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THE TANK'S DYNAMIC RESPONSE UNDER NUCLEAR EXPLOSION BLAST WAVE

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ABSTRACT

To weapons and equipments, blast wave is the primary destructive factor. In this paper, taken the real model-59 tank as an example, we try to transform the damage estimation problem into computing a fluid structure interaction problem with finite element method. The response of tank under nuclear explosion blast wave is computed with the general-coupling algorithm. Also, the dynamical interaction of blast wave and tank is reflected in real time. The deformation of each part of the tank is worked out and the result corresponds to the real-measured data.

Keywords: blast wave of nuclear explosion, finite element method, fluid structure interaction, explosion similar law, overpressure impulse of blast wave.

1. INTRODUCTION

The destroy of tank under nuclear explosion blast wave is very complicated, which is influenced by many factors, such as the blast wave's energy, the propagation characteristic, the tank's shape, size, material and so on. In the past, we estimated the damage grade of tank according to the data from the nuclear test. Now, with the Completed Banned Nuclear Test Treaty being put into effect, it is impossible to get new data from the nuclear test. So the most feasible way is to simulate the interaction of blast wave and tank.

2. NUCLEAR EXPLOSION BLAST WAVE

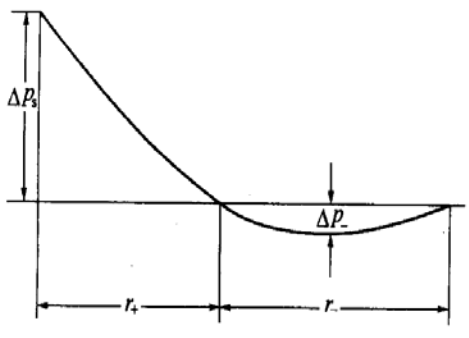


Fig 1. Nuclear explosion blast wave line

The front of the nuclear blast wave is a strong disconnected one, through which the pressure is lifted up suddenly, and the medium's density, temperature and particle velocity is enhanced altogether. The typical time-changing wave line is shown as figure 1. When the blast wave reaches one certain point, the pressure suddenly highs up to $p_0 + \Delta p_s$, and the particle velocity highs up to v_s. After the duration time τ_+, the disturbed atmosphere returns back to the undisturbed state. Then the pressure begins to lower down, and the decreased part is called Δp_-. After a certain time τ_-, the disturbed atmosphere returns completely to the normal state. During the time-changing course of the blast wave, the structure bears with the impulse load. In order to describe the action to the structure, the overpressure impulse I is introduced:

$$I = \int_{\theta}^{\theta+\tau_+} \Delta p(t) dt \qquad (1)$$

which is the wave line area above time axis in figure 1[1].

3. THE SYSTEM'S MOVEMENT EQUATION

In fact, the interaction between the nuclear explosion blast wave and tank is a typical fluid-structure dynamic problem. But until recently when we analyze its physical course, the force of the blast wave is loaded to the tank as a foreknown force. Usually, we divide the region of action into straight reflection area, oblique reflection area and composition wave reflection area, and then compute the overpressure on different part of the tank. Such method could not reflect the dynamic course of blast wave and tank. MSC.Dytran is one of the most famous finite element analysis software which has great power in simulating fluid-structure interaction. The Lagrange mesh and the Euler mesh are joined in one analysis model, and the interaction takes place in their boundary.

Let's make three hypothesis before describing the system's movement: ①the whole tank is regarded as a single-layer shell made up with isotropy materials; ②the influence of inner instruments is neglected as well as the doors, windows and holes; ③the nuclear explosion blast wave is similarly regarded as a plane wave without considering the tank's move.

Thus, the structure's (tank's) movement equation is defined as:

$$M_s \ddot{u} + C_s \dot{u} + K_s u = F_s + Q_p p + Q_v v \qquad (2)$$

and the fluid's movement equation is defined as :

$$M_f \dot{v} + (C + C_b) v = F_f + (A^T + A_b^T) p + Q_v^T \dot{u} \quad \text{and}$$

$$(A + A_b) v = -Q_p^T \dot{u} \qquad (3)$$

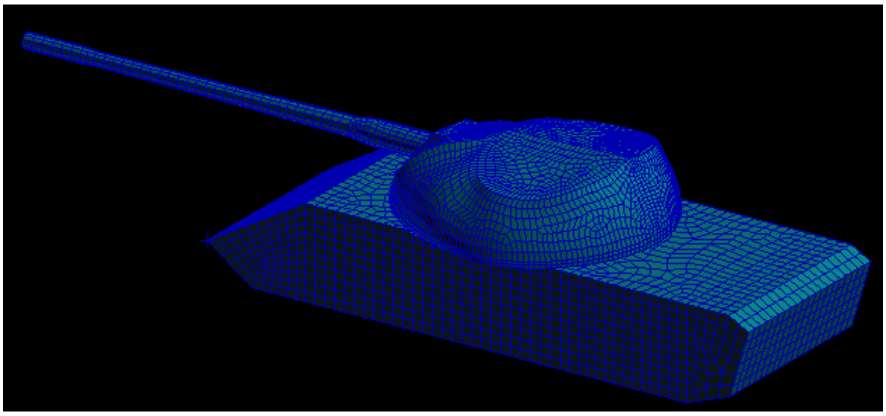
Every symbol has its own meaning which can be consulted in reference [5].

The system's complete equation is composed of equation (2) and equation (3), which is a mixed time-changing non-linear differential equation. The theoretical solution is still undiscovered, so we could not give out the system's analytic expression formula. What we can do is to give out the numerical solution with finite element method.

4. SIMULATION

4.1 BUILDING UP THE GEOMETRY AND FEM MODEL

The geometry is the foundation of FEM computation. In fact, as one of the main weapon, the structure of tank is very complicated. In order to carry out the computation, the model must be simplified. After long time discussion, we adopt the following parts as the tank's simplified model: the tank body, the gun turret, and the barrel.



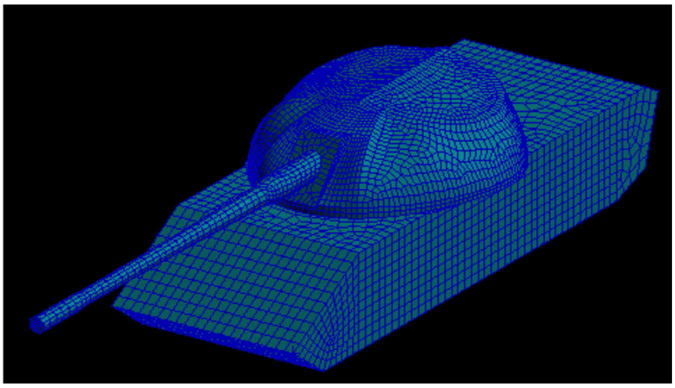


Fig.2 Simplified model of tank-59

The simplified model of the whole tank is given in figure 2. The tank body is 6.002 meters long, 2.01 meters wide and 0.98 meter high if not considering the gun. The detailed size can be consulted in reference [4]. The geometry is described with Lagrange quadrilateral shell element (CQUAD4) with certain thickness. In the end, tank-59 is divided into 6749 shell elements and 8209 nodes.

Based on explosion similar law, an equivalent method on computing interaction between blast wave and target is advanced. For the same target, if the relationships between two explosion centers and the target are the same, if both of the two explosion blast wave can be regarded as plane wave, and if the overpressure impulses of the two blast wave equal to each other, then the damage effects of this two explosions are thought to be the same. According to the equivalent method, the damage effect of tank-59 under a 570m-distance explosion is equivalent to a 19m-distance explosion but with different energy.

Explosion is simulated through a region of gas with high temperature and high pressure. The whole simulated blast wave propagation space is 20meters long, 12 meters wide and 14 meters high. Before explosion, the space is full of the ideal gas with the pressure of 1×10^5Pa. The related position is shown in figure 3. The simulating explosion center is shown in figure 3 as a black point which is 19 meters away from the tank center.

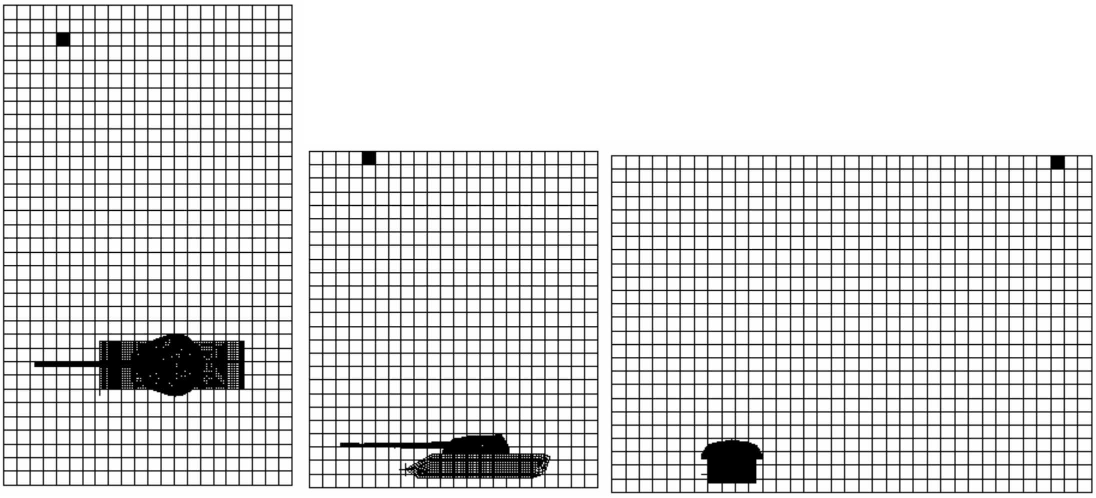


Fig. 3 Tank-59 and the blast wave propagation space

The blast wave propagation space is described with Euler elements (CHEXA4). In the end, the space is divided into 19250 solid elements and 21528 nodes.

4.2 MATERIAL

To tank-59, different parts are made up of different materials including 603-steel, 601-steel, 100-steel, high pressure-IV steel and high pressure-V steel.

In MSC.Dytran, DMATEP card is used to define the isotropy material with failure model. In this paper, the material is considered as being totally destroyed if the element's EFFPL is larger than 0.5. The thickness of different part on tank-59 can be consulted in reference [4].

4.3 COMPUTATION

The course of destroy of blast wave to tank is just the course of fluid-structure interaction.

- **Boundary conditions**

In our simulation, tank-59 could not move, and is supposed to be fixed in the original place. This assumption is acceptable under the explosion yield we adopted. So, the four angles of the tank body's bottom are constrained with all the freedom limited, which are defined with SPC1 card in MSC.Dytran. Five surfaces of the blast wave propagation space is defined as "BOTHFLOW" with the pressure 1×10^5 Pa on the boundaries. The bottom surface of the space is not defined so as to simulate the realistic reflecting blast wave.

- **Initial condition of the explosion gas**

Not considering the internal change of the explosion material, we simulate the explosion as follows:

Suppose there is one spherical area filled up with gas of high-temperature and high-pressure in the blast wave propagation space, which is full of ideal gas. The initial specific inner-energy of the high-pressure gas is noted as e_1 and the density noted as ρ_1, and the radius of the sphere is noted as R_0, then the initial energy of the simulated explosion can be described as $E_{simulate} = e_1\rho_1 \frac{4}{3}\pi R_0^3$. Because of the pressure difference between the spherical region and the surrounding atmosphere, the gas with high-temperature and high-pressure in the sphere flow to every direction and form the blast wave front, and thus simulate the explosion blast wave.

According the equivalent model[5], the actual yield and the simulating yield should meet the following equation $Q_{simulate} = \left(\frac{r_{simulate}}{r_{actual}}\right)^{\frac{3}{2}} \cdot Q_{actual}$ to guarantee the same overpressure impulse. Besides, based on the theory of Spot Explosion, $E_{simulate} = 0.6Q_{simulate}$, we have the following equation :

$$e_1\rho_1 \cdot \frac{4}{3}\pi R^3 = \left(\frac{r_{simulate}}{r_{actual}}\right)^{\frac{3}{2}} \cdot Q_{actual} \tag{4}$$

In order to reduce the expense of the calculation, the value of $r_{simulate}$ is supposed to be three times of the tank width that is 18.972 meters. According to MSC.Dytran's internal requirement, the initial radius of the explosion sphere should amount with the smallest Euler element dimension. So we set the radius of the explosion sphere to be 0.5m——$R_0 = 0.5m$. The value of e_1 and ρ_1 should meet the equation (4), here we set their value depending on the value of Q_{actual} and r_{actual}•.

- **Defining the coupling surface**

In the calculation, the coupling surface must be enclosed. In order to meet the algorithm, a dummy surface is built up on the opening of the gun. So, the entire tank plus the dummy surface as the coupling surface take part in the coupling computation. In MSC.Dytran, coupling surface is defined with COUPLE card and SURFACE card.

4.4 RESULT

① Simulating the nuclear explosion blast wave with the same overpressure impulse

According to equation (1) and the secret real-measured data Q_{actual} and r_{actual}, under a certain real nuclear explosion in air, the overpressure impulse of the blast wave in the place of tank –59 is 17547Pa · s. So to meet the same impulse, according to equation (4), the simulating explosion source parameter can be set as follows: $\rho_1 = 7.74kg/m^3$, $e_1 = 8.65\times10^{10} m^2/s^2$.

The wave lines of element 8542 and element 7650 are shown in figure 4. Element 8542 faces the blast wave front, and element 7650 is on the sheltered side.

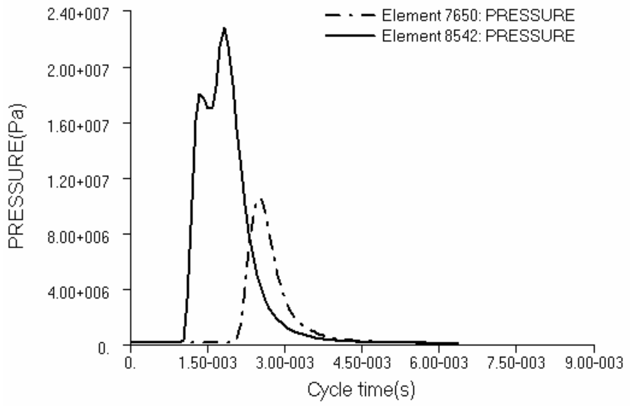


Fig.4 Blast wave lines of element 8542 and element 7650

• secret data

On the front side, the original blast wave is enhanced and appears a second higher peak due to the reflection of the ground and the tank itself. The computed blast wave overpressure impulse is about 17556 $Pa \cdot s$, $I_{front} \approx 17556 Pa \cdot s$, which approximately equals to the real explosion overpressure impulse. While on the sheltered side, the overpressure impulse of the blast wave reduces greatly, which is about 7336 $Pa \cdot s$, $I_{back} \approx 7336 Pa \cdot s$.

The simulated blast wave's propagation cloud picture is shown in figure 5, and the color label from top to the bottom represents the value of the pressure from high to low.

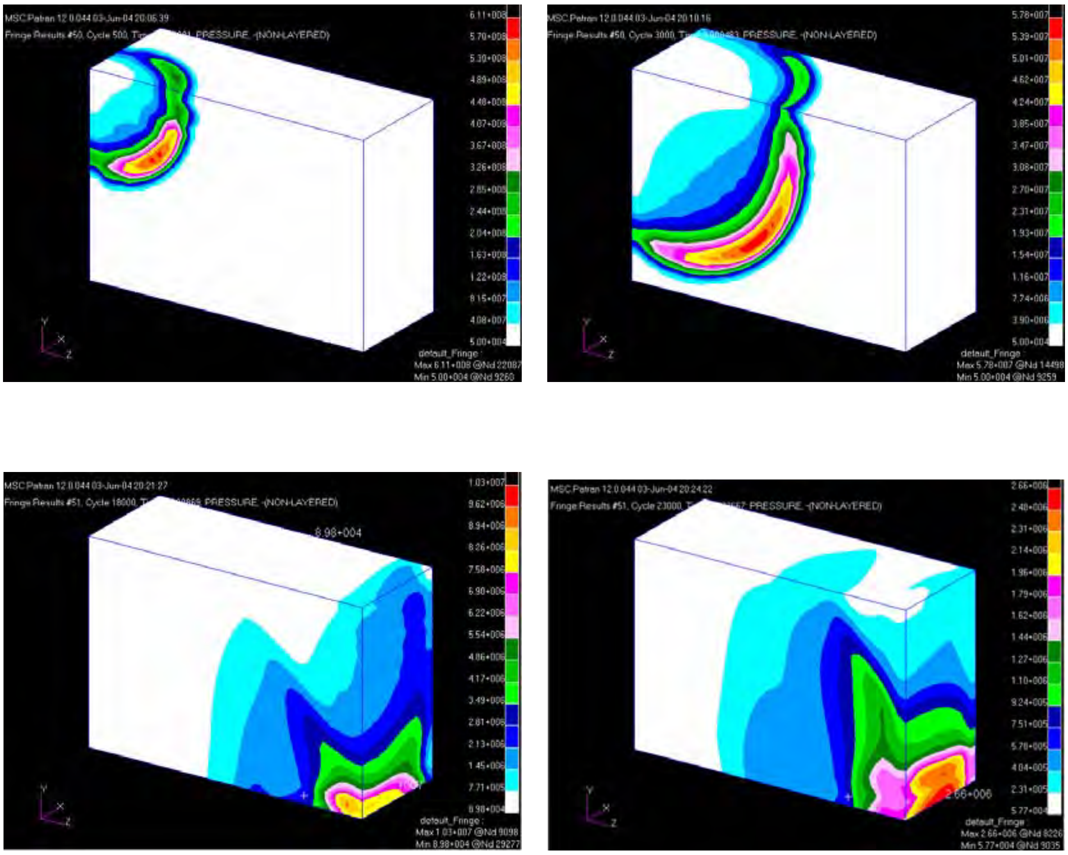


Fig.5 The propagation of the blast wave

② **The computation result compares with real data**

The whole tank's EFFPL cloud picture is shown in Figure 6, and the color label from top to the bottom represents the value of the equal plastic strain from high to low.

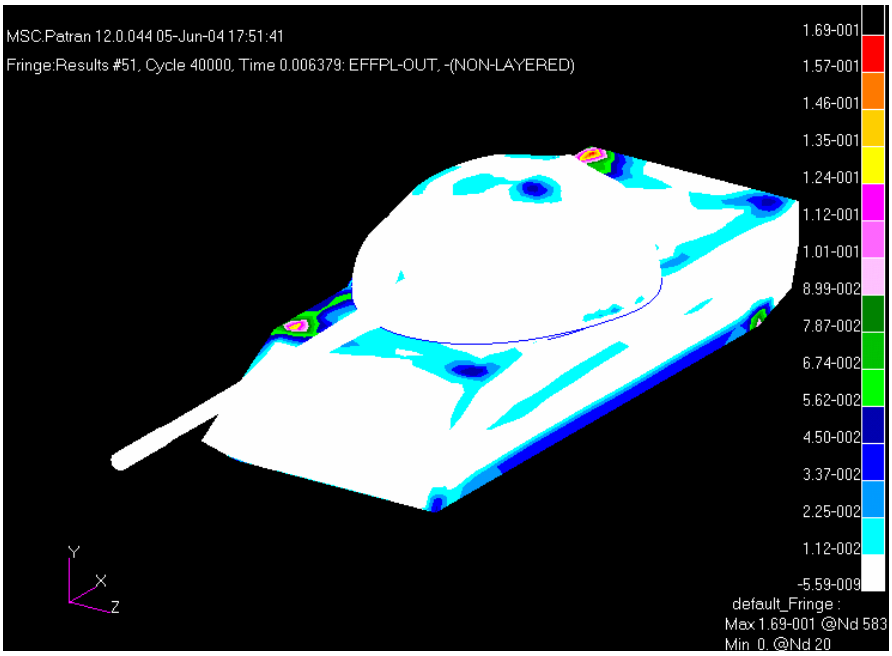


Figure 6: The plastic strain of the whole tank

Figure 6 show that the plastic strain is inclined to occur at the front side facing the blast wave and the acute place of the structure. The conjunction parts as well as the top and the bottom are more liable to be destroyed. Not only the distance from the explosion center but also the position relationship between tank and the explosion center affects the deformation result greatly. Computation results show that totally under such given overpressure impulse, the plastic strain of the tank is small, and the destroy degree should be regard as light.

More detailed comparison can be consulted in reference [5].

5. ANALYZE THE RESULT

In nuclear test site, the destroy degree of the tank under the given impulse is light. The simulating result with finite element method is similar to the real data on the whole. The computation errors may come from the following respects:

① **The simplification of the geometry brings up the error.**

In this paper, the model is built up with shell elements. While there exist supporting beams in the tank, which can make the tank endure higher overpressure of the blast wave. So if we consider the structure characteristics more thoroughly, the result will be more accurate.

② **The chosen element brings up the error.**

To reduce the expense of the calculation and the calculating time, we limit the number of the elements. Therefore in this paper quad shell elements with four nodes and thickness are used to describe the tank, and thus bring up the error, because quad shell element itself has limited ability to describe deformation and strain. The error will be decreased if we adopt hexahedron solid element with eight nodes.

③ **The boundary conditions brings up the error.**

In this paper the tank is fixed to the ground without considering its move. In fact, there is friction between tank bottom and the ground. When the overpressure is lower, the pushing force caused by the blast wave could not offset the friction, so the tank would not move. But when the overpressure is higher, the pushing force caused by the blast wave could offset the friction, the tank would move and even turn around. So if we considered the tank’s move, the simulating result would be more accurate especially to those under higher overpressure.

④ **The model of the blast wave propagation space brings up the error.**

In fact the bottom of the propagation space is the ground, there are coupling interaction between the blast wave and the ground. In our simulation, this kind of coupling is neglected for simplification.

⑤ **The simulated explosion source brings up the error.**

In real nuclear test site, the distance between the tank and the nuclear explosion center is 570 meters. While in order to carry out the computation, an equivalent explosion source is simulated and the distance between the simulating center to the tank is 19 meters and thus brings up the error.

6. CONCLUTION

In this paper, the course of tank-59's destroy under nuclear explosion blast wave is simulated. From the result we can say, the computation model is relatively perfect in describing the blast wave's propagation, while the deformation of tank matches with the real data on the whole. The success of simulating damage computation with finite element method is very encouraging. Our simulating method is believed to be useful to some other research work related to blast wave and structure interaction.

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