TNT

Material parameters	A (KPa)	B (KPa)	R1	R2	ω
TNT	3.7377x10^8	3.7471x10^6	4.15	0.9	0.35

Since the air in the AUTODYN material library is in an ideal gas state, and the air density is the value at the standard altitude, in order to simulate the evolution law of the blast field shock wave pressure at different altitudes, the function conversion relationship between altitude and air density is as follows As shown in formula (3), the air density at altitudes of 198m, 1500m, 2000m and 4650m can be obtained as shown in the following Table 2.

$$\rho_x = \frac{P_x}{P_0}\rho_0 \qquad (3)$$

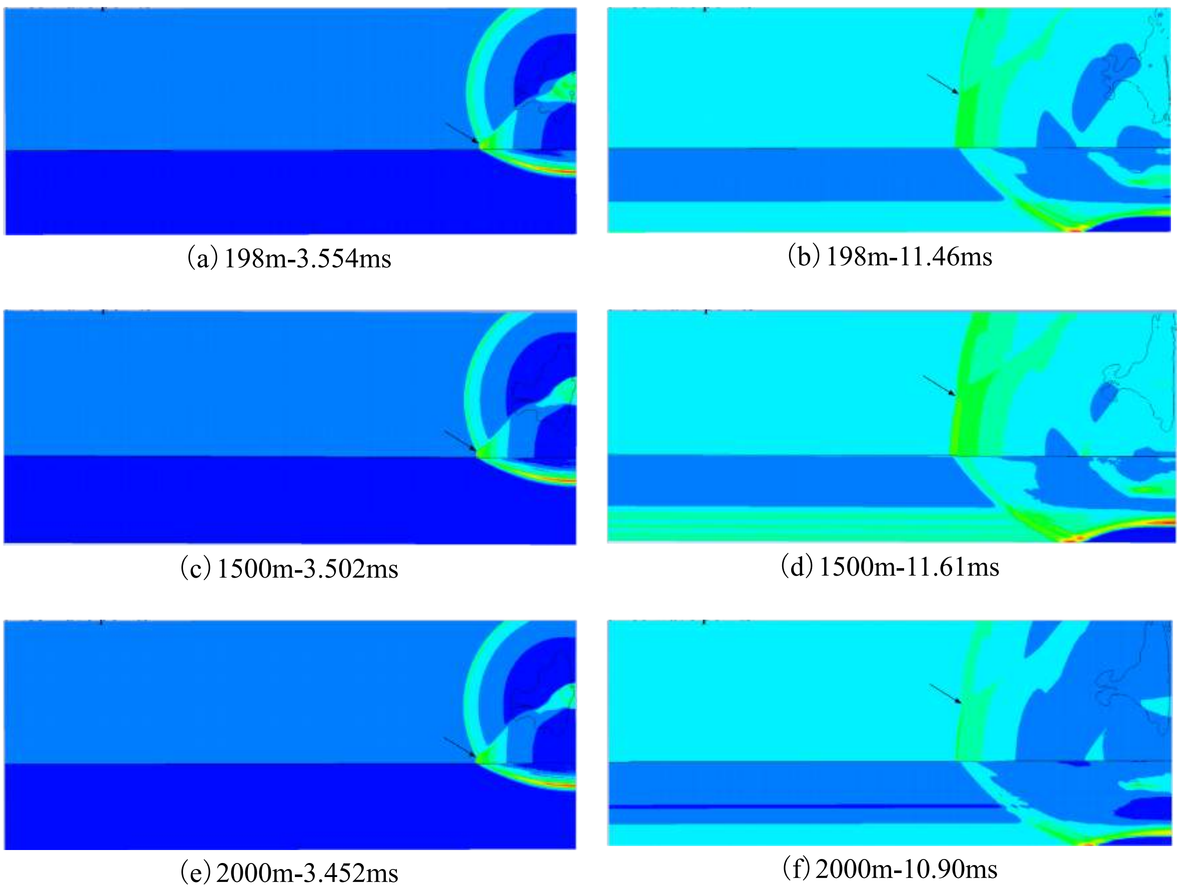
Table 2: Atmospheric pressure and density at different altitude

Altitude/m	198m	1500m	2000m	4650m
Atmospheric pressure/KPa	98.967	84.545	79.481	56.570
Air density kg/m3	1.26	1.076	1.012	0.720

The atmospheric pressure and air density calculated above are used to establish a finite element numerical simulation model of blast field shock wave pressure at different altitudes, and the distribution law of TNT blast shock wave pressure at different altitudes is obtained.

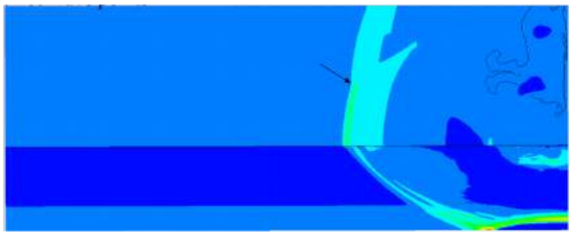
IV. THREE-WAVE POINT TRAJECTORY HEIGHT ANALYSIS

Numerical simulation is carried out using the finite element numerical simulation model of shock wave pressure in the blast field established above, and the height evolution cloud map of the three-wave point trajectory of shock wave pressure at different altitudes and at different explosion times is obtained as shown in Figure. 3.



(a) 198m-3.554ms
(b) 198m-11.46ms
(c) 1500m-3.502ms
(d) 1500m-11.61ms
(e) 2000m-3.452ms
(f) 2000m-10.90ms

(g) 4650m-3.103ms



(h) 4650m-10.60ms

Figure. 3: Three-wave point trajectory height evolution cloud map

It can be seen from the above-mentioned evolution cloud diagram of the trajectory height of the three-wave point of shock wave pressure that the height of the three-wave point of shock wave pressure increases gradually with the increase of explosion time at different altitudes. At the same explosion moment, at the altitudes of 156m, 1500m, 2000m, and 4650m, the heights of the three-wave points are different. With the change of the explosion time, the height trajectory of the three-wave points of the shock wave pressure at the four different altitudes changes. There is also a big difference in the degree. In order to quantitatively analyze the height trajectory of the shock wave pressure three-wave point at four altitudes, the above pressure evolution cloud map is numerically extracted, and the shock wave pressure three-wave point height trajectory at different explosion times at the four altitudes is obtained as shown in Table 3.

Table 3: The height of three wave points at different altitudes and different explosion moments

Altitude/m	Explosion time/ms	Three-wave point height/m	Three-wave point distance from explosion center/m
198	3.554	0.18	3.40
198	4.003	0.30	3.74
198	4.505	0.36	4.06
198	8.359	1.14	6.18
198	10.41	1.52	7.08
198	11.46	1.84	7.52
1500	3.502	0.26	3.50
1500	4.000	0.34	3.86
1500	4.554	0.44	4.24
1500	8.350	1.28	6.28
1500	10.56	1.64	7.36
1500	11.61	1.96	7.78
2000	3.452	0.24	3.52
2000	3.954	0.38	3.88

2000	4.552	0.48	4.28
2000	8.603	1.38	6.48
2000	10.90	1.90	7.46
4650	3.103	0.24	3.52
4650	3.402	0.36	3.76
4650	3.702	0.4	3.98
4650	7.651	1.4	6.36
4650	9.610	2.0	7.26
4650	10.60	2.22	7.70

Analysis of the shock wave pressure three-wave point height trajectory data in the above table shows that at the same altitude, with the increase of explosion time, the three-wave point height gradually increases, and as the explosion time goes on, the three-wave point height changes The rate is getting faster and faster; at different altitudes, the three-wave point height trajectory of the shock wave pressure at the same explosion moment increases with the increase of the altitude, that is, the altitude is positively correlated with the three-wave point height trajectory. In order to more intuitively reflect the law reflected by the above data, the curve plotting of the three-wave point height trajectory change data of shock wave pressure at different altitudes is carried out, and the plotting results are shown in Figure. 4.

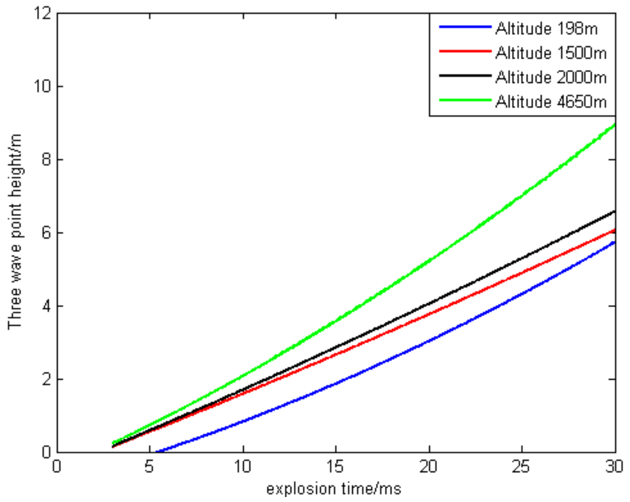


Figure. 4: Variation curve of three-wave point height with explosion time at different altitudes

It can be seen from the above figure that the heights of the three-wave point trajectories at the four different altitudes are $H_{4650} > H_{2000} > H_{1500} > H_{195}$ respectively, and with the increase of the explosion time, the three-wave point trajectory height approximately increases exponentially.

V. CONCLUSION

The paper uses AUTODYN to establish a finite element numerical simulation model of blast field shock wave pressure at different altitudes, obtains the variation law of the height trajectory of the three wave points at different altitudes and different explosion times, and conducts a comparative analysis. The analysis results show that the altitude and shock wave pressure The trajectory height of the three-wave point is positively correlated. The higher the altitude, the higher the trajectory height of the three-wave point at the same TNT equivalent and the same explosion moment. In the free field shock wave pressure test of the actual shooting range, the influence of the altitude on the height of the three-wave point needs to be considered. The law is used to guide the engineering installation of the pressure sensor, so as to accurately obtain the free field shock wave pressure data during the explosion of the ammunition.

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