

Study on Impingement Damage Characteristics of Liquid Jet on Flat Plate

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Abstract. A study has been made of the deformation of solids which are produced by the impact of a liquid jet on the surface of the solid. Simulations were conducted to investigate the damage characteristics and the effect of impact velocity and jet length. It is found that impact velocity has a decisive role in the destruction and jet length has little effect on the structural damage.

1. Introduction

As is well known, the high-velocity collision of a liquid mass on a solid material generates extremely short high-pressure transients which cause serious damage to the surface and interior of the material [1-3]. A high-speed liquid jet is also produced within bubbles when they collapse asymmetrically. Many researchers have already observed the creation of high-speed liquid microjets in the final stage of the bubble collapse [4, 5]. The problem of high-speed liquid jet impact is of significance in a wide range of technology concerned with rain erosion, cavitation, turbine-blade erosion and jet cutting techniques, etc. However, there remain unexplained and poorly understood phenomena associated with liquid-jet impact and the resulting damage processes.

This paper describes a simulation study of the deformation of solid surfaces under the impact of a high-speed liquid jet. A liquid jet of about 0.5m in diameter traveling at velocities of about 100m/s~200m/s in air was impacted onto the surface of steel plate. By studying different jet parameters such as impact velocity and jet size, the characteristic deformation patterns are analyzed.

2. The simulation model

2.1. Jet impact model

In this section, the bubble jet is equivalent to the water column. The model for jet impinging on a flat plate is established by HYPERMESH software, and the impact process is calculated with the aid of the Fluid-Solid Coupling Algorithm in LS-DYNA software. The bubble jet is approximated as a cylinder in the simulation process as shown in Fig. 1, in which L represents the length of the bubble jet and D represents the diameter of the cylinder.



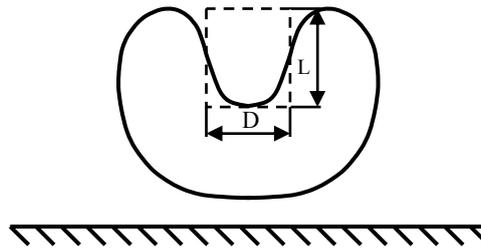


Figure 1. Bubble jet equivalent diagram.

2.2. Validation with the simulation model

The pressure over the wall after the liquid jet impacting is based on the analysis of water hammer theory. The jet is a moving column with a velocity of V_j . When its movement is blocked by the wall, the strong impact makes the jet head produce a high pressure. Considering that the fluid is compressible, Huang&Hammitt [6] gave a simplified formula for calculating the maximum pressure after water column impacting:

$$P = \rho c V \tag{1}$$

Where P is the water hammer pressure, ρ the density of the undisturbed liquid, c the sound velocity in the liquid and V the velocity of the column. Bubble jet impact load [7] can be expressed as:

$$p = \begin{cases} \rho c V - \frac{\rho c V - 0.5 \rho V^2}{t_m} t, & 0 \leq t \leq t_m \\ 0.5 \rho V^2, & t_m < t \leq t_{total} \end{cases} \tag{2}$$

Where t_m is the time when the shock pressure falls to the surrounding pressure, which is approximately equal to $D/(2c)$, and D is the diameter of the jet. The time of the jet impact on the structure is:

$$t_{total} = L/V \tag{3}$$

Water column with a diameter of 3mm at a speed of 570m/s impacting on the rigid plate is simulated. The impact pressure-time curve for a jet striking the plate is recorded in Fig. 2. The impact pressure on the plate center rises to a peak value (9.39×10^8 Pa) within $1 \mu s$ and then falls rapidly within $3 \mu s$ to a steady value. The peak value is slightly larger than 8.55×10^8 Pa calculated by equation (1). After jet impacted the plate, jet flows sideways and sparse waves are generated in the jet. Therefore, the pressure on the wall drops rapidly to a stable value of $0.5 \rho V^2$. By comparing the calculated value with the theoretical value, the agreement between the two values is good.

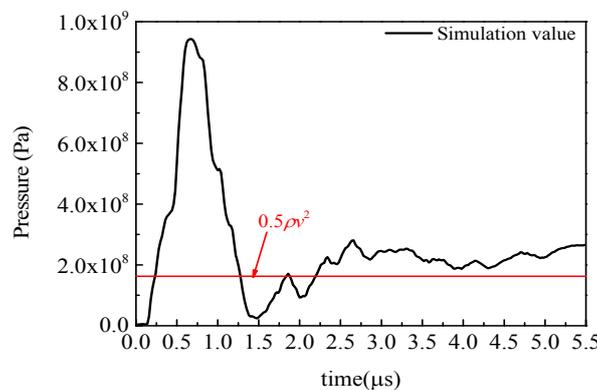


Figure 2. The impact pressure-time curve for the impact of a water jet on a steel target.

3. Results and Discussion

In order to explore the damage effect of jet velocity and length on the structure, simulations were carried out according to the conditions listed in table 1. The velocity of underwater explosion bubble jet is about the order of magnitude of 10^2m/s [8]. Therefore, this section selects conditions with jet impact velocity of 100m/s, 150m/s and 200m/s respectively. According to the calculations below, cracks of different size occur over the circular plate center.

Table 1. Model parameters.

Condition	Jet parameters			Plate parameters	
	Impact velocity $V_j(\text{m/s})$	Length $L(\text{m})$	Radius $r(\text{m})$	Radius $R(\text{m})$	Thickness (m)
I-1	100	0.5	0.25	1	0.01
I-2	150				
I-3	200				
II-1	200	0.10			
II-2		0.15			
II-3		0.20			

Fig. 3 illustrates the deformation of circular plates at impact velocity of 100m/s, 150m/s and 200m/s respectively. It shows that the larger the impact velocity, the more the deformation range and deflection of the plate. The main feature of the failure pattern is the cross crack. The damage area increases rapidly as the velocity is increased. Fig. 4 illustrates the strain distribution of condition I-1~condition I-3 at $980\mu\text{s}$ after the jet impinged on the circular plate. Cross fractures occur where tensions exceed the breaking strength of the solid, indicating that the load strength of the jet impact is very high, and the cracks keep propagating along the direction of the cross.

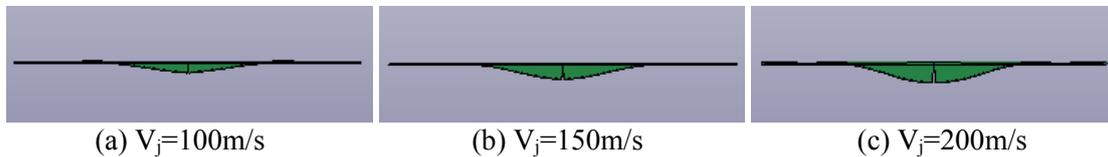


Figure 3. The deformation diagrams of conditions with different jet velocities.

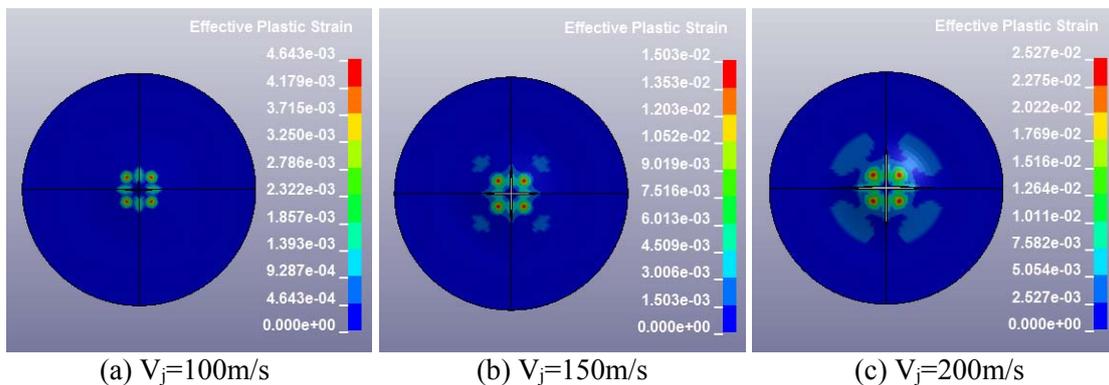


Figure 4. Plate strain cloud diagrams of conditions with different jet velocities.

Fig. 5 (a) illustrates the velocity variation of conditions with different jet velocities along the initial normal direction. The impact energy carried by jet increases with the impact velocity of the liquid jet. Thus the plate obtains more kinetic energy from the jet and the velocity of the plate center is larger. As the energy obtained increased with time, the impact stress exceeded the fracture limit of the material.

The center of the plate broke into four segments and continued to move at a high speed together with the jet under the inertia effect.

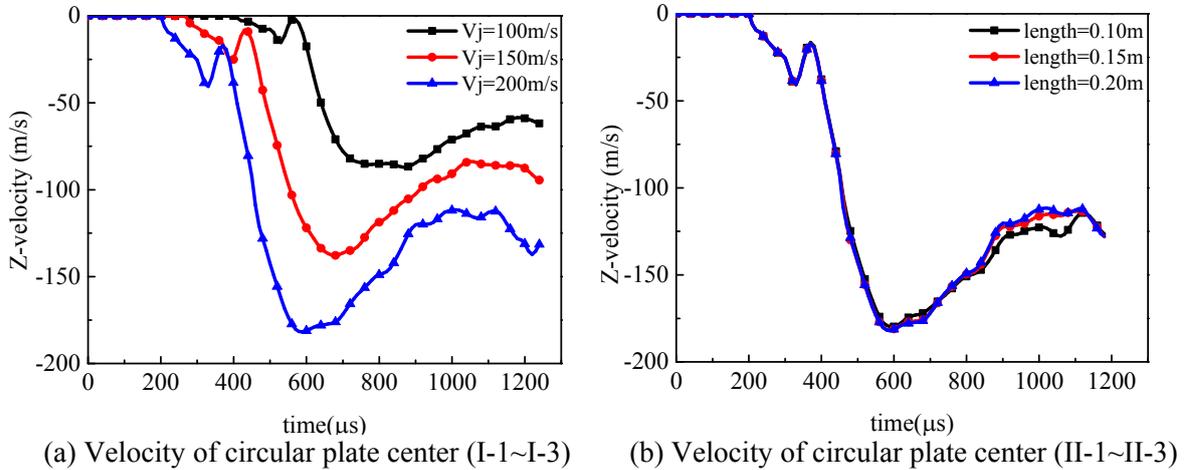


Figure 5. Velocity-time curve for different impact velocities and jet length.

As for the influence of jet length, the circular plate deformation diagrams of condition II-1~condition II-3 is shown in Fig. 6 and the strain cloud diagrams at 950 μ s after the jet impinged on the circular plate is shown in Fig. 7. Cross cracks occur in all three conditions. The center deflection of the three conditions is 10.98cm, 10.87cm and 10.8cm respectively. The size of the cross crack and the center deflection of three conditions due to the impact of water jet don't appear to be much different from one another. However, it can be seen in Fig. 5 (b) that the center velocity of the circular plate of three conditions is slightly different after 870 μ s. Therefore, the smaller the center velocity of the plate shown in Fig. 5 (b), the smaller the maximum strain in the strain cloud diagram. All in all, they have a similar level of damage.

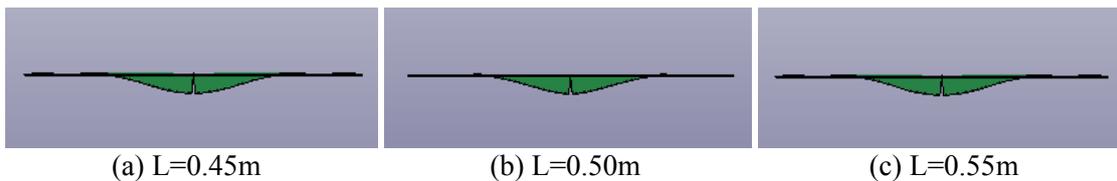


Figure 6. Plate deformation diagrams of conditions with different jet lengths.

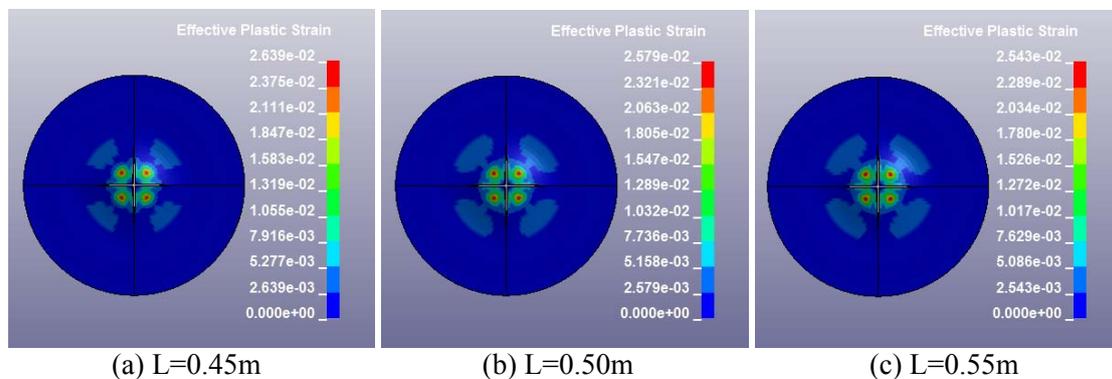


Figure 7. Plate strain cloud diagrams of conditions with different jet lengths.

4. Conclusion

Liquid jets with impact velocities about 10^2m/s were impacted on the surface of a flat plate. The simulation evidence has been given and the results obtained are summarised below.

Impact velocity has a decisive role in the destruction. With the increase of jet velocity, the area and extent of plate deformation is increasing rapidly. Jet length has little effect on the structure damage. The failure pattern is basically the same, which reflects the extremely strong locality of the jet impact.

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