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Author: Chen Jiahui, Xu Chundong
Nanjing University of Science and Technology, China

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STUDY ON QUASI-STATIC PRESSURE OF TNT INTERNAL EXPLOSION IN CONFINED SPACES

Chen Jiahui, Xu Chundong
Nanjing University of Science and Technology
China

ABSTRACT

Afterburning-effect accompanies the explosion of TNT explosion. To accurately analyze and study the quasi-static pressure characteristics of TNT explosion in confined space, using AUTODYN finite element software to numerically simulate the explosion of TNT explosives of different masses in a confined space, and through parameter settings, The afterburning-effect of detonation products produced by TNT explosion is considered. The quasi-static pressure values of TNT explosives with the different masses of TNT in the confined space are obtained. Through dimensional analysis, it is concluded that the ratio of the confined space volume to explosive charge is the main factor affecting quasi-static pressure. And conclude by fitting the numerical simulation results that the functional relationship between quasi-static pressure value and charge volume ratio of confined space Within the scope of 2.79kg / m3 W / V 27.9kg / m3 the maximum relative deviation between the calculated value and the test value is 10.5%, which can be used to predict the quasi-static pressure peak value of TNT explosion in a confined space.

Keywords: TNT, quasi-static pressure, numerical simulation, mass-space volume, dimensional analysis

INSTRUCTION

The explosion energy release of explosives in confined space differs from that in free space. After the explosion of explosives in the confined space, the shock wave pressure is reflected in the confined space due to space restrictions during the propagation process. At this time, the pressure load in the confined space is composed of the initial reflected shock wave and several subsequent reflected and oscillating superimposed shock waves (CAI,2019). After the blast shock wave stage ends, relatively stable, slow change and prolonged quasi-static pressure will be formed inside it, causing more severe damage to the target in the confined space. Quasi-static pressure is an essential characteristic parameter of the total energy of explosives (WANG et al., 2020). The research on quasi-static pressure of explosion in confined space is of great significance for evaluating explosive power and structural protection design.

The source of quasi-static pressure is mainly the detonation products and the expansion of the gas with increased temperature caused by the explosion heat in the confined space, which is constrained by the space (WANG et al.,2012; ZHANG et al.,2018). When TNT explosive explodes in a confined space, the subsequent combustion effect supported by oxygen has an essential influence on the formation of quasi-static pressure and its peak value (LI et al.,2020; JIN et al.,2013). When numerically simulating the explosion in a confined space, to better analyze the explosion shock wave and quasi-static pressure load in the confined space, it is necessary to consider the energy released by the combustion effect (KONG et al.,2019). Domestic and foreign researchers have done much research on quasi-static pressure load. T.P.E. David (David,1996.) and R.J. Lee(LEE et al.,2010)established the evaluation method of explosive internal explosion effect based on quasi- static pressure; Some scholars have studied the quasi-static pressure load characteristics of explosion in confined spaces by conducting explosion tests and numerical simulation methods and obtained that the mass / space volume ratio W /V is the main factor determining the quasi-static pressure, and used relevant test data to fit the quasi-static pressure calculation formula (ZHANG et al.,2019; XU,2019; XU, 2019).

At present, the research on quasi-static pressure mainly focuses on numerical simulation. However, in numerical simulation of explosions in confined spaces, the afterburning effect release energy of explosives is often ignored, which leads to some errors in the results. The calculation formulas of quasi-static pressure obtained are quite different, and the application scope is small. The quasi-static pressure of TNT explosives in a confined space is studied by numerical simulation。

NUMERICAL SIMULATION

Explosion in a confined space is a fluid structure coupling problem. The AUTODYN nonlinear dynamics analysis software’s ALE algorithm is selected to simulate the explosion process of TNT explosion in a closed container. The total dimension of the closed container is 100mm □100mm □ 300mm, the thickness is 10mm, and the volume of the explosion cavity is 80mm □ 80mm □ 280mm. Choose 5g, 10g, 15g, 25g, 35g, and 50g TNT explosives of different masses to explode inside, and set the explosive position as the centre of the closed container. Lagrange models the confined container, Euler models the air and explosives, and the grid elements are hexahedral grids. The grid size is set to 2.5mm to save time and ensure calculation accuracy. All six surfaces of the confined space are set as fixed supports, and the explosive initiation mode is set as centre point initiation. A Gauss measuring point is set at every 50mm interval on the central axis of the inner side and bottom of the confined container. The numerical simulation model is shown in Figure 1.

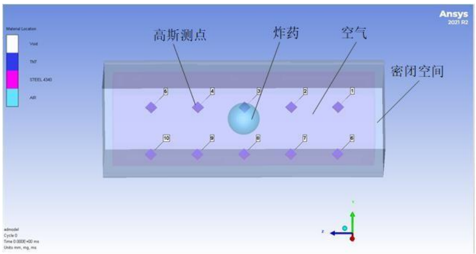

Figure 1 Numerical simulation model

The material of the closed container is steel 4340; its density is 7830 kg/m3, the elastic modulus is 1.59E+5MPa, and the Poisson's ratio is 0.3. Its constitutive model is defined by the Johnson-Cook model, which can simultaneously consider the hardening effect of strain on materials, the strengthening effect of strain rate on materials, and the softening effect of temperature on materials, and has a wide range of applications, failure model of material is Johnson-Cook.

Table 1 steel 4340 Johnson Cook equation of state and main parameters of failure model

A/Pa	B/Pa	n	C	$\dot{\varepsilon}_0 / s^{-1}$	m	D1	D2	D3	D4	D5
5.9E+8	4.51E+8	0.496	0.0061	1.0	1.454	0.16	0	0	0	0

The air material model is simplified as a non-dense ideal gas, and the shock wave expansion is assumed to be an adiabatic process. LINEAR POLYNOMIAL expresses the equation of the state of air material. The specific parameters are set as follows: the initial density is 1.293 g/cm-3, the initial pressure is 1E+5Pa, the initial internal energy is 2.068E+5 mJ/mm3, and the adiabatic index is 1.4.

The JWL equation of state describes TNT; the specific parameters of TNT explosive materials and equation of state are shown in Table

Table 2 State equation parameters of TNT explosive materials

density / （kg/m^{-3}）	C-J pressure / kPa	detonation velocity / （$m•s^{-1}$）	A/ kPa	B/ kPa	ω	R_1	R_2
1630	2.1E7	6930	3.74E8	3.75E6	0.35	4.15	0.9

JWL equation has some limitations in describing TNT, a highly harmful oxygen explosive. The energy released by the afterburning effect of detonation products is not considered in the setting of the above parameters, so it needs to be supplemented and corrected. In AUTODYN analysis software, the afterburning effect shall be considered. It can be realized by adding additional energy based on the JWL equation. Select the Additional Energy item in the Additional Option (Beta) of the material parameter panel of TNT to add extra energy

NUMERICAL SIMULATION RESULTS AND ANALYSIS

Numerical simulation results

Figure 2 shows the pressure curve of a 10gTNT explosive explosion in a confined space. It can be seen from the figure that the pressure load change in the confined space is mainly divided into two stages. The first stage is the high-frequency shock wave pressure. Because the shock wave is constrained by the space structure in the propagation process, multiple reflections and superimposition occur in the confined space, and numerous pressure peaks appear in the shock wave load stage. It can be seen from the partial view in the following figure that at the end of the shock wave pressure loading phase, the pressure peak value has increased, which is caused by the afterburning effect of the TNT explosion. After that, the pressure load in the confined space enters the second stage - the quasi-static pressure load stage. The pressure curve no longer attenuates with the change of time. The pressure peak value tends to be stable and lasts for a long time.

Figure 3 shows the pressure curve of each Gauss measuring point when a 35gTNT explosive explodes in a confined space. It can be seen from the figure that in the stage of shock wave pressure loading, due to the different distances between each measuring point and the explosion centre, the peak value of shock wave overpressure decreases with the increase of the explosion centre distance. With the end of the process of reflection and superposition of the shock wave pressure in the confined space, the quasi-static pressure reaches the peak value, the pressure in the confined space tends to be stable and evenly distributed, and the quasi-static pressure values of each measuring point are equal.

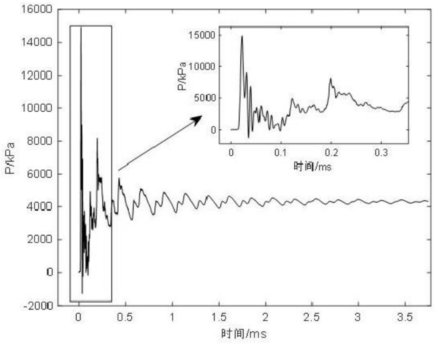

Figure 2 10gTNT Explosion pressure time curve

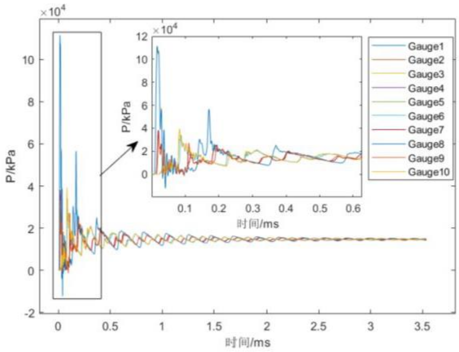

Figure 3 Pressure Curve of Gauss Points in 25gTNT Explosion Confined Space

Scholars at home and abroad have different views on the value of quasi-static pressure. The quasi-static pressure shall be a certain value for the determined charge mass and confined space structure volume. Considering the instability of the peak and trough pressure values of the pressure curve in the quasi-static pressure stage, the average value of this stage is taken as the quasi-static pressure value in this paper takes the average value of this stage as quasi-static pressure value. Based on the above analysis, the quasi-static explosion pressure values of 5g, 10g, 15g, 25g, 35g, and 50g TNT in the confined space are obtained by using the average method, as shown in the table3 below

Table 3 Quasi-static pressure value in confined space

m/kg	5	10	15	25	35	50
m/V/(kg•m^3)	2.79	5.58	8.37	13.956	19.53	27.9
P/kPa	2157.4	4284.8	6354.5	10572	14751	20960

Analysis of numerical simulation results

To obtain a universal calculation method of TNT explosion quasi-static pressure peak value in a confined space, a dimensional analysis of the quasi-static pressure in a confined space is carried out. The quasi-static pressure in confined space was analyzed by dimension. It can be seen from Figure 2 that the quasi-static pressure in the confined space is evenly distributed, and its peak value is independent of the distance between explosion centres. TNT explodes in a confined space, and there are many factors affecting the quasi-static pressure peak value, mainly including the mass of TNT W, dimension is M; TNT explosive density *P*e, dimension is ML^{-3}; Energy released by unit mass explosion E, dimension is L^{2}T^{-2}; Expansion index of explosion products γ_e, dimension is S; Initial air pressure in confined space P_a， dimension is ML^{-1}T^{-2}; Initial air density ρ_a, dimension is ML^{-3}; air adiabatic index γ_a, dimension is SI； Confined space volume V, dimension is L^3; P_q stands for quasi-static pressure value, it can be expressed as a function of physical quantity:

$$P_q = \psi(W, \rho_e, E_e, \gamma_e; P_a, \rho_a, \gamma_a; V) \tag{1}$$

The total number of physical quantities involved in equation (2) is 9, and there are three basic dimensions, including M, L, T. according to the π theorem， Get six dimensionless parameters, including:

$$\frac{P_q}{\rho_e E_e},\ \gamma_e,\ \frac{P_a}{\rho_e E_e},\ \frac{\rho_a}{\rho_e},\ \gamma_a,\ \frac{\rho_e V}{W}\ 。$$

The dimensionless relation can be obtained:

$$\frac{P_q}{\rho_e E_e} = \phi\left(\gamma_e, \frac{P_a}{\rho_e E_e}, \frac{\rho_a}{\rho_e}, \gamma_a, \frac{\rho_e V}{W}\right) \tag{2}$$

For the explosion of the same type of explosives in the general confined space:

$$(\rho_e, E_e, \gamma_e; \rho_a, P_a,\ \gamma_a) = const \tag{3}$$

Therefore, equation (4) can be simplified as follows：

$$P_q = \phi(V / W) \tag{4}$$

It can be seen that the quasi-static pressure peak value of an explosion in a confined space is related to the ratio between the volume of the confined space and the explosive charge. According to the numerical simulation in the previous section, the quasi-static pressure peak value of TNT explosives with different qualities exploding in a confined space is obtained by fitting

$$P_q = 0.781\left(\frac{W}{V}\right)^{0.9883} \left(2.79kg/m^3 \le \frac{W}{V} \le 27.9kg/m^3\right) \tag{5}$$

The goodness of fit R^2=0.998. The comparison results between the quasi-static pressure test values of explosion in confined spaces in literature [12] and literature [3] and the calculated values in (6) are shown in the table. It can be seen from Table 5 that, within the calculation range of equation (6), the relative deviation between the test values and the calculated values is 10.5%, which can be used to predict the peak quasi-static pressure of TNT explosion in confined spaces.

Table 5 Comparison between test value and calculated value

m/V/(kg•m^3)	test value /MPa	calculated value /MPa	Relative deviation /%
3.84	3.3	2.95	10.5
6.46	4.8	4.94	2.8
8.87	6.48	6.75	4.2
17.69	12.58	13.36	6.2

CONCLUSION

When the TNT explosive explodes in a confined space, the rise of quasi-static pressure is accompanied by multiple shock wave reflections. At the end of the shock wave pressure reflection, the combustion effect of detonation products releases a certain amount of energy, and the quasi-static pressure reaches the peak value for a long time ; The quasi-static pressure load is uniformly distributed in the confined space, and the quasi- static pressure at different locations is approximately equal. Through dimensional analysis, it is proved that the ratio of enclosed space volume to explosive charge is the main factor determining the quasi-static pressure. Through numerical simulation, the quasi-static pressure peak value of TNT explosives with different qualities exploding in the confined space is. The functional relationship between the quasi-static pressure value and the charge volume ratio of the confined space within the range. Within its application scope, the maximum relative deviation between the calculated value and the test value is 10.5%, which can be used to predict the quasi- static pressure peak value of the TNT explosion in a confined space 2.79kg / m3 □ W / V □ 27.9kg / m3 . It is obtained through data fitting.

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