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A numerical study on the high-velocity impact behavior of pressure pipes

Key words:
Pressure pipes, High-velocity impact, Fluid-structure interaction, Impact resistance, Numerical simulation

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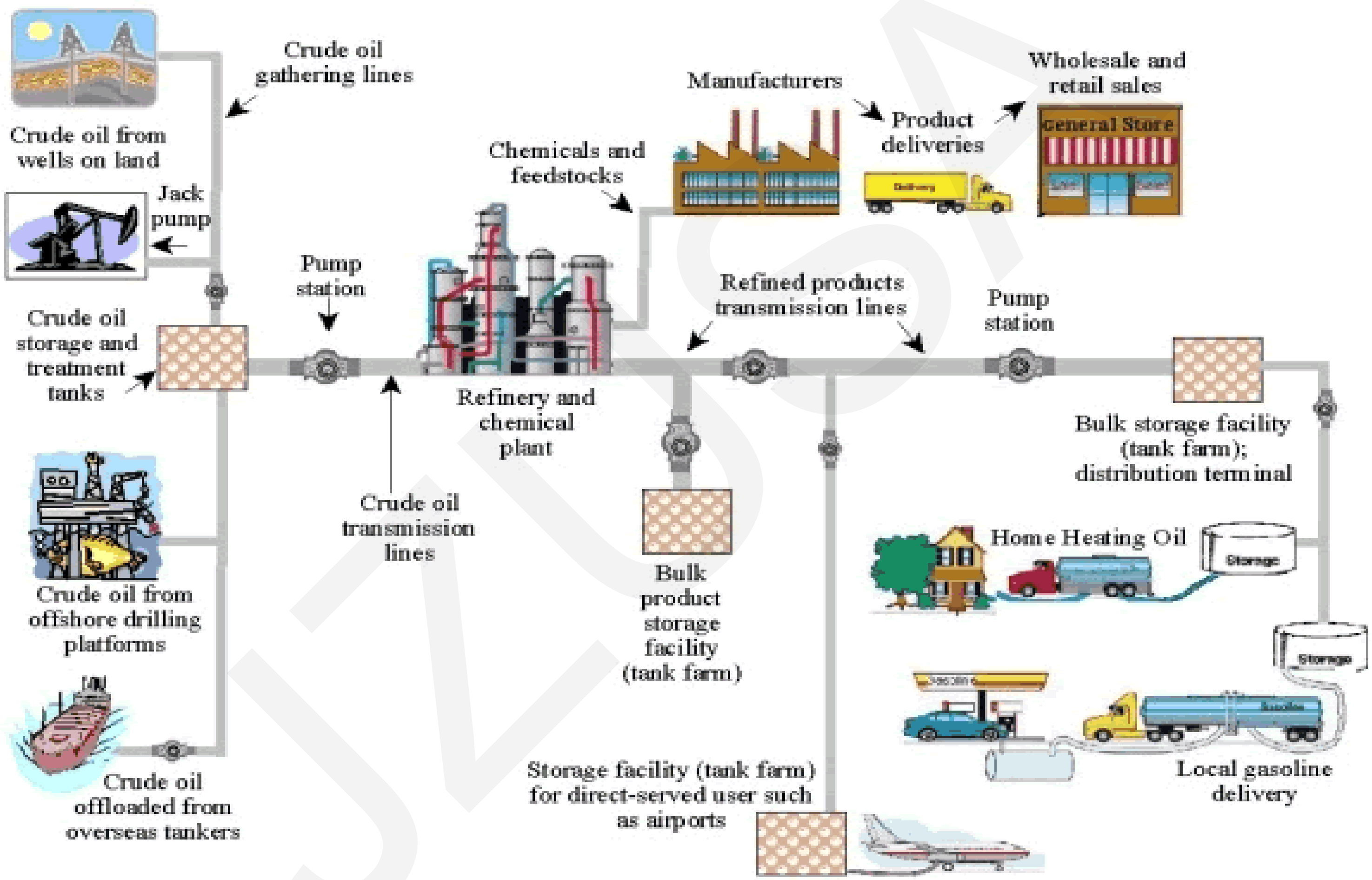
Background



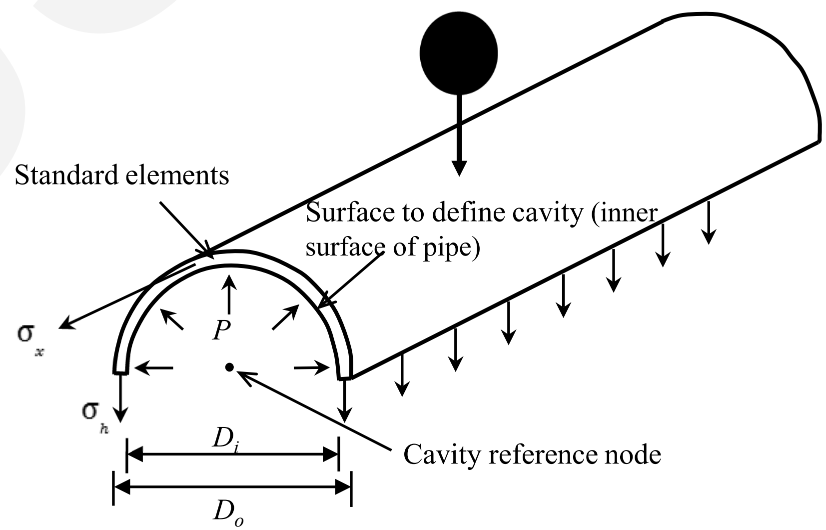
Pressure pipes are widely used in modern industry with some in potentially dangerous situations of explosion and impact

Method

Johnson-Cook model: The Johnson-Cook model is a phenomenological-based plasticity model that deals with the behavior of metals due to strain hardening, strain-rate hardening, and thermal softening. Johnson and Cook also developed a dynamic failure model which is suitable for high-strain-rate deformation of metals. This failure model is based on the value of the equivalent plastic strain at element integration points.

Surface-based fluid cavity: The surface-based fluid cavity, which behaves like a liquid-filled or gas-filled structure, is selected to model the coupling between the deformation of the pipe and the gas pressure. The gas-filled pipes can be modeled with the following steps:

1. Specifying the boundary of the fluid cavity.
2. Specifying the cavity reference node.
3. Defining the ambient conditions and the initial conditions for the fluid cavity.
4. Defining the fluid cavity behavior in the pipe.



Results

1. Influence of pipe wall thickness :

The thickness of the pipe plays an important role in certain diameter pressure pipes subjected to impact loads. It is clear from the figure that with the increase of wall thickness the impact-resistance capacity of the pipe increases.

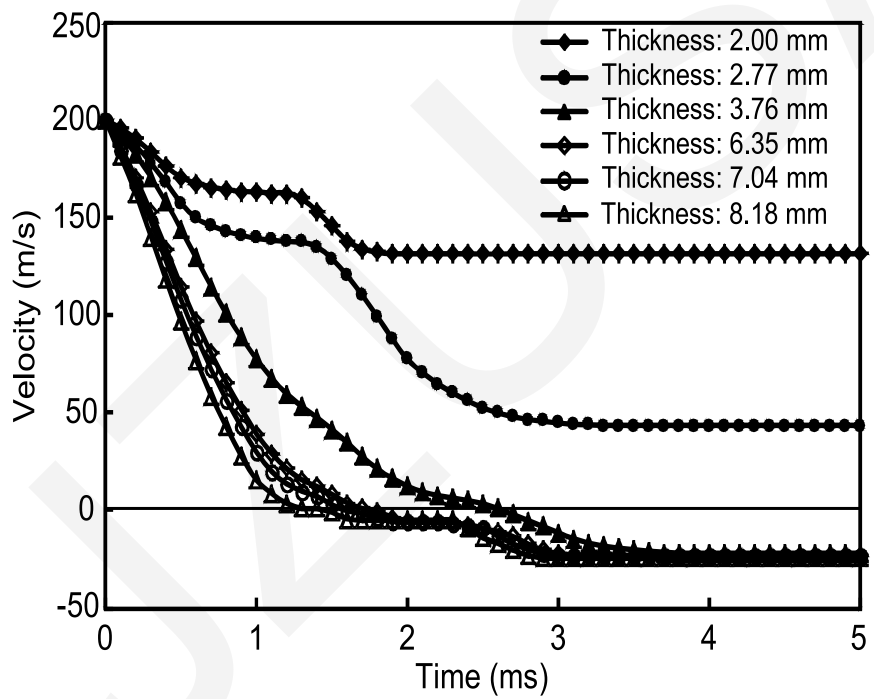


Fig. 6 Velocity of missile over time for various pipe wall thicknesses (P=1.8 MPa)

Results

2. Influence of missile nose shape:

It can be seen from Fig. 7 that the conical missile and the spherical missile perforate the pipes, while the projectile with the blunt nose bounces back. It is obvious that it is easier for a projectile with smaller contact area to perforate the pipes.

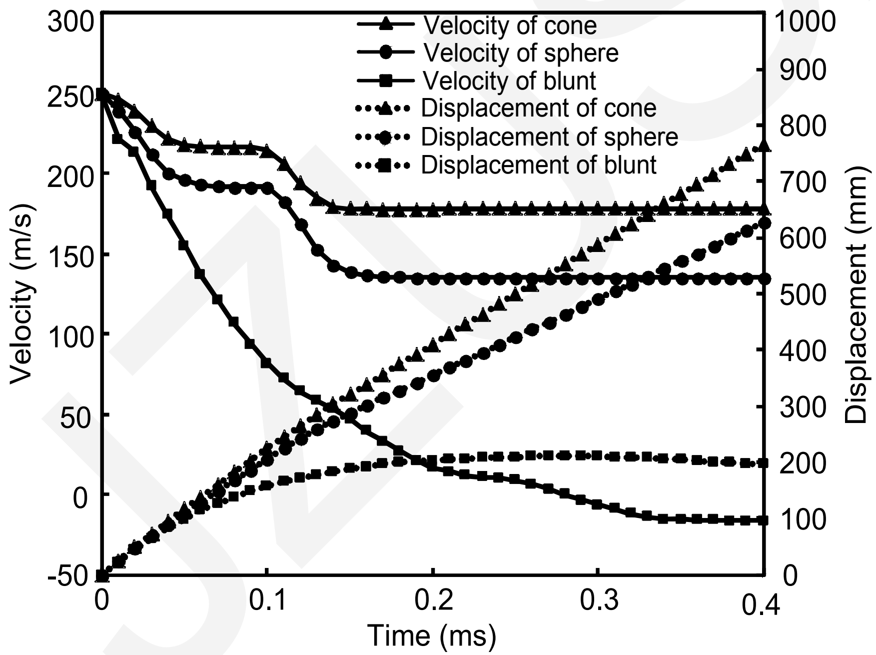


Fig. 7 Velocity and displacement of missile over time for various shaped projectiles (P=1.8 MPa)

Results

3. Influence of diameter of spherical missiles:

As shown in Fig. 8, a broken line is obtained by linking crack limit velocities of different projectile diameters. As indicated by the broken line, the crack limit velocities for pressure pipes decrease as the diameter of the projectile increases. Fig. 9 shows that it is easier for larger spherical projectiles to perforate the pipes because of their larger mass and larger momentum. However, when the momentum of the projectiles is equal, the smaller projectile perforates the pipes more easily because of its smaller contact area.

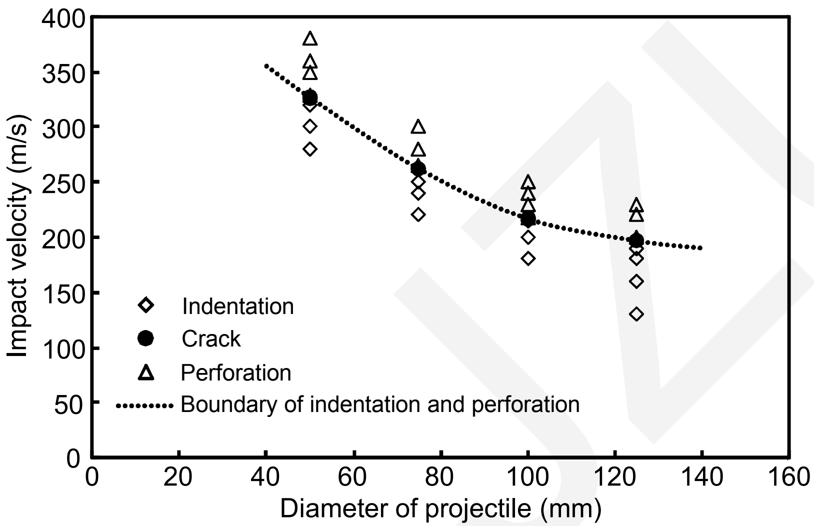


Fig. 8 Crack limit velocities of pressure pipes for different projectile diameters (P=1.8 MPa)

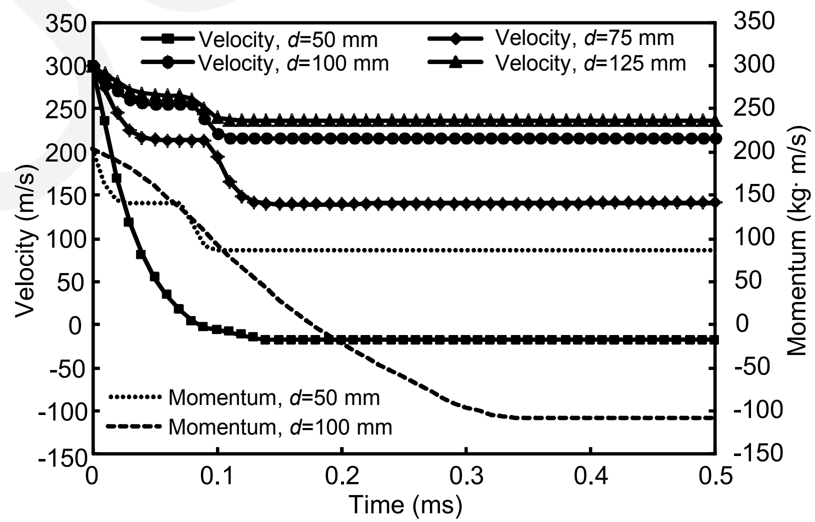


Fig. 9 Velocity and momentum of missile over time for various projectile diameters (P=1.8 MPa)

Results

4. Influence of internal pressure:

As shown in Fig. 10, all the missiles bounce back and the pipe walls vibrate due to the impact. It also can be seen from Fig. 10 that the deflection is relatively small for higher gas pressure pipes. As shown in 12, the permanent deflections increase with the increase of impact velocity and decrease with the increase of internal pressure.

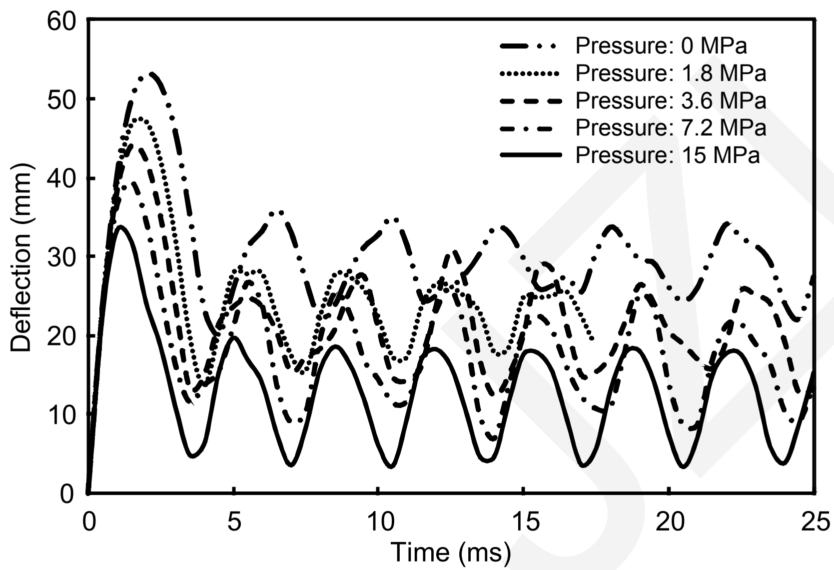


Fig. 10 Transverse deflection time history at the point of impact for various internal pressures

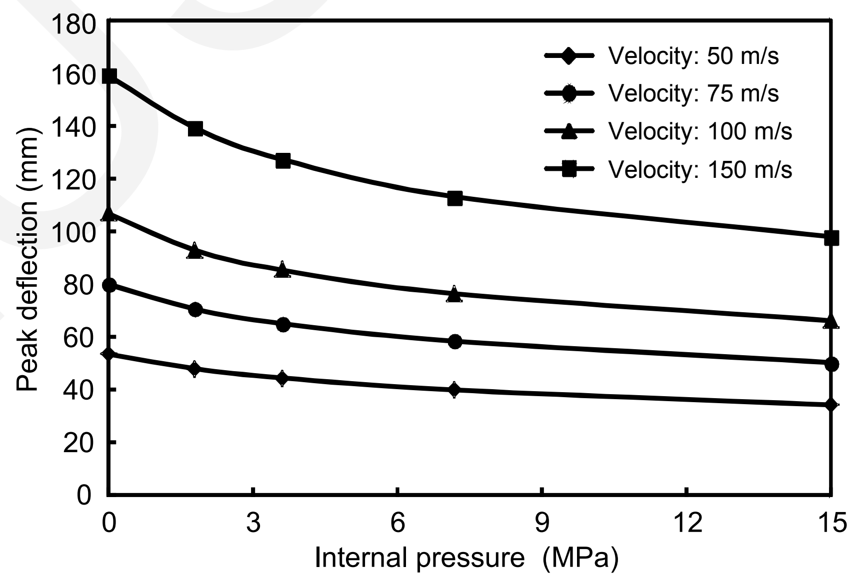


Fig. 12 Permanent deflections at impact point for various internal pressures

Conclusions

- 1. An FE model was developed to simulate gas-filled steel pipes impacted by high-velocity projectiles. In the detailed FE analyses, the Johnson-Cook model was used to simulate the dynamic behavior of steel due to strain hardening, strain-rate hardening, and thermal softening, and surface-based cavities were used to simulate the coupling between the pipe and the gas pressure.
- 2. Some parameters, such as pipe wall thickness, missile nose shape, diameter of spherical missile, and internal pressure of the pipe, were investigated, and the parametric study indicated that greater wall thickness increases the impact-resistant capacity of the pipe, and it is easier for projectiles with small contact area and high momentum to perforate steel pipes. The internal pressure decreases the perforation resistance of pipes while increasing their elastic resistance toward impacts without crack formation.
- 3. The numerical model reported in this paper provides reasonable estimates of the failure mode and the transverse deformation of pipes subjected to high-velocity impact loads, and it is helpful for the blast-resistant design of pressure pipes and other similar structures in an environment with an explosion risk.