The explosion resistance analysis of the safety evacuation device

Yong Wang, Xuezhi Feng*, Lizhuang Cui, Gengyu Sun, Yongyan Wang and Xiumin Jing

School of Qingdao University of science and technology, Qingdao, China

*Corresponding author e-mail: 2500875646@qq.com

Abstract. The explosion resistance is one of the main functions of the safe evacuation device, and the explosion resistance of the safety evacuation device is mainly determined by the safe evacuation cabin, and therefore it requires the building structure to have sufficient strength and stiffness to resist the blast wave application to the cabin. In this paper, a new model of the similar triangular cabin structure is established. The explosion resistance impact analysis of the similar triangular cabin structure is carried out by AUTODYNA and ABAQUS software. The similar triangular cabin structure is placed in the simulated residential building, and the pressure cloud in the room during the explosion and the change of the pressure at each time in the single room can be obtained by TNT explosion test simulation. The pressure curve is used to analyze explosion resistance of the safe evacuation device, and the stress and deformation of the new cabin structure can be obtained. At the same time, the stress concentration are located at the corners of the interior of the cabin and the maximum deformation is located on the front and back walls of the pod which can meets the safety evacuation shock resistance.

1. Introduction

The so-called safety refuge device is a kind of airtight cabin structure which can provide emergency refuge, protect life safety and have a certain volume for the evacuees who are affected or suffered in sudden disasters or disasters. When explosion occurs, it is impossible to escape from the fire passage smoothly, which requires that the safety refuge device must have explosion-resistant ability to provide security for the lives of trapped people.

Abroad, Brzedzislav et al. used Auto Rea Gas to simulate the whole process of gas explosion in a mine with 9.5% TNT concentration. By comparing the results of simulation and test, it was found that the results were basically similar [2]. Dmitry Khokhlov et al. simulated and analyzed the whole process of mixed gas explosion, and considered the explosion comprehensively. There is a coupling relationship between combustion factors and physical quantities [3]. In China, Yu Yicheng of Harbin University of Technology and others used numerical simulation method to obtain the diffusion law of indoor gas under different influencing factors, and analyzed and calculated the consequences of explosion [4]. Gao Erxin and others used Fluent fluid software to simulate the movement law of TNT explosion shock wave flow. The distribution law of pressure field and temperature field in Coal Mine Roadway after TNT explosion...
is obtained. Dou Hongying and Baibo of Taiyuan University of Technology re-studied the anti-explosion analysis of movable lifesaving cabin.

In this paper, the advantages and disadvantages of the existing shelter structures are analyzed, and a new triangle-like shelter structure is proposed. In addition, AUTODYN is used to simulate the propagation of shock wave in a single room, and the explosion pressure curve is obtained. On this basis, the ABAQUS software is used to load the explosion pressure curve on the surface of the cabin to obtain the stress and deformation of the cabin, and to verify the anti-explosion performance of the cabin structure.

2. Cabin design of safety refuge device

According to the design requirements of pressure resistance [7], the pressure resistance of the round cabin is the best, but higher requirements are put forward for the placement and space utilization. The pressure resistance of the square cabin is the worst, but its placement is flexible and suitable for placement. On the basis of this, combined with the characteristics of circle and square, a new design scheme, i.e. triangle-like cabin structure, is put forward, which can improve the compressive performance, reduce the deformation and stress concentration as much as possible under the premise of guaranteeing the high utilization of space. Appearance. Fig.1 is a triangle-like cabin structure model.

![Fig. 1 The structural model of similar triangle cabin](image)

3. Analysis of Cabin Explosion Based on AUTODYN

3.1. Material Model Setting

The materials used in Explosion Analysis in this paper include TNT explosive, air and material of cabin structure.

(1) According to the relevant literature, HIGH_EXPLOSIVE_BURN model is selected as the material model of explosives, while JWL equation of state is used for the equation of explosives [8]:

$$P = A \left(1 - \frac{\omega}{R_V V}\right) e^{-\frac{R_V V}{\omega}} + B \left(1 - \frac{\omega}{R_V V}\right) e^{-\frac{R_V V}{\omega}} + \frac{\omega E}{V}$$  \hspace{1cm} (1)

(2) The material model of air is NULL material model, and LINEAR_POLYNOMIAL equation of state [8]:

$$P = C_0 + C_1 \mu + C_2 \mu^2 + C_3 \mu^3 + \left(C_4 + C_5 \mu + C_6 \mu^2\right) E$$  \hspace{1cm} (2)

$$\mu = \frac{1}{V} - 1$$  \hspace{1cm} (3)

And: $C_0 = C_1 = C_2 = C_3 = C_6 = 0$; $C_4 = C_5 = 0.4$; air density $\rho = 1.225\text{kg/m}^3$; initial relative volume $V_0 = 1.0$

(3) The material used in the cabin structure is 35CrMo steel plate, the corresponding material model is MAT_JOHN_COOK model, and the equation of state is John Cook [8]:

$$\sigma_y = \left(A' + B' \bar{\varepsilon}'\right) \left(1 + C' \ln \bar{\varepsilon}'\right) \left(1 - T^{\alpha m}\right)$$  \hspace{1cm} (4)
3.2. Establishment and Setting of Cabin Model
The space size of each residential building is uncertain and the decoration methods are different, which makes it difficult to calculate the model. This paper chooses a single room in general to study. It is assumed that the structure of the safe shelter cabin is placed on one corner of the room, the equivalent TNT explosive is placed on the diagonal line of the cabin position, and the whole room is equipped with ventilated windows and exit doors, etc. The plane layout of the model is obtained as follows. Figure 2 shows.

![Fig. 2 Plane layout in a single room](image)

The equivalent TNT is put into a single chamber and filled with air to mix the air with the equivalent TNT. The cabin structure of the safety refuge device is placed in a corner of the single chamber. The explosion point is located at the center of the TNT explosive, and the TNT explosive is placed on the diagonal line of the safety refuge device, and the boundary condition is added. In AUTODYN software, the boundary of air area automatically defaults to rigid wall [9], while for the cabin structure, the boundary condition is fixed, and the system will automatically identify. The density of meshing should not be too dense, otherwise it will be difficult for computer to realize because of the huge amount of calculation. Therefore, the cabin structure model is calculated by unstructured grid, and the Eulerian multi-material field grid is used in the air domain [10]. The model diagram after adding material is obtained, as shown in Figure 3. After the pretreatment of the whole Explosion Analysis target, 40 Gaussian monitoring points are applied to the walls of the single chamber and the surface of the safety refuge device, in order to further analyze and observe the pressure changes of the explosion in each part of the single chamber. The distribution of Gauss points in the whole single room is shown in Figure 4.

![Fig. 3 Single chamber calculation model](image) ![Fig. 4 Single chamber Gaussian point distribution](image)

3.3. Result Analysis
The explosion time of a single chamber is set at 100 ms. After analysis, the pressure cloud of a single chamber is obtained from the beginning of explosion to 100 ms, as shown in Fig. 5.
From the pressure nephogram of single chamber at each time in Fig. 5, it can be clearly observed that once the explosion source is detonated, it will produce high pressure. After detonation for 10 ms, the maximum pressure in single chamber reaches 641.8 KPa, and the shock wave after detonation first begins to spread around the detonation, and then it propagates to a little farther from the opposite side. Until it reaches the walls of a single room.

Take several observation points from a single chamber and observe the pressure change curve of the observation points during the whole explosion process, as shown in Fig. 6 and Fig. 7.

Fig. 6 The pressure curve of the points on each side wall of a single chamber

Fig. 7 Pressure curve of points on the surface of the cabin

Fig. 6 the pressure curves of the walls in the single room are taken from the left wall 23, the right wall 40, the back wall 26, and 34, respectively. From the analysis, it can be seen that the shock waves in a single chamber reach the walls with similar degree of vibration, and the closer to the explosion source, the greater the peak pressure, and its value reaches 350 KPa.

Fig. 7 Pressure curves on the surface of the cabin. The left side of the cabin is 14, the right side is 10, the top surface is 27, and the door is 2. From the analysis chart, it can be seen that the waveform of the monitoring points on the surface of the cabin is less oscillating than that near the explosion source in a single chamber, and the peak pressure on the left cabin is higher than that on the right cabin. The peak pressure on the left cabin has exceeded 220KPa, which is due to the reflection overpressure of the side
walls in a single chamber. The peak pressure is applied to the deck near the side of the wall, while the peak pressure is in the range of 180-200 KPa at other locations on the surface of the deck.

4. **Explosive Shock Resistance Analysis Based on ABAQUS**

4.1. **Analytical Pretreatment Device**

Model import: The cabin model in Creo is imported into ABAQUS.

Additional materials: The materials used in this paper are 35CrMo steel plate, 213GPa for Young's Modulus and 0.286 for Poisson's Ratio.

Mesh generation: Free mesh generation is adopted.

Applying boundary conditions: Because the safety refuge device is affected by the installation location, all other aspects of the safety refuge device are impacted by explosion except the bottom. According to the propagation law of shock wave produced by gas explosion studied by scholars in document [11], this paper simplifies the load conditions applied in the finite element analysis of anti-gas explosion shock performance of safety refuge device. Based on the analysis results of shock wave in the above section, ABAQUS software is used in the cabin. By applying the required waveform, the shock wave is simplified to a triangular shock wave. Since the pressure on the cabin does not exceed 0.4 MPa, the peak pressure can be set to 0.4 MPa. The shock wave can be retained 60 ms before the shock wave, and the shock wave can be reduced from 60 ms to 400 ms. The dynamic response of the anti-gas explosion shock performance of the safety refuge device is calculated. The applied shock wave waveform is shown in Fig. 8.

![Fig. 8 The explosive shock waveform](image)

4.2. **Result Analysis**

The calculation time of the whole cabin analysis is 0.4s. Considering the impact of explosion inside the cabin, after the whole cabin analysis, the cabin structure is sliced along the XOZ plane by the create command under view cut in the Tools menu, and the cabin interior situation is observed. The post-processing of the cabin is checked by using ABAQUS/Explicit solver. As a result, the stress and deformation nephograms of the cabin structure at each time are obtained, as shown in figs. 9 and 10.
From Fig. 9, the stress nephogram of the cabin structure can be clearly observed under the action of simulated explosion and blast wave. The maximum stress of the cabin structure is concentrated at the edge of the connection between the cabin and the door. The maximum stress value is 394.4 MPa, while the yield strength value of the materials used is 835 MPa. The analysis results are within the yield strength range of the materials, thus meeting the strength requirements. The other stress concentration of the cabin structure is located at the corner of the cabin interior, and the stress value is between 200 and 300 MPa. The trend of the maximum stress of the cabin decreases with the change of time during the whole analysis process. From Fig. 10, we can clearly observe the deformation cloud of the cabin structure under the action of simulated explosion and blast wave. The maximum deformation of the cabin structure occurs on the front and rear walls of the cabin, and its maximum deformation is 5.127mm. This is because there is no reinforcement on the front and back walls of the cabin, so the deformation is relatively large here, limited by the area of residential buildings, and the installation location should be relatively reasonable, the cabin structure should be based on the wall. According to the actual situation, the impact load on the rear wall of the cabin should be smaller than that of the simulation analysis, and the deformation of the other positions of the cabin should be about 2-3 mm.
5. Conclusion

(1) Based on the structure of the original safety refuge device, a new triangle-like safety refuge device is proposed in this paper, and on this basis, a model is built by Creo.

(2) The triangle-like cabin structure is placed in the simulated residential building, and the TNT is used to simulate the explosion test. The pressure cloud in the room during the explosion and the pressure variation curve in each time in the single room are obtained.

(3) The pressure curve is used to analyze the explosion resistance of the safety refuge device, and the stress and deformation nephogram of the new cabin structure is obtained. The stress concentration is located at the corner of the cabin interior, and the maximum deformation is located on the front and back walls of the cabin, which meets the explosion shock resistance performance of the new safety refuge device.

Acknowledgments

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