Simulation Analysis and Research on the Influence of Three-Wave Point Trajectory in the Explosion Field

Yi-Kang Tang & Chun-Dong Xu

Nanjing University of Science and Technology

ABSTRACT

Predicting the location of the three-wave point and the changing law of the three-wave point is of great significance for accurately assessing the power of large-yield explosives or warheads. Based on the AUTODYN finite element analysis software, the three-wave point trajectory in the explosion field is studied by numerical simulation. The preliminary analysis shows that in the blast field, the explosion shock wave always spreads around the explosive center, and the three-wave point height trajectory Both maintain a rising trend. In the midfield (burst distance 4.0~7.0m), regardless of changing the charge equivalent, explosion height, initiation point position, size, material and reflection interface, the three-wave point height increase rate is relatively slow, while in the far field (burst center distance >7.0m) The growth rate is relatively fast. When the explosive height of the explosive does not change, change the explosive equivalent. The smaller the equivalent, the higher the three wave points at the same measuring point. When the explosive equivalent is unchanged, change the explosion height, the smaller the explosion height, the higher the three wave points at the same measuring point. The change of the initiating point position in the midfield has little effect on the three-wave point trajectory. The higher the initiating point position in the far field, the faster the three-wave point trajectory increases.

Keywords: three wave points; numerical simulation; equivalent; explosion point location; explosion height.

Classification: DDC Code: 303.4840973 LCC Code: HN57

Language: English

London Journals Press

LJP Copyright ID: 392954
Print ISSN: 2631-8474
Online ISSN: 2631-8482

London Journal of Engineering Research

Volume 22 | Issue 4 | Compilation 1.0

Simulation Analysis and Research on the Influence of Three-Wave Point Trajectory in the Explosion Field

Yi-Kang Tang[α] & Chun-Dong Xu[σ]

ABSTRACT

Predicting the location of the three-wave point and the changing law of the three-wave point is of great significance for accurately assessing the power of large-yield explosives or warheads. Based on the AUTODYN finite element analysis software, the three-wave point trajectory in the explosion field is studied by numerical simulation. The preliminary analysis shows that in the blast field, the explosion shock wave always spreads around the explosive center, and the three-wave point height trajectory Both maintain a rising trend. In the midfield (burst distance 4.0~7.0m), regardless of changing the charge equivalent, explosion height, initiation point position, size, material and reflection interface, the three-wave point height increase rate is relatively slow, while in the far field (burst center distance >7.0m) The growth rate is relatively fast. When the explosive height of the explosive does not change, change the explosive equivalent. The smaller the equivalent, the higher the three wave points at the same measuring point. When the explosive equivalent is unchanged, change the explosion height, the smaller the explosion height, the higher the three wave points at the same measuring point. The change of the initiating point position in the midfield has little effect on the three-wave point trajectory. The higher the initiating point position in the far field, the faster the three-wave point trajectory increases.

Keywords: three wave points; numerical simulation; equivalent; explosion point location; explosion height.

Author α σ: School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing City, Jiangsu Province, China, 210094.

I. INTRODUCTION

When the ammunition in the air explodes, the nearby medium will be squeezed by the huge energy of the ammunition, which causes the energy in the air to increase sharply, thus forming an explosive shock wave [1]. In order to accurately assess the power of large explosives or warheads, it is necessary to measure the shock wave pressure of the ammunition. The shock wave pressure is divided into free field pressure and ground reflected pressure. The measured ground launch pressure is greatly affected by the surface environment so that the measured The value does not meet the requirements, so in order to better evaluate the power of the explosive, it is obviously more appropriate to choose the free field pressure of the ammunition. Only a reasonable choice of the location of the free field pressure sensor can measure the free field of the ammunition more accurately. Therefore, studying the changes of the three-wave point trajectory has guiding significance for the layout of the free-field pressure sensor.

Scholars at home and abroad have carried out many related studies on the three wave points of the explosion field. Guo Wei [2] used the method of adjusting the height of the PCB137 free-field pressure sensor at the same measuring point, and obtained the changing law of the three-point trajectory of the explosion shock wave through multiple experiments. Qiao Dengjiang [3] extensively analyzed the results of free-field explosion tests, and finally summed up the empirical formula for the height of the three wave points of the explosion shock wave of TNT explosives. Du Hongmian [4] studied the propagation law of shock waves by comparing the results of explosive explosion experiments with theoretical values. Duan Xiaoyu and others

London Journal of Engineering Research

studied the numerical simulation of the three-wave point height of RDX-based aluminum-containing explosives, and obtained the three-wave point characteristics of three different explosives in the air [5]. Qu Yandong et al. concluded that the shape of the explosive has a greater influence on the height of the three wave points [6]. Wang Feng [7] used LS-DYNA numerical simulation to study the formation process and trajectory of the three wave points of the penetration bomb explosion field. Zhang Xuelun [8] used AUTODYN explicit finite element program to simulate the explosion field, and compared the simulation results with the experimental data. At present, there are relatively few problems in studying the influence of a single variable of explosives on the trajectory of the three-point trajectory of the explosion shock wave.

II. THE GENERATION OF THREE WAVES

Based on the basic theory of explosive shock wave, the AUTODYN explicit finite element program is used to numerically simulate the process of explosive air explosion, forming a three-wave point trajectory on the reflective interface, and explore the influence of a single variable of the explosive on the three-wave point trajectory.

The actual ammunition charge is mostly cylindrical, and its explosive products will diffuse to the surrounding at a very fast speed to form a spherical shock wave. As the shock wave propagates outwards, the rigid surface is squeezed by the shock wave and there is a reflection phenomenon, which is the reflected wave. The reflections generated on rigid surfaces can be divided into two types: normal incidence and oblique incidence, When the angle between the normal of the wavefront of the incident wave and the normal of the reflecting surface (called the "incident angle"), When it is zero, the reflection process of the shock wave on the rigid surface at this time is called regular reflection; When it is not zero, it is called oblique incidence. At this time, there are two situations. When the incident angle exceeds a certain limit angle, the incident wave and the reflected wave form a new shock wave on the reflecting surface, which is Mach wave[9], This kind of reflection is called Mach reflection or irregular reflection. When the incident angle is less than a certain limit angle, the oblique reflection is called normal reflection.

The intersection of the incident wave, the reflected wave and the Mach wave is the three wave point. When the time and the burst center distance change, the position of the three wave point will also change. Figure 1 is a schematic diagram of the air pressure field distribution when the charge explodes near the ground. It can be seen from Figure 1 that the trajectory of the three wave points is a concave upward curve.

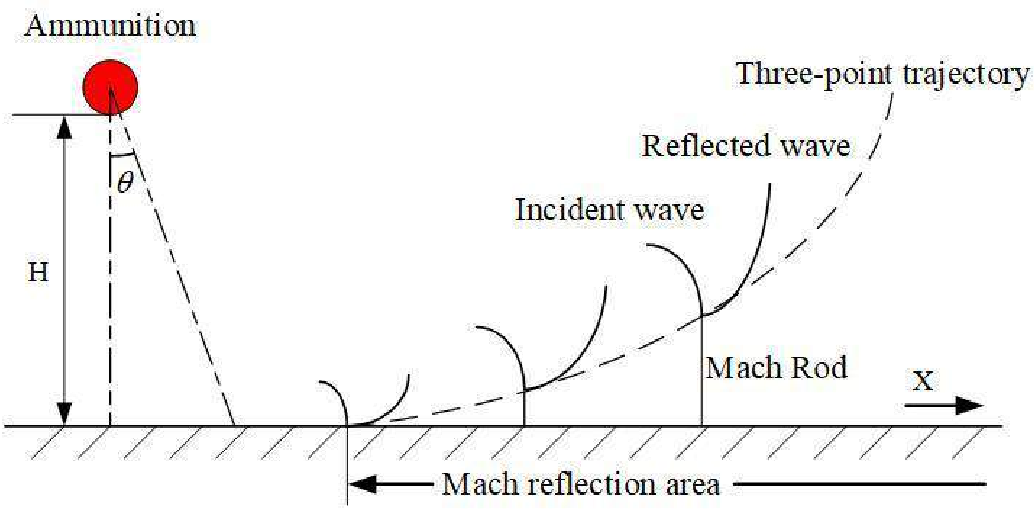
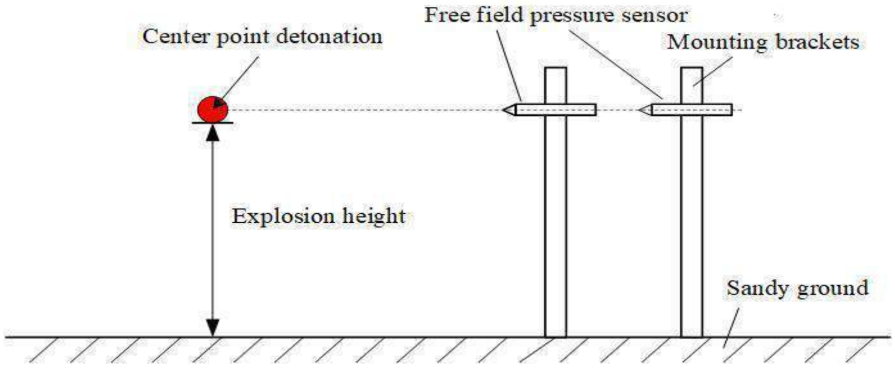


Figure 1: Schematic diagram of near-ground explosion field

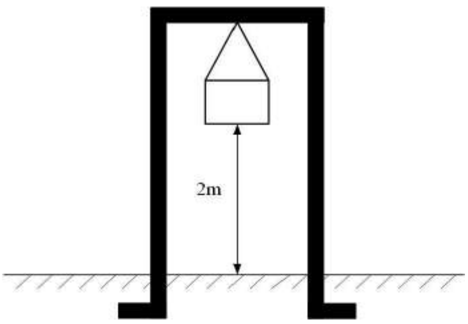
III. Numerical Simulation

3.1 Establishment of finite element model

The finite element model in the simulation test needs to be established according to the physical model in the test, so as to provide a reference for the research of the test method and the layout of the measuring points. The physical model in the test is shown in Figure 2 below:



(a) The overall picture of the test physical model



(b) Physical model of grain suspension

Figure 2: Test physical model

The explosion of TNT cylindrical explosive in free field is selected as the calculation model for numerical simulation. The model is divided into three parts: air domain, ground and TNT grains.The size of the air domain is 6000mm×30000mm, the grid of the air domain is 400×1100, the size of the ground is 200mm×30000mm, and the grid of the ground is 20 ×1100, the overall size of the model is 6200mm×30000mm, and the overall grid is divided into 420×1100, all using BOX structure. The calculation model is shown in Figure 3. The TNT grain is placed in the air domain in a filled form. The upper surface and the front surface of the model are set as the outflow boundary to allow the air medium to flow out. The ground material is sand, and the numerical simulation adopts the mm-mg-ms unit system.

When the shock wave pressure is actually measured, the pressure sensor is placed at different heights and burst center distances to obtain different pressure time history curves, so as to better study the free field shock wave pressure. Modeling can achieve the same purpose as the free field pressure sensor in the actual measurement by setting the Gauss point. A total of 15 Gauss points are set in the model, among which the burst center distances of Gauss points 1, 2, and 3 are 5m, and the heights are 1m, 2m, and 3m respectively; the burst center distances of Gauss points 4, 5, and 6 are 7m, and the heights are respectively 1m, 2m, 3m; the burst center distance of Gauss points 7, 8, and 9 are 9m, and the heights are 2m, 3m, 4m respectively; the burst center distance of Gauss points 10, 11, and 12 are 11m, and the heights are 2m, 3m, 4m, respectively; The burst distances of Gauss points 13, 14, and 15 are 11m, and the heights are 3m, 4m, and 5m respectively.

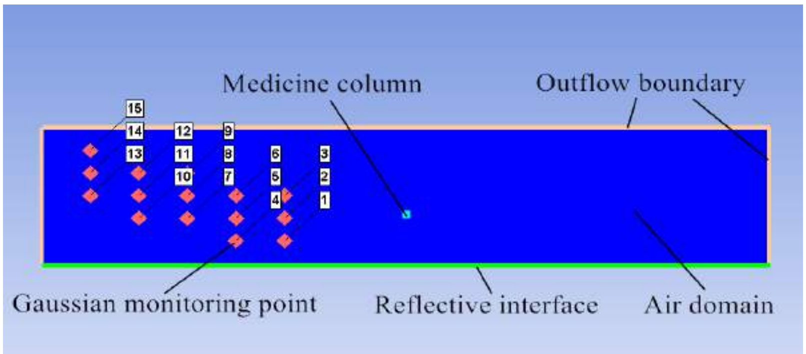


Figure 3: Finite element model

In order to study the influence of the three-wave point trajectory on the charge equivalent, the TNT grain equivalent is 8kg, 20kg, and 50kg respectively through the controlled variable method, the length-to-diameter ratio of the grain is 1:1, the explosion height is 2m, and the initiation point is the charge. The center point of the column detonated.

In order to study the influence of the three-wave point trajectory by the size of the charge, the charge size is 2:1, 1:1, 1:2 by the control variable method, and the TNT charge equivalent is 50kg, the explosion height is 2m, and the detonation The point position is the detonation at the center of the grain.

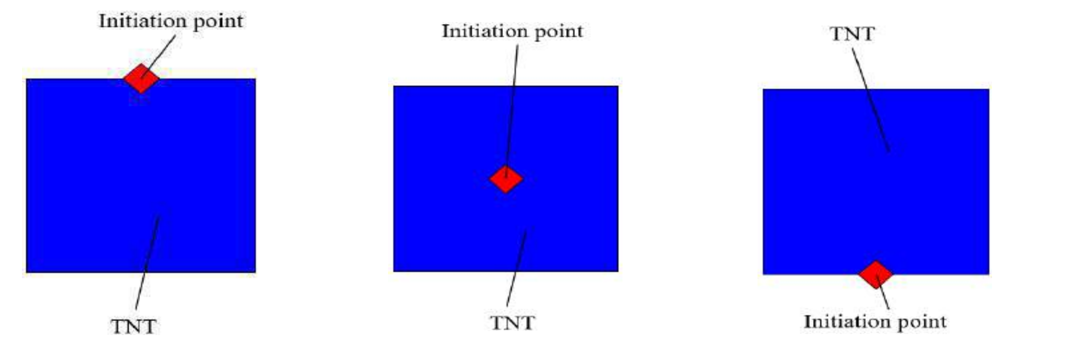
In order to study the influence of the trajectory of the three wave points on the explosion height, the explosion height is 1m, 2m, 3m respectively through the control variable method, the TNT equivalent is 50kg, the TNT length-to-diameter ratio is 1:1, and the detonation point is the center point of the charge.

In order to study the influence of the three-wave point trajectory on the position of the initiation point of the grain, the initiation point was detonated at the center of the top of the grain, the center of the grain, and the center of the bottom of the grain by the control variable method. The TNT equivalent was selected as 50kg. The length to diameter ratio is 1:1, and the explosion height is 2m.

In order to study the influence of the three-wave point trajectory on the reflective interface material, the reflective interface material was set to sand, steel, and concrete by the control variable method, and the TNT equivalent was 50kg, the TNT aspect ratio was 1:1, and the explosion height was 2m.

In order to study the influence of the three-wave point trajectory on the explosive material, the explosive material was set to TNT and HMX by the control variable method, and the TNT equivalent was 50kg, the aspect ratio was 1:1, and the explosion height was 2m.

As shown in Figure 4, the initiation points of the grains are set at different positions.



(a) Top center point (b) Center point of grain (c) Bottom center point

Figure 4: Schematic diagram of different positions of the initiation point of the grain

3.2 Material model and equation of state

The explosion process of TNT grains is simulated and analyzed by the JWL equation of state. The expression of the JWL equation of state is:

$$p = A\left(1 - \frac{\omega}{R_1 V}\right)e^{-R_1 V} + B\left(1 - \frac{\omega}{R_2 V}\right)e^{-R_2 V} + \omega \rho e \quad (1)$$

It can be seen that the formula is composed of 3 parts. The first term affects the high-pressure part, the second term affects the medium-voltage part, and the third term affects the low-pressure part. Where $\boldsymbol{P}$ is the gas pressure of the detonation product, $\boldsymbol{A}$、$\boldsymbol{B}$、$\boldsymbol{R_1}$、$\boldsymbol{R_2}$、$\boldsymbol{\omega}$ are material constants, Get through test fitting, $\boldsymbol{\rho}$ is the density, $\boldsymbol{e}$ is internal energy, and $\boldsymbol{\eta}$ is efficiency。

The material parameters of TNT are listed in Table 1, where the explosive density is the explosive density, and $\boldsymbol{D}$ is the explosive detonation velocity. The input parameters of TNT materials [10] are shown in Table 1, where $\boldsymbol{V_0}$ is the initial relative volume, $\boldsymbol{D}$ is the explosion velocity, $\boldsymbol{P_{cj}}$ is the explosion pressure, and $\boldsymbol{\rho}$ is the density.

Table 1: Material parameters of TNT explosives

ρ/ (g·cm^{-3})	A/ GPa	B/ GPa	R_1	R_2	ω	E_0/ (MJ·m^{-3})	V_0	D/ (m·s^{-1})	P_{CJ}/ GPa
1.58	373.7	3.74	4.15	0.9	0.35	6000	1.00	6930	21

The constitutive relationship of air materials is described by the Ideal Gas equation of state, which is expressed as follows:

$$p = (\gamma - 1)\rho e + \quad (2)$$

Among them: $\boldsymbol{P_{shift}}$ is the initial pressure, taken as 100kPa; $\boldsymbol{e}$ is the internal energy; $\boldsymbol{\gamma}$ is the ideal gas constant, taken as 1.4; $\boldsymbol{\rho}$ is the density, taken as 0.001293g/cm3.

The material of the ground model is SAND, and its material parameters are shown in Table 2.

Table 2: Sand and soil material parameters

ρ/ (kg/m^3)	A	N	Q_0	B_Q	f_c/ GPa	f_t / f_c	f_s / f_c
2284	1.62	0.71	0.6645	0.0102	37	0.12	0.19

3.3 Calculation results

The model established by the operation of AUTODYN finite element software can observe the pressure cloud diagram of TNT explosion at different times. Figure 5 shows the pressure cloud diagram when the TNT equivalent is 50kg and the charge clearance is 2m.

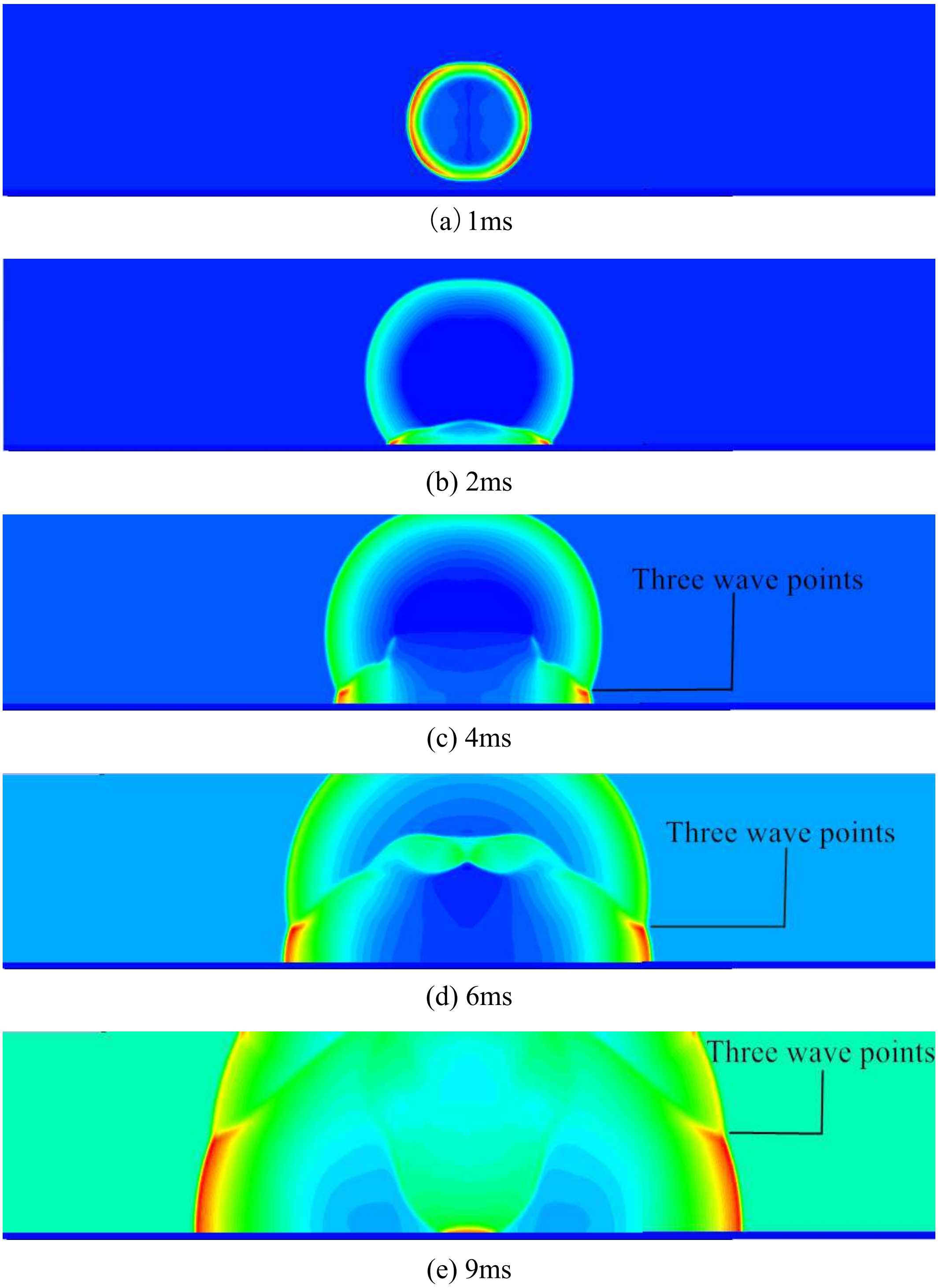


Figure 5: Shock wave pressure cloud diagram at different times

It can be clearly seen from the cloud chart that the three-wave point changes. The three-wave point trajectory presents a concave upward trend, and as time becomes longer, the height of the three-wave point becomes higher and higher.

In order to verify the rationality of the finite element model in Section 3.1, the explosion height of the TNT grain is 2m, the equivalent size is 2kg, the detonation point is the center point of the grain, and the overall size (length-to-diameter ratio) is 1:2. Model and simulate, and then compare the measured results [11] with the simulation results to prove whether the model in Section 3.1 is reliable. As listed in Table 3.

Table 3: Comparison of measured results and simulation results

Horizontal distance /m	4	5	6	7	8	9
Measured value /m	0.31	0.42	0.76	1.01	1.44	1.72
Simulation value /m	0.29	0.45	0.73	1.07	1.46	1.77
error	6.4%	6.7%	3.9%	5.6%	1.3%	2.8%

It can be seen from Table 3 that whether the three wave points are in the midfield (horizontal distance is 4.0~7.0 m) or in the far field (horizontal distance is greater than 7.0 m), the error between the measured results and the simulation results is very small, not more than 10%. The error between the simulation results and the test results is within the allowable range, so the use of AUTODYN software to establish a simulation model can get results consistent with the test results.

IV. SIMULATION RESULT ANALYSIS

4.1 The three-wave point trajectory is affected by the charge equivalent

The equivalent of TNT grain is 8kg, 20kg, 50kg, the length-diameter ratio of the irrelevant variable grain is 1:1, the explosion height is 2m, and the detonation point is the center point of the grain for simulation calculation. Different burst centers can be obtained from the pressure cloud chart. The height of the three wave points at the distance, as shown in Table 4, is the simulation calculation result.

Table 4: The height of the three wave points of different charge equivalents at each burst distance

8kg		20kg		50kg	
High/m	Horizontal distance/m	High /m	Horizontal distance/m	High /m	Horizontal distance/m
0.351	3.12	0.342	3.21	0.323	3.15
0.363	3.25	0.591	4.24	0.486	3.83
0.656	4.34	0.876	5.05	0.591	4.35
0.932	4.95	1.251	6.06	1.043	5.95
1.235	5.65	1.312	6.45	1.356	6.65
1.656	6.85	1.921	7.95	1.851	7.97
1.954	7.55	2.157	8.45	2.036	8.65
2.352	8.48	2.431	9.17	2.286	9.05
2.655	9.26	2.643	9.63	2.475	9.65
3.151	10.05	2.866	10.38	2.634	10.25

By fitting the curve, we can more intuitively understand the change law of the burst center distance and the height of the three wave points, as shown in Figure 6 below.

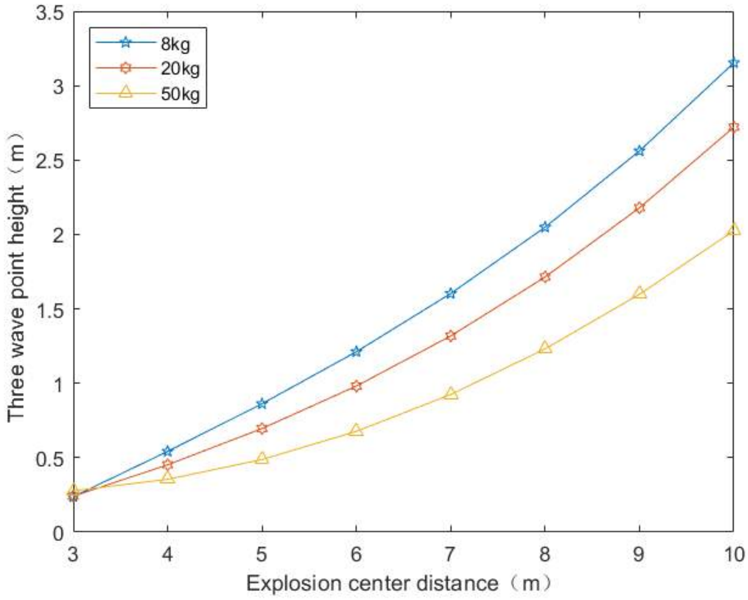


Fig. 6: The height of the three wave points varies with the burst center distance at different equivalents

It can be concluded from Figure 6 that the trajectory of the three-wave point shows an upward trend with the increase of the burst center distance. The height of the three-wave point has been increasing, and it roughly conforms to the law that the larger the equivalent is, the faster the height of the three-wave point increases. The greater the charge equivalent at the measuring point, the higher the height of the three wave points.

4.2 The three-wave point trajectory is affected by the explosive height of the grain

In order to study the influence of the three-wave point trajectory on the explosive height of the grain, the explosion height is respectively 1m, 2m, 3m, the TNT equivalent is 50kg, the length- to-diameter ratio is 1:1, and the detonation point is the central point of the grain. The three wave point heights at different burst center distances are shown in Table 5 for the simulation results.

Table 5: The height of the three wave points at each explosion center distance at different explosion heights

	Explosion center distance /m	Explosion height /m		
		1	2	3
Three wave point height /m	3	0.215	0.206	0.201
	3.5	0.458	0.354	0.312
	4	0.954	0.557	0.353
	4.5	1.153	0.655	0.425
	5	1.643	0.854	0.543
	5.5	1.957	0.958	0.557
	6	2.358	1.445	0.654
	6.5	2.643	1.623	0.826
	7	2.958	1.885	1.053
	7.5	3.254	2.254	1.254
	8	3.553	2.853	1.358
	8.5	4.056	3.355	1.557
	9	4.783	3.757	1.746
	9.5	5.345	4.343	2.054
	10	6.133	4.856	2.476

According to Table 5, the three-wave point height at each burst center distance at different explosion heights, the least square method is used for data fitting through MATLAB software, and the three-wave point trajectory curve at different explosive heights of charge is obtained. As shown in Figure 7.

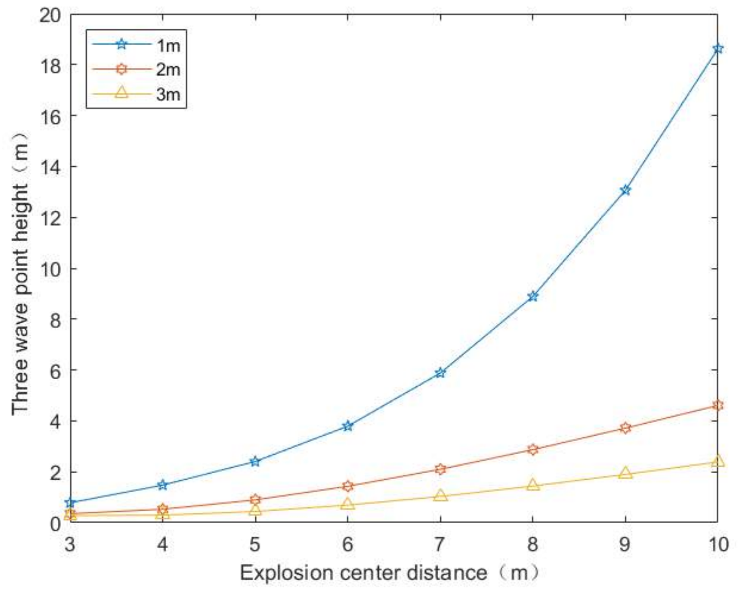


Figure 7: Comparison of three-wave point trajectory curves at different explosion heights

It can be seen from Fig. 7 that in the near field (burst distance <4.0m) the explosion height has no obvious influence on the three-wave point height trajectory, and in the midfield (burst distance 4.0~7.0m) and far field (burst distance> 7.0 m) The height of the three wave points at the same measuring point decreases with the increase of the explosion height. The lower the explosion height, the faster the height trajectory of the three wave points rises.

4.3 The three-wave point trajectory is affected by the position of the explosive point of the grain

The three-wave point trajectory is affected by the position of the detonation point of the grain. The detonation points are detonated at the center of the top of the grain, detonated at the center of the grain, and detonated at the center of the bottom of the grain. The TNT equivalent is 50kg, and the length-to-diameter ratio is 1:1. The explosion height is 2m for simulation analysis, and the three wave point heights at different explosion center distances can be obtained from the pressure cloud chart. Table 6 shows the simulation calculation results.

Table 6: The height of the three wave points of different initiation point positions at each burst center distance

	Explosion center distance/m	Detonation position		
		Top center point	Center point of grain	Bottom center point
	3	0.113	0.109	0.106
	3.5	0.161	0.154	0.134
Three wave point height /m	4	0.228	0.223	0.196
	4.5	0.356	0.307	0.263
	5	0.443	0.355	0.334
	5.5	0.558	0.457	0.427
	6	0.655	0.621	0.605
	6.5	0.836	0.826	0.795
	7	1.054	1.052	1.037
	7.5	1.353	1.352	1.312
	8	1.678	1.552	1.513
	8.5	2.245	1.935	1.835
	9	2.975	2.555	2.245
	9.5	3.453	3.243	3.146
	10	4.426	4.146	4.053

According to the three wave point heights at various burst center distances for different initiation point positions of TNT grains given in Table 6, the data fitting is performed by using the least square method through MATLAB software, and the three wave point trajectories at different initiation point positions of TNT grains are obtained. curve. As shown in Figure 8.

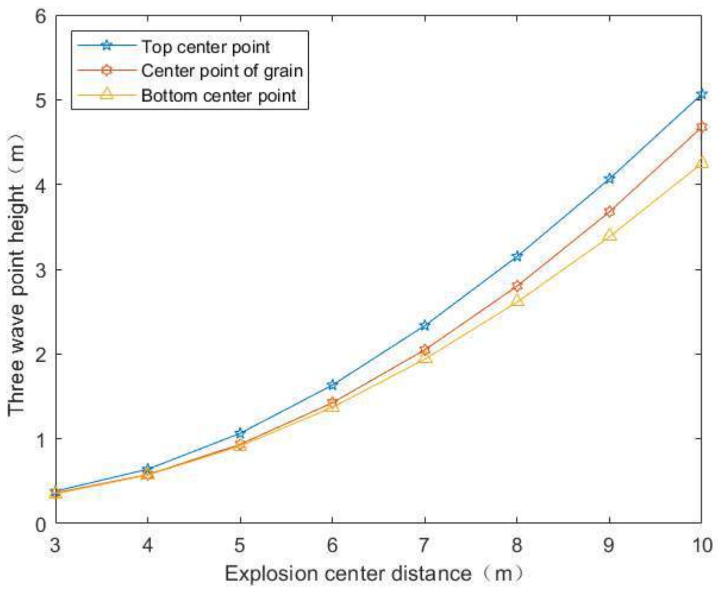


Figure 8: Comparison of three wave point height curves at different initiation points

It can be seen from Figure 8 that there is little difference in the three-wave height trajectories at different initiation point positions in the near field (burst distance <4.0m) and midfield (burst center distance 4.0~7.0m), but in the far field (burst center distance> 7.0m) The influence of different initiating point positions on the height trajectory of the three wave points begins to appear. At this time, the order of the height of the three wave points at the same measuring point is: the top center point, the grain center point, and the bottom center point. It shows that the higher the position of the initiation point, the higher the height of the three wave points at the same measuring point, and the faster the overall three wave point trajectory rises.

4.4 The three-wave point trajectory is affected by the size of the charge

The three-wave point trajectory is affected by the size of the charge. The charge size is 2:1, 1:1, 1:2. The TNT charge equivalent is 50kg, the explosion height is 1.5m, the explosive material is TNT, and the detonation point The position is the top center point for simulation analysis, and the three wave point heights at different burst center distances can be obtained from the pressure cloud chart. Table 7 shows the simulation calculation results.

Table 7: Three wave point heights of different charge sizes at each burst distance

	Explosion center distance /m	Charge size		
		2:1	1:1	1:2
Three wave point height /m	3	0.221	0.312	0.353
	3.5	0.278	0.352	0.454
	4	0.314	0.567	0.767
	4.5	0.346	0.658	1.056
	5	0.436	0.855	1.254
	5.5	0.574	0.954	1.554
	6	0.726	1.478	1.733
	6.5	0.924	1.653	1.925
	7	1.157	1.868	2.052
	7.5	1.446	2.253	2.457
	8	1.832	2.857	3.258
	8.5	2.167	3.352	4.242
	9	2.352	3.756	4.955
	9.5	3.033	4.357	5.752
	10	3.535	4.853	5.855

According to the three-wave point heights at each burst point for different TNT charge sizes given in Table 7, the least squares method is used to fit the data through MATLAB software, and the three-wave point trajectory curves for different TNT charge sizes are obtained. As shown in Figure 9:

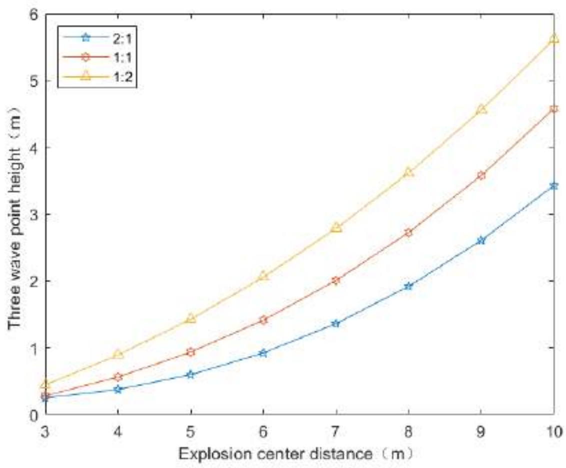


Figure 9: Comparison of three-wave point trajectory curves of different charge sizes

It can be seen from Figure 9 that, according to the size of the charge, the change of the three-wave point trajectory is also different. In the near field (burst distance <4.0m), the heights of the three-wave points with an aspect ratio of 1:1 and 2:1 are lower than the height trajectories of the three-wave points with an aspect ratio of 1:2. At the same measuring point in the midfield (burst distance 4.0~7.0m), the order of the height of the three wave points is length-diameter ratio 1:2>

length-diameter ratio 1:1> length-diameter ratio 2:1. In the far field (burst distance>7.0m), the three-wave point height sequence is the same as in the midfield, but the difference is more obvious. Overall, it shows that at the same measuring point, the larger the length-diameter ratio of the charge, the lower the height of the three wave points, and the more stable the overall trajectory.

4.5 The trajectory of the three-wave point is affected by the explosive material

The three-wave point trajectory is affected by the explosive material. The charge materials are TNT and HMX, the charge equivalent is 50kg, the explosion height is 2m, and the detonation point is the center of the charge for simulation analysis. Different burst centers can be obtained from the pressure cloud chart. The height of the three wave points at the distance, as shown in Table 8 is the simulation calculation result.

Table 8: Three wave point heights of different charge materials at each burst point

	Explosion center distance/m	Charge material	
		TNT	HMX
Three wave point height/m	3	0.221	0.354
	3.5	0.352	0.456
	4	0.524	0.557
	4.5	0.653	0.763
	5	0.852	0.968
	5.5	0.952	1.135
	6	1.495	1.535
	6.5	1.686	1.755
	7	1.742	1.864
	7.5	2.255	2.365
	8	2.454	2.653
	8.5	3.351	3.631
	9	3.753	3.842
	9.5	4.341	4.421
	10	4.646	4.924

According to the three wave point heights at each burst center distance for different charge materials given in Table 8, the least square method is used to fit the data through MATLAB software, and the three wave point trajectory curves for different charge materials are obtained. As shown in Figure 10.

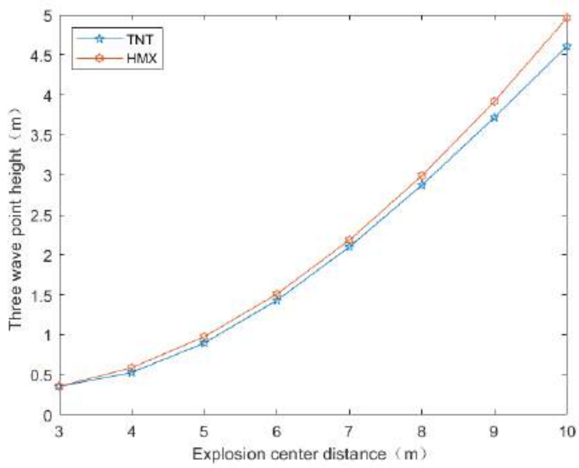


Figure 10: Comparison of three-wave point trajectory curves for different charging materials

It can be seen from Figure 10 that, according to the different charge materials, the changes of the three-wave point trajectory are also different. In the near field (burst distance <4.0m), the three wave point height trajectories of TNT and HMX are not much different. At the same measuring point in the midfield and far field, the order of the height of the three wave points is HMX>TNT, and the gap is more obvious than that in the near field.

4.6 The three-wave point trajectory is affected by the reflective interface

The three-wave point trajectory is affected by the reflection interface, and SAND, STEEL, and CONC-35 MPA are selected as the reflection interface. The TNT charge equivalent is 50kg, the explosion height is 2m, and the detonation point is the center point of the grain for simulation analysis. The pressure cloud chart can get the height of the three wave points at different burst center distances, as shown in Table 9 for the simulation calculation results.

Table 9: The height of the three wave points at each burst point at different reflection interfaces

	Explosion center distance/m	SAND	CONC-35MPA	STEEL
Three wave point height/m	3	0.221	0.214	0.203
	3.5	0.351	0.341	0.326
	4	0.555	0.513	0.485
	4.5	0.658	0.612	0.602

According to the three wave point heights at each burst center distance at different reflection interfaces given in Table 9, the data fitting is performed by using the least square method through MATLAB software, and the three wave point trajectory curves at different reflection interfaces are obtained. As shown in Figure 11.

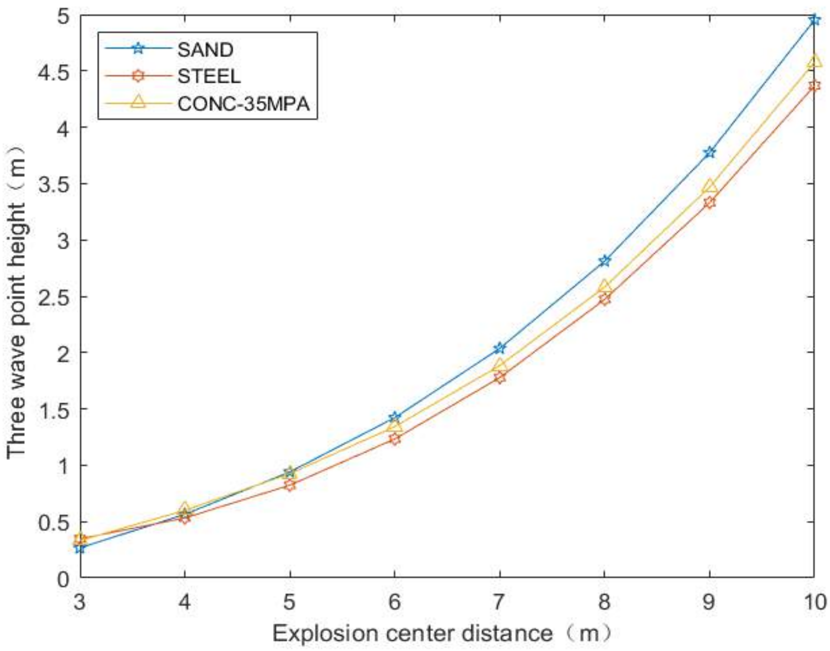
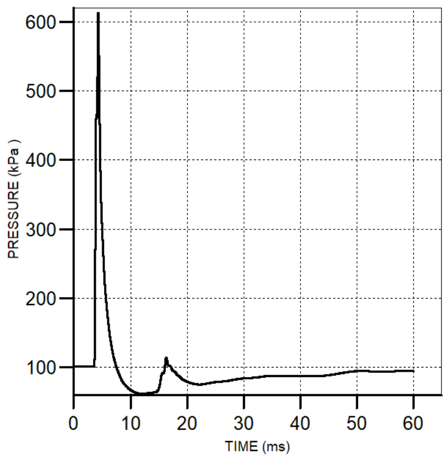


Figure 11: Comparison of three-wave point trajectory curves at different reflective interfaces

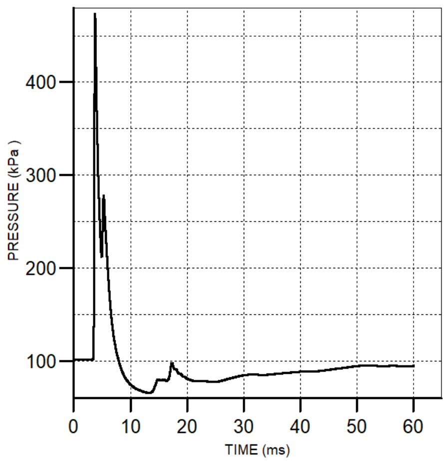
It can be seen from Figure 11 that the height of the three wave points at the same measuring point of the reflection interface of the sand material is the highest. The second is the concrete reflective interface, and the three-wave point trajectory is the lowest at the rigid interface. Because of the difference of the reflective interface, the ability to absorb the shock wave of the explosion is also different. Therefore, the different reflective interface has a great influence on the trajectory of the three wave points.

4.7 The influence of sensor measuring point position on shock wave pressure test

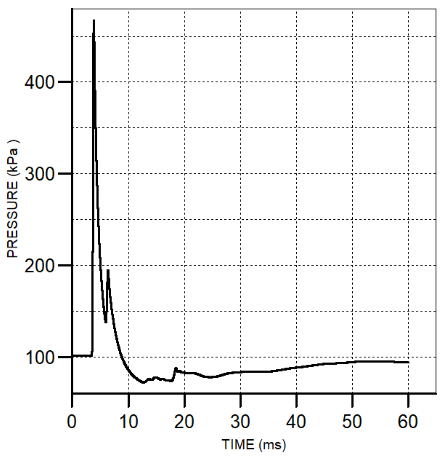
When the finite element model was established, 15 Gaussian monitoring points were set up at different heights and different burst center distances in order to study the change law of free field pressure at different positions with time. Figure 12 shows the pressure time history curve at each Gauss point when the TNT grain equivalent is 50kg, the length-to-diameter ratio of the grain is 1:1, the explosion height is 2m, and the detonation point is the center point of the grain.



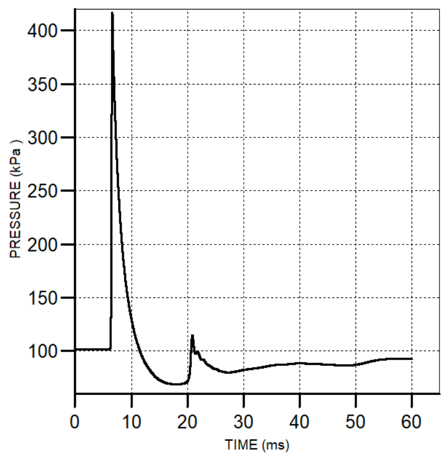
(a) 1m from the ground at 5m



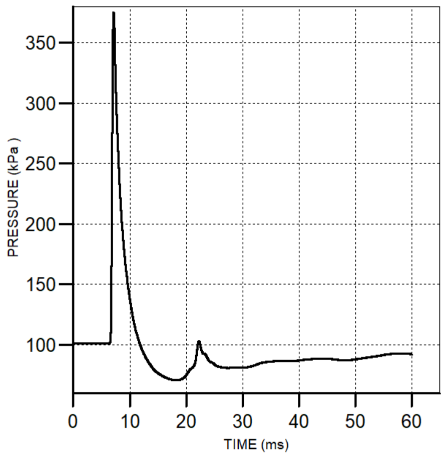
(b) 2m from the ground at 5m



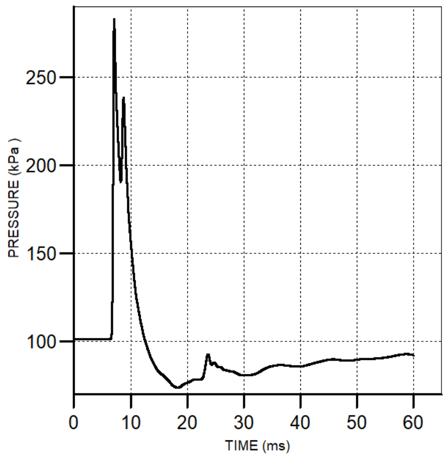
(c) 3m from the ground at 5m



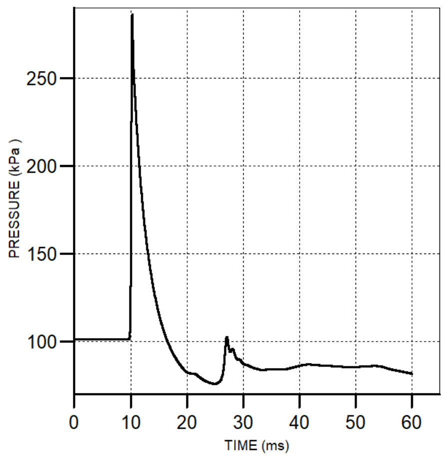
(d) 1m from the ground at 7m



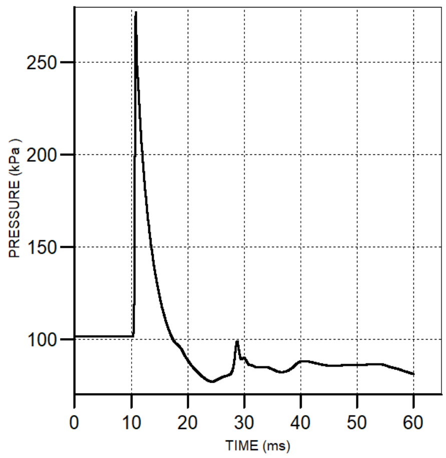
(e) 2m from the ground at 7m



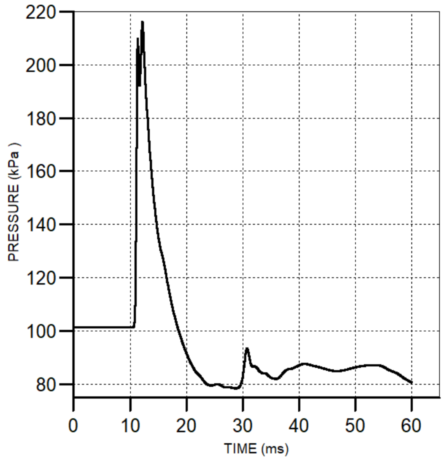
(f) 3m from the ground at 7m



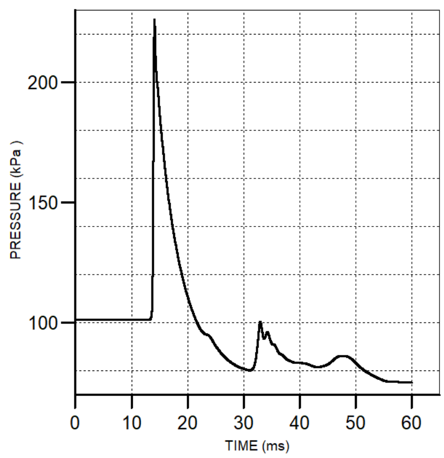
(g) 2m from the ground at 9m



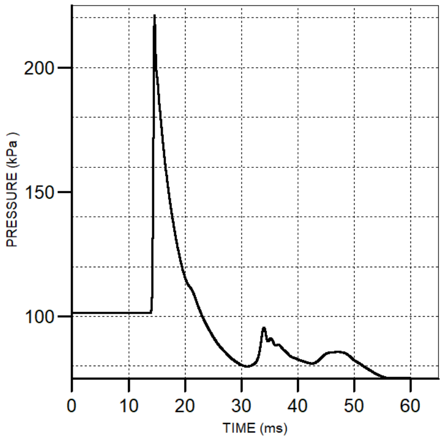
(h) 3m from the ground at 9m



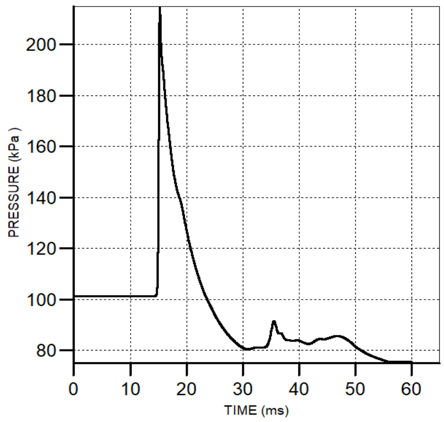
(i) 4m from the ground at 9m



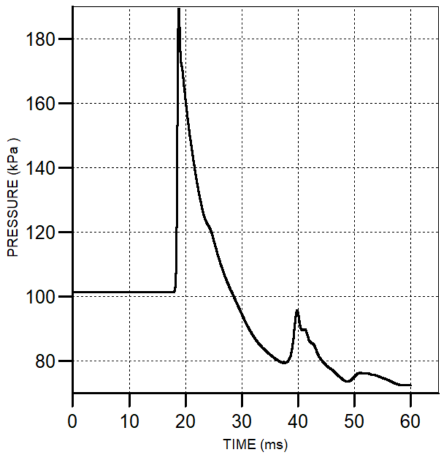
(j) 2m from the ground at 11m



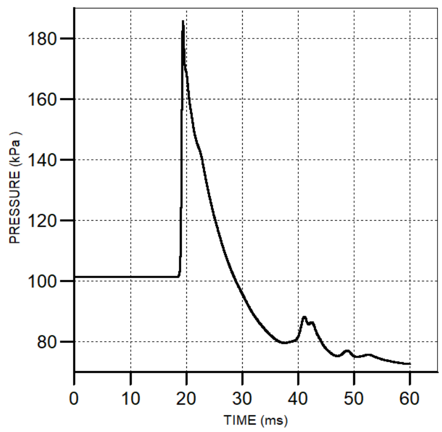
(k) 3m from the ground at 11m



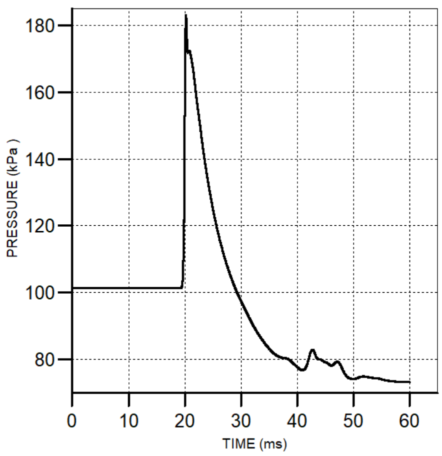
(l) 4m from the ground at 11m



(m) 3m from the ground at 13m



(n) 4m from the ground at 13m



(o) 5m from the ground at 13m

Figure 12: Time history curve of free field pressure at different burst center distances

According to the free field pressure time history curve at different burst center distances in Fig. 12, Gauss points 1, 4, 5, 7, 8, 10, 11, 12, 13, 14, and 15 are below the three-wave point trajectory. At this time, the measured The Mach wave is a shock wave synthesized by the incident wave and the reflected wave when the incident angle exceeds a certain limit angle, so at this time there is only one wave crest in the pressure-time history curve; Gauss points 2, 3, 6, 9 are at Above the three-wave point trajectory, the incident wave is measured first, and then the ground reflection wave is measured. Therefore, there are two wave crests on the pressure time history curve. The first wave crest is the overpressure of the incident wave, and the latter is the overpressure of the reflected wave. According to the pressure time history curve measured at Gauss point 2 at a distance of 5m from the center of the explosion and a distance of 2m from the ground, it can be seen that the overpressure of the incident wave here is greater than the overpressure of the reflected wave. According to the pressure time history curve measured at Gauss point 9 at a distance of 9m from the center of the explosion and 4m from the ground, it can be seen that the overpressure of the incident wave here is smaller than the overpressure of the reflected wave. The reason for the two different situations is that the Gaussian point 2 is far away from the three-wave point trajectory. At this time, the wave front continues to spread and the reflected shock wave energy attenuates. At this time, the incident wave overpressure exceeds the reflected wave overpressure. The Gaussian point 9 is close to the three-wave point trajectory. At this time, the incident wave touches the ground to produce a complex reflected wave, and the reflected wave overpressure exceeds the incident wave overpressure.

In the experiment, if you want to measure the parameters of the incident wave more accurately, you need to set the sensor above the three-wave point.

V. CONCLUSION

This paper uses AUTODYN finite element software to carry out numerical simulation, and calculates the influence of different factors on the three-wave point trajectory, which has guiding significance for the accurate measurement of various parameters in the explosion field in practice.

1. The height of the three-point trajectory of the shock wave formed by the explosion of the ammunition always increases with the increase of the distance between the center of the explosion.
2. The explosion height of the grain has a negative correlation with the height of the three-wave point. When the charge equivalent is the same, the explosive height of the charge is changed. The higher the explosion height of the grain, the lower the height of the three-wave point and the slower the growth rate. The trajectory is smoother.
3. The change of the initiating point position in the midfield has little effect on the three-wave point trajectory. The higher the initiating point position in the far field, the faster the three-wave point trajectory increases.
4. The influence of the reflective interface on the height of the three-wave point is more complicated, and further research is needed.
5. Numerical simulation calculation has certain guiding significance for the layout of sensors.

REFERENCES

1. Luo Xingbai, Zhang Yukui, A Course in Explosive Mechanics Theory[M]. Beijing: National Defense Industry Press, 2016:259-262. (in chinese).
2. Guo Wei, Yu Tongchang, Jin Penggang, Three -wave point measurement and experimental technology research [J]. Journal of Prope-llants, 2007(4):55-57+61. (in chinese).
3. Qiao Dengjiang, Air Blast Shock Wave (I) Basic Theory [J]. Explosion and Shock, 1985 (4):78-85. (in chinese).
4. Du Hongmian, Cao Xueyou, et al. Analysis and verification of air and ground shock wave characteristics of near-ground explosion [J]. Journal of Projectiles, Rockets and Guidance, 2014.34(4):65-68. (in chinese).
5. Duan Xiaoyu, Guo Xueshui, Nie Jianxin, et al. Numerical simulation of three wave point heights of RDX-based aluminum-containing explosives[J]. Chinese Journal of High Pressure Physics,2018(3):75-82. (in chinese).
6. Qu Yandong, Yang Shang, Li Siyu, et al. Numerical simulation of three wave points in the explosion field of TNT explosives[J]. Engineering Blasting,2019(1);1-6. (in chinese).
7. Wang Feng, Wang Bao, Dong Jing, et al. Study on the height of three wave points in the explosive field of penetration bomb[J]. Chinese Journal of Ordnance Equipment Engineering, 2018, 39(5):31-34. (in chinese)

8. Zhang Xuelun, Zhang Tuan, Wang Zhaoming. .Numerical simulation based on the three-wave point of AUTODYN explosion field[J]. Chinese Journal of Ordnance Equipment Engineering,2015,36(3):17-19. (in chinese).
9. Zhang Ting, Explosive shock wave measurement technology (electrical measurement method) [M]. Beijing: National Defense Industry Press, 1984:7-15. (in chinese).
10. Song Pu, Yang Kai, Liang Anding, et al. The JWL equation of state of TNT explosives at home and abroad and the analysis of the difference in energy release[J].Journal of Explosives, 2013, 36(2):42-45. (in chinese).
11. ZHANG X F, QIAO L. Detonation wave propagation in double-layer cylindrical high explosive charges[J]. Propellants Explosives Pyrotechnics, 2011, 36(3):210-218.