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Simulation analysis on structure safety of coal mine mobile refuge chamber under explosion load ☆

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ABSTRACT

In order to check structural strength of coal mine mobiles refuge chamber, and do security evaluation of the mobile refuge chamber, a refuge chamber model was established, then a finite element method was instituted for it to ensure the refuge chamber would not be severely damaged when gas or coal dust explosion suddenly happened. A triangle shock wave with 1.2 MPa over-pressure, 300 ms lasting time was settled. Explicit nonlinear dynamic analysis program was used to simulate response of the refuge chamber. The maximum stress was 244 MPa, located in central part of sides and tail end of the last capsule. The maximum displacement was 29.32 mm, located in central part of sides and tail end of the last capsule. The calculation indicated that the refuge chamber was not obviously damaged. It could reliable work to meet safety requirements. Compared with the reported experimental results, the simulation method was verified. Based on analysis, suggestions were put forward for further improving.

1. Introduction

There may be many kinds of risk oxygen depletion near the explosion area, filled with high-temperature smoke or high concentrations poisonous gases, escape line collapsed after accidents such as gas or dust explosion, coal and gas outburst, flooded coal mine, roof collapse and others. Miners in coal mine would not been able to evacuate to a safe area or get out in time (State Administration of Work Safety, 2004–2009). About 80% miners who were killed in accidents should due to this reason (Zhou and Chen, 2008). Therefore, January 27, 2011, State Administration of Work Safety issued the 'coal mine emergency management system construction Interim Provisions', in which the design, construction, using of coal mine underground emergency system including refuge chamber had been detailed provide. That will improve coal mine Emergency ability and reduce accident casualties and promote coal mine safety (Wang et al., 2010a).

Gas and coal dust explosion may produce a strong shock wave. That can result in certain degree of plastic deformation of the refuge chamber capsule shell structure. When dumping and distortions takes place, the refuge chamber capsule will be serious damaged and lose protective action. Currently, the domestic and overseas key technology (Fasouletos, 2007; Sun, 2011), experimental study about antiknock performance (Pan, 2010), heat-shielding performance (Wang et al., 2010b), etc. for refuge chamber capsule has matured. Strength check for the refuge chamber need more theoretical support, but there is less simulation analysis of structure for refuge chamber under explosion load domestic and overseas. To this end, a chamber capsule model will be established, do simulation for this model, and find out possible weak links of it for improvement. Finite element analysis will be used to analyze the stress and deformation of the refuge chamber produced by blast loading. The location of maximum stress and maximum plastic deformation occurring will be found out to determine whether the structure of it is damaged. Safety and reliability of it under blast loading will be checked out, with a view to provide a basis theoretical research for further improvements.

2. Numerical simulation for the refuge chamber under blast loading

2.1. Overview for the refuge chamber

The five-sides besides bottom of this mobile refuge chamber will absorb shock. The structure is shown in Fig. 1. The basic segments of

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the chamber are connected by bolts through flanges. Thick of each basic cabin is mm-level. Thick of flange is mm-level, too. Thick of flange in front and back doors acting as gusset piece for the flange connection is cm-level. Thick of the door is cm-level. There have wheels sited in the bottom of the chamber. That ensures the refuge chamber could slide along the track direction. As the wheel will not affect the strength reliability of it, geometric models for the wheels are not shown. Ordinary low-carbon steel Q235 is chosen as material of capsule while iron of doors.

2.2. The basic assumption and equations

As the refuge chamber structure is mainly connected by welding and bolted connections, there are no relative motion parts, so hypothesis is determined: the welding of structural parts is completely reliable. There has no penetration between structural parts. There has eliminated all stress of welding. There does not exist any deformation due to manufacture or installation. Bolted connection is reliable. There is no effect produced by pre-stressed of bolted connection.

Explicit nonlinear dynamic analysis program ANSYS/LS-DYNA (Beijing Institute of Technology ANSYS/LS-DYNA Technical Support Center) will be used to calculate stress and elastic–plastic deformation for the refuge chamber under blast loading. The fundmental equation for this dynamic problem can be written as follows.

$$Md^2\delta/dt^2 + Cd\delta/dt + K\delta(t) = P(t) \quad (1)$$

where $\delta(t)$ is the displacement of nodes on the elastomeric matrix; $P(t)$ is a unit nodal load matrix; K is the total stiffness matrix; M is the total mass matrix; C is the total damping matrix.

For the dynamic structure, stress and displacement is a function of time, strain and stress in unit can be written as follows.

$$\epsilon(t) = B\delta(t)^e \quad (2)$$

$$\sigma(t) = D\epsilon(t) = DB\delta(t)^e \quad (3)$$

where $\varepsilon(t)$ is the strain in unit; $\sigma(t)$ is stress in unit; $\delta(t)^e$ is displacement vector in unit nodal; B is the strain matrix; and D is the elastic matrix.

2.3. Simulation model analysis

The method of loading pressure wave is used to simulate the effect in the refuge chamber produced by blast loading. The condition that the refuge chamber bears the most severe disruption will be taken for calculating. This condition is the most probable damage condition while the refuge chamber faces to blast loading. For these reasons, the same blast loading is loaded on the five-sides besides the bottom side. The refuge chamber is expected to bear a certain level of load and satisfy definite safety coefficient. 2.0 is taken as safety coefficient. According to shock data and shock limit that human can bear in explosion. A maximum no less than 0.3 MPa is chosen as explosion pressure maximum. In order to get better effects of response, 1.2(0.6 * 2.0) MPa is chosen as calculated maximum. The establishment of pressure–time curve for the triangle shock wave is shown in Fig. 2. The maximum pressure of the triangle shock wave is 1.2 MPa, the pulse width is 300 ms. The data of this shock wave is shown in Table 1.

In the finite element analysis, contact of the refuge chamber wheels and the track surface is point surface contact which will be reduces to simply supported constraints. The coordinates will be set by frame of reference of the axle. The simply supported constraint is release the translational motion of Y axis, release the rotation around of X axis, while restrain the direction of the degree of freedom of others constraints. That will ensure that the refuge chamber only can do the horizontal movement along the track direction.

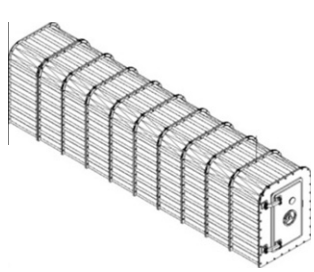

Fig. 1. Geometry constructional of refuge chamber.

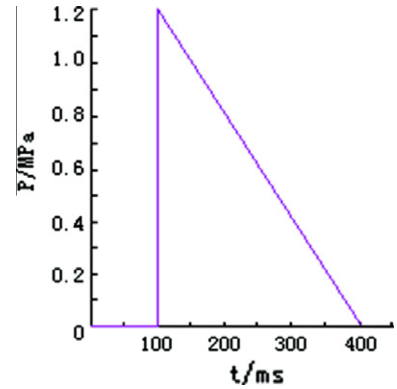

Fig. 2. Pressure–time curve of shock wave.

Table 1
Data of shock wave.

Time (ms)	0	100	100.1	400.1
Pressure (MPa)	0	0	1.2	0

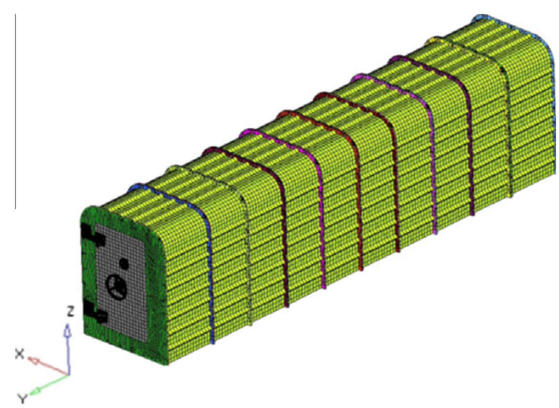

Fig. 3. Model of finite element mesh.

2.4. Simulation model building

The thickness of basic cabins made of corrugated plate and flanges playing as connection are much smaller compared with the size of the refuge chamber. Considering the actual size of the model and need of compute numeration, the kind of SHELL163 element will be used to partition basic cabins and flanges.

The thickness of cabin door and emergency door cannot be elided compared with the size of the refuge chamber. Considering the actual size of the model and the need of compute numeration,