The effect on the shock wave resulting from the rocket explosion on launch pad

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Abstract. Once an explosion occurs, it would threaten the safety of personnel and facilities around the launch site. In order to study the propagation law of shock wave near-ground and the multiplicative effect on peak overpressure of the ground, the finite model of near-surface explosion has been established based on explicit nonlinear dynamic ANSYS/LS-DYNA program. Results show that the existence of the ground will change the propagation law and conform to the reflection law of the shock wave. For gauges at different heights, ground may have different effects on the peak overpressure. When $x$ is not greater than 20m, the peak overpressures of $h$ greater than 2m are the same, but less than the peak overpressures of $h$ equal to 2m. When $x$ is greater than 20m, the peak overpressure decreases with the increase of $h$, and eventually the peak overpressure of different $h$ gradually tends to be the same.

1. Introduction

As is known to all, the launch vehicle is a complex and large-scale technology-intensive system and it plays an important role in the deep space exploration mission. Once an explosion occurs, it would threaten the safety of personnel and facilities around the launch site[1]. Study of rocket shock environment is an ongoing effort to characterize the environment resulting from catastrophic rocket explosion. The purpose is to develop the data and information required to allow launch vehicle designers to develop safer launch systems.

Explosion hazard modeling is a challenging problem since it involves several physical, often complex, interacting aspects. The problem becomes even more complex when the subsequent shock wave propagation is assumed to interact with the ground, which has a more destructive effect on the personnel and facilities at the launch site [2].

When explosives exploded near the ground, because of the limitation of the ground reflection will happen after the air shock wave in the ground, at the same time it also can pass in underground. The propagation rules of its propagation law different from free atmosphere, to launch site personnel and equipment to produce more damage, so the explosion shock wave propagation law above the ground is of great significance. It is Difficult to derive for the explosion shock wave parameters in theory, so now most of the research is based on a lot of testing on the basis of empirical formula to estimate the shock wave. But due to the limitation of experimental conditions, different empirical formula to calculate the results often differ greatly, so the empirical formula method sometimes cause greater error. With the development of computer technology, finite element method is more and more used in numerical simulation of complex calculation, and more and more reasonable results can be obtained.
At present, the empirical or semi-empirical methods used in engineering to calculate the explosive overpressure load are generally based on the test or assumption of the open field, which is greatly different from the actual explosion load in the complex environment of the launching site. It will bring hidden dangers to the anti-explosion safety of the building [3]. However, the explosion test in the launch site will have a great safety risk, and this is also unrealistic. Therefore, many scholars have studied the propagation law of blast wave in complex environment. Explosion test has the characteristics of short duration, poor repeatability and high cost, so it is not easy to carry out.

The shock wave generated by the explosion is affected by the reflection of the ground. The amount of superimposed energy depends on the rigid conditions of the ground. Because the impact of explosives on the ground into a pit, shock wave downward infiltration will affect the superimposed shock wave energy. For rigid ground explosion, only half of the air in air explosion is involved in shockwave forming, which is equivalent to 2 times the charge, and 1.8 times the charge for ordinary soil surface.

At present, many scholars have studied the near-field overpressure, propagation law and empirical formula of TNT charge detonation shock wave, but there is no systematic study on the far-field overpressure law of TNT charge detonation far field, especially considering the ground factors[4-12].

In this paper, in order to simulate the propagation of near-ground shock wave and quantify the multiplicative effect on peak overpressure, explicit nonlinear dynamic ANSYS/LS-DYNA program is employed to setup near-ground explosion models. The multiplication effect on peak overpressures of the ground is carried out, which will provide a reliable reference for design and safety evaluation of launch site.

2. Finite element model

In order to investigate the impact of ground on the shock wave propagation law when the rocket exploded on the launch pad, the whole rocket is selected to carry out numerical simulation. Numerical model is the TNT that explodes above the rigid ground. In the model, air domain is a Φ258m×40m cylinder and the ground is rigid constraint. After considering the symmetry of the simulation model, a 1/4 symmetrical geometrical model is adopted. In order to reduce the calculation amount, the air domain is divided into three parts according to the horizontal distance, which are 0~30m, 30~70m, 70~129m. The mesh size of the air domain is 0.58m, 1.16m and 2.32m, respectively. The TNT is divided into mesh sizes of 0.20m. The height of the detonation center to the ground surface is 30.668m.

Finite element model and gauges distribution are shown in Figure 1.

![Figure 1. Finite element model of near-ground explosion](image)

As are shown in Figure 2, gauges in the model are set at five different heights, which are from 2m to 10m with an interval of 2m. Twelve gauges are set at each height, whose x is from 0 to 110m, with an interval of 10m.
3. Verification of blast model

Figure 3 shows the empirical data and numerical data about the peak overpressure along the distances $x$ at the height of 2m. As can be seen, the prediction values of each empirical formula in the near-field of explosion are quite different, which is mainly because the detonation products in the near-field are quite different from the test values. In the far-field of explosion, the influence of detonation products decreases and the predicted values of each empirical formula tend to be consistent. The simulation results show a large deviation from the fitting formula in the near-field, and a large consistency in the far-field. Therefore the deviation of simulation results decreases with the increase of proportional distance [13-15].

By comparison, there is a certain deviation between the simulation value and the average value of the empirical formula, mainly because the empirical formula is obtained by fitting the experimental results, while the simulation model is relatively ideal by solving the aerodynamic equation. There are some differences between the simulation results and the test conditions, but the simulation results are still within the allowable range of the project.

4. Results and analysis

4.1. Propagation law of the shock wave

In order to show the impact of shock wave propagation on the ground, figure 4 shows the pressure distribution of explosive shock wave after encountering rigid ground. Different cloud images represent the typical moment of shock wave propagation, and different pressure values are represented by different colors. After explosive explosion, the explosive products of high temperature and high pressure were expanded and diffused rapidly in all directions, and the shock wave propagated outward in the form of spherical wave. As shown in figure 4-(a), when the air shock wave encounters the rigid...
ground, \(x=0\). As the incident Angle of the shock wave is close to zero, positive reflection will occur. This is because the velocity of airflow particles at the front of the shock wave is reduced due to obstruction, which forms superposition with the subsequent shock wave and forms an enhanced shock wave at the ground. As shown in Fig. 4 - (b), the shock wave emits superposition near the ground, forming a high-pressure zone. This is due to regular reflection when the incident angle of the shock wave is less than 40 degrees of the limit incident angle at the range of 0 to 44.116m. As shown in Fig. 4-(c), the high pressure zone gradually begins to rise off the ground. At this time, Mach reflection occurs when \(x\) is greater than 44.116m because the incident angle of shock wave is greater than the limit incident angle of 40 degrees. As shown in Fig. 4 - (d), the height of Mach rod increases gradually, the shock wave pressure decreases and tends to plane wave. Due to the Mach reflection, the pressure of the shock wave near the ground appeared in a high pressure area. With the passage of time, the height of the Mach bar gradually increased, and the pressure near the ground was higher than that of other areas in the air, indicating that the ground had an enhanced effect on the propagation of the shock wave, and the enhanced area was mainly concentrated near the ground. Data analysis is needed to further study the enhancement effect of shock wave in different properties.

It can be seen from the figure that the development process of the flow field is basically consistent with the actual physical process. The initial shock wave is not a spherical wave, but gradually approaches a spherical wave at a certain distance. At the moment when the air shock wave contacts the ground, the velocity of the airflow particles at the front of the shock wave is slowed down by the obstruction action, and the direction changes to some extent, forming superposition with the subsequent shock wave, and forming an enhanced shock wave inside the body of the arrow.

4.2. The multiplicative effect on peak overpressure of the ground

It can be seen from Figure 5, when \(x\) is not greater than 20m, the peak overpressures of \(h\) greater than 2m are the same, but less than the peak overpressures of \(h\) equal to 2m. When \(x\) is greater than 20m, the peak overpressure decreases with the increase of \(h\), and eventually the peak overpressure of different \(h\) gradually tends to be the same.
5. Conclusion
The finite element model of near-surface explosion is established and verified by comparing with the empirical formula. The propagation law of blast wave near ground and the multiplicative effect on peak overpressure of the ground are obtained by numerical simulation. From analysis and discussion of results, the following main conclusions were drawn:

1) The existence of ground will change the propagation law of shock wave, which conforms to the reflection law of shock wave. Rigid ground does not absorb shock wave energy, and it will reflect all the energy. The concrete floor absorbs some of the energy and reflects some of it. However, the shock wave was intensive by different ground near the ground.

2) For gauges at different heights, different ground may have different effects on the peak overpressure. When \( x \) is not greater than 20m, the peak overpressures of \( h > 2 \)m are the same, but less than the peak overpressures of \( h \) equal to 2m. When \( x \) is greater than 20m, the peak overpressure decreases with the increase of \( h \), and eventually the peak overpressure of different \( h \) gradually tends to be the same.

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