Numerical investigation on air explosion and its effect on thin shell structure under low-pressure condition

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We developed the high-order large-scale numerical method on air explosion, as well as the pressure-loading method of ABAQUS. Based on Fortran language, the pressure-loading function called VDLOAD was programmed to simulate the two-way fluid-structure interaction between explosive products and shell structure. The fluid field, including explosive products and air, is solved by Euler equation, which can be written as

$$\frac{\partial U}{\partial t}+\frac{\partial F(U)}{\partial x}+\frac{\partial G(U)}{\partial y}+\frac{\partial H(U)}{\partial z}=S(U)$$

$$U=[\rho,\rho u,\rho v,\rho w,\rho E]^T$$

$$F=\left[\rho u,\rho u^2+P,\rho uv,\rho uw,u(\rho E+P)\right]^T$$

$$G=\left[\rho v,\rho uv,\rho v^2+P,\rho vw,v(\rho E+P)\right]^T$$

$$H=\left[\rho w,\rho uw,\rho vw,\rho w^2+P,w(\rho E+P)\right]^T$$

$$S=[0,0,0,0,0]^T$$

Where, ρ is the density; P is the pressure. u, v and w are the velocity component of x, y and z directions, respectively. E is the total energy per mass and is related with the internal energy per mass,

$$E=\frac{1}{2}\left(u^2+v^2+w^2\right)+e$$

Jones-Wilkins-Lee(JWL) and ideal gaseous equations of state(EOS) describes the explosive products and air.

Air explosion under low-pressure (80pa) and atmospheric pressure (101kpa) are simulated. The numerical results, as Fig. 1, show that it doesn't form shock wave but only explosive products at low-pressure. The duration of positive pressure and impulse are the same as those at atmospheric pressure (Table 1).

The structural dynamic response under atmospheric and low-pressure condition is compared. Numerical model is shown as Fig. 2-3. As shown in Fig. 4, the deformation, equivalent plastic strain and velocity of Q235 steel shell under the above two conditions are similar. It is found that, in some extent, the internal structure explosion experiments under atmospheric pressure can replace those under low-pressure condition due to the same failure mode of the shell (Fig. 5-6).

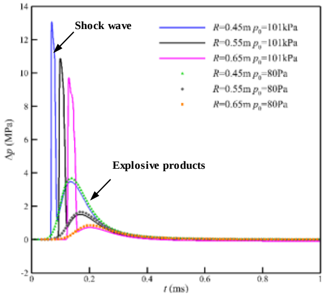

Fig. 1. Overpressure-time curve at typical point. (R - explosion distance, p_0 - ambient pressure)

Table 1 Duration of positive pressure and positive pressure impulse at typical position.

Atmospherical pressure p_0	Position R / m	Duration of positive pressure t_+ / ms	Positive pressure impulse I_+ / Pa·s
101 kPa	0.45	0.394	607.1
	0.55	0.366	402.6
	0.65	0.328	325.8
80 Pa	0.45	0.397	602.7
	0.55	0.368	395.9
	0.65	0.331	315.4

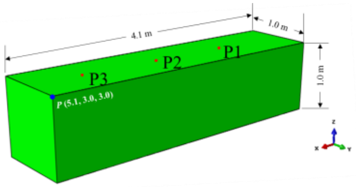

Fig. 2. Finite element model and measuring points of thin shell structure.

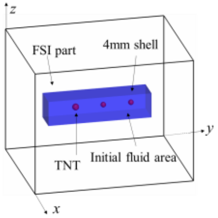

Fig. 3. A schematic diagram of 3D numerical model.

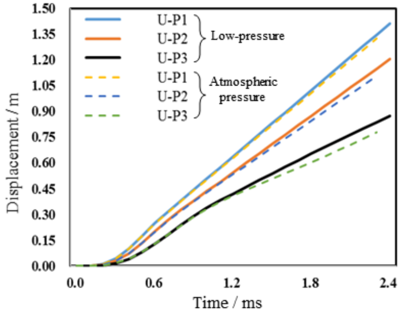

Fig. 4. Displacement-time curve at point P1, P2 and P3 under two kinds of ambient pressure.

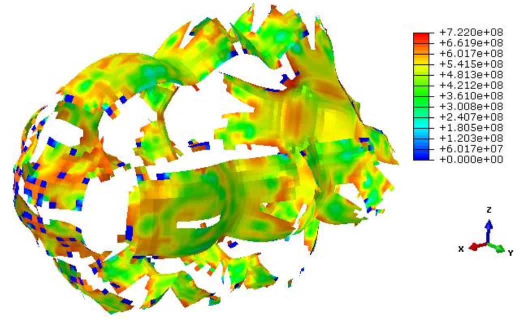

Fig. 5. Von Mises stress at atmospheric pressure (unit: Pa).

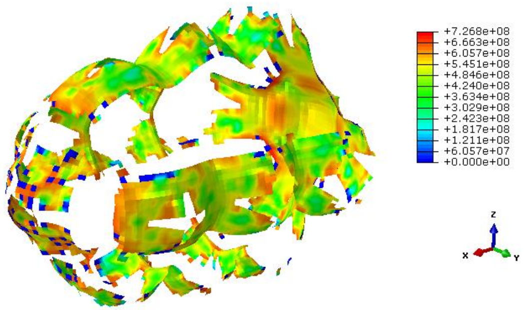

Fig. 6. Von Mises stress at low-pressure (unit: Pa).