Design And Implementation Of Water Jet Device

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Received: December 20, 2023; Accepted: April 24, 2024

In recent years, terrorist attacks have spread frequently. Whether it is an organized strategic attack or a personal suicide attack, it has seriously affected the safety of people. The easy way of terrorist attacks is to make a bomb, like steel pipe bombs or gas barrel bombs, which were easy to produce. Generally, there is no difference between the pipe bomb and the normal steel pipe by exterior. Hence, the civilian hard to distinguish between them, and the potential hazard could happen. The general method to deal with the steel pipe bombs is to use high pressure water cannons to render them ineffective. However, if the canon didn't combine the metal projectiles within, it is hard to penetrate the structure. In this study, we use the shaped charge concept of anti-tank warhead to design a water disruptor device. This device contains few explosive, water and simple shell. When initiated the explosive, high speed water jet was formed and penetrated the steel pipe bomb. Then, the forensic investigators can execute further investigate. The field test results showed that the 0.38 cm thickness steel pipe with ammonium nitrate inside was fractured by water jet and generate a large hole in size of 8.3 cm×1.1 cm. This large hole not only destroyed the bomb but also provide inside view of the bomb for further inspection. The experimental results also indicated that the numerical model in this research is useful and efficient can be further developed for related disruptor device.

Keywords: Steel pipe bomb; Water jet device; Shaped charge; Numerical simulation; LS-DYNA

http://dx.doi.org/10.6180/jase.202504_28(4).0002

1. Introduction

In recent years, terrorist attacks have been frequent, causing serious harm to innocent people through organized strategic attacks or individual suicide attacks, creating panic in countries around the world. With the rapid development of internet technology, terrorists can easily obtain the information about the manufacture of explosive materials, integrated with easy access to raw materials and low manufacturing difficulty, radical extremists are eager to imitate and use improvised explosive devices (IED), also known as homemade bombs, for attacks.

The most common technique used in terrorist attacks was IED devices, including steel pipe bombs, gas cylinder bombs, pressure cooker bombs, and car bombs. Among them, steel pipe bombs have the lowest manufacturing difficulty and their appearance is no different from that of ordinary metal pipes, making it difficult to detect them. A typical steel pipe bomb as shown in Fig. 1.

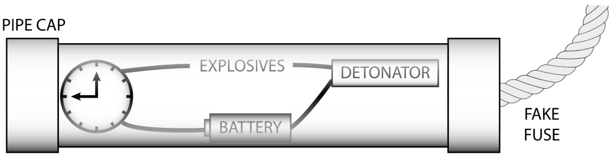


Fig. 1. Schematic diagram of a typical steel pipe bomb.

The general method for dealing with explosive device was moving them to a safety location for disposal or destroying them on site by cutting the detonation chain. However, during the transfer process, it may trigger the detonation mechanism, causing harm to people. Cutting the detonation chain may also fail due to the multiple detonation mechanisms of the device, so one of the methods for handling is to destroy the explosive on the spot. The basic component of an explosive device consists of powder, casing, and detonation mechanism. By opening a large hole in the explosive casing or destroying the detonation mechanism, explosive damage can be reduced or its detonation chain can be destroyed [1–3]. The design concept of water jet devices is to use a small amount of gunpowder to accelerate water to destroy explosives. Because water has the characteristics of fast energy dissipation and the ability to absorb explosive heat, it can reduce additional damage and retain evidence, increasing the probability of successful follow-up evidence collection. The two common types of water jet devices as known were water cannon and bottle-type devices. The water cannon device uses machine gun bullet gunpowder as the propulsive force of water, making a hole damage of target, but it is not easy to penetrate a thick casing unless metal projectile added. The other type is the bottle-type device [4], which uses explosives or detonation cord as the propulsive force of water to create large-area but not aimable damage (such as luggage bombs). In response to the characteristics of these two types of equipment, the US Sandia National Laboratories designed a dual-effect water jet device [5]. It can produce a focused energy water jet that can cut through steel plates and a large-area damage water hammer. This effort is based on the principle of shaped charges, and the original concept of Sandia National Laboratories came from the US Navy's patent application for a conical-shaped charge structure using "water" in 1990, called "Shaped charge with explosively driven liquid follow-through" (US Patent 4,955,939A) [6].

This study employed the concept of shaped charges device to develop a water jet cutting device for the purpose to penetrate the steel pipe bombs. After jet penetration, not only destroying the detonation mechanisms but also provide a clear view for bomb squad. The forensic experts can further gather evidence after water jet penetrated the pipe. In this paper, we used LS-DYNA program to design the water jet device and analyze the penetration performance of the water jet breaking through steel pipes. Based on the numerical results, experimental verification was carried out, which showed that the water jet device designed in this study can effectively destroy steel pipe bombs, reduce damage to surrounding structures, and increase the safety of bomb disposal staff.

2. Design of water jet device

The water jet device in this study was developed in response to the need for counter-terrorism required, and aims to create a water jet to destroying steel pipe bombs. The preliminary design of this device is based on the concept of shaped charge warhead in military weapons. The metal liner of the shaped charge was replaced with a certain volume of water, and a small amount of explosive were used to generate an appropriate shock wave, which compresses the water chamber into a high-speed water jet for destroying cylindrical steel pipes. In addition, the water jet not only reduced the danger of pipe bombs, but also be used for identify the filling materials of pipe bombs.

Shaped charge technology has been widely used in anti-armor warheads, fortified structures attack, and anti-ship missile warheads since World War II. Generally, the shaped charge mechanism consists of components such as an initiator, explosive, case, and liner, as shown in Fig. 2. The liner is conical in shape and is made of a ductile metal such as copper or iron, while the case is mostly made of steel. The explosive portion may include Composition-B, Octol, Research Department explosive (RDX), Cyclotetramethylene tetranitramine (HMX), and so on. When the initiator detonates the explosive, a powerful shock wave is rapidly transmitted forward to impact the liner. At this time, the center of the liner will start to move forward quickly and form a high-speed metal jet called "jet tip" on the central axis. After few microseconds, the shock wave continues to push the liner towards the central axis, eventually forming a low-speed jet called "slug" and finally flying towards the target [7].

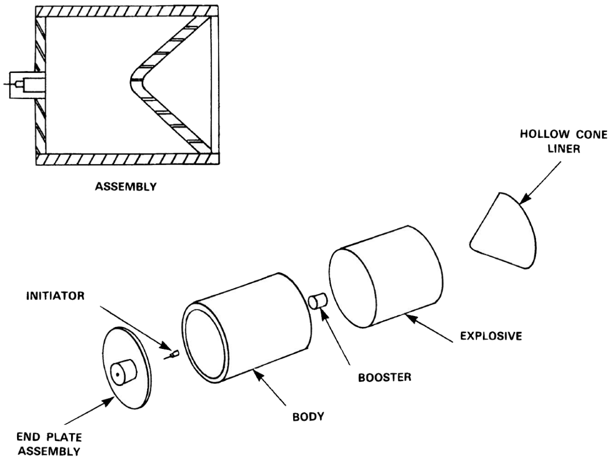


Fig. 2. Shaped charge mechanism [8].

The high-speed metal jet generated by the shaped charge has a relatively small mass, about 15-20% of the liner weight. Generally, the velocity of the jet tip is about 7000 m/s to 10000 m/s, and the slug is about 1000 m/s to 2000 m/s. The jet has good penetration ability against the target, but it causes a relatively small area of damage. Owing to the velocity gradient between the tip and the slug, the jet breaks are prone to occur which will reduce the penetration performance.

The configuration of the metal jet which produced by a conical shaped charge has long and narrow shape, it may not be suitable for inspecting the interior filling material of a steel pipe bomb as the resulting breach is relatively small. This could make it difficult for bomb squad to gather sufficient information to perform subsequent destruction. Therefore, it is necessary to transform the conical shape into a linear shape, which is also known as a linear shaped charge. A typical linear shaped charge [9] produces a flat, sheet-like jet that can cause greater damage to a steel pipe bomb, making it easier to inspect the interior structure and filling material.

This study is based on the concept of linear shaped charge to develop a water jet device. The main components include 1. detonator holder, 2. explosive chamber, 3. water, and 4. water chamber casing, as shown in Fig. 3. The explosive chamber is filled with C-4 explosive, and the detonator holder is loaded with an 8# detonator, which initiates the explosive using a central single-point initiation method. The high temperature and high pressure expanding gas will drive the water chamber, squeezing the casing and water into a high-speed flat jet, which will be used to destroy the steel pipe.

3. Methodology

Generally, there are three numerical methods for structural analysis: finite element method (FEM), finite difference method (FDM), and discrete element method (DEM). Currently the analysis program includes ANSYS, LS-DYNA, EDEM, etc.

For high energy, high strain rate and short duration time problems, such as high velocity impact and blast loading, the structure take place non-linear displacement. It is suitable use FDM program to prevent the numerical converge problems. The LS-DYNA program is a FDM program which is a non-linear explicit dynamics code, implicit integration method were also include for lower strain rate problem. Three solver provided by LS-DYNA: Lagrangian, Eulerian and ALE(Arbitrary Lagrangian-Eulerian), it is suitable for analyzing high velocity impact, armor penetration, and blast loading with large impact energy and short duration time problem. LS-DYNA also provides a database of more than 140 material models and equations of state, making it quite diverse and practical in dealing with numerical simulations of penetration, explosions, and other issues. Therefore, in this study we used LS-DYNA program to simulate the water jet penetration of steel pipes.

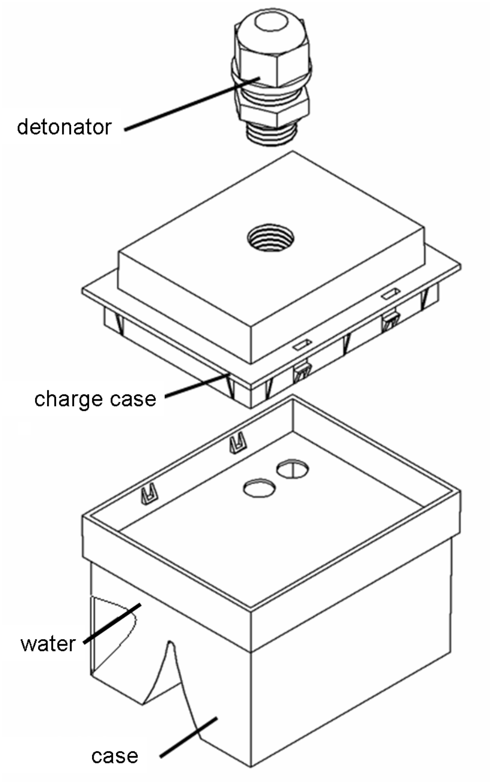


Fig. 3. Water jet device and component.

The different numerical solvers and their properties provided by LS-DYNA are as follows [10]: In the Lagrange solver, the numerical mesh move and distorts with the physical material. This formulation is widely used because of its advantages, such as being able to track accurately and efficiently material interfaces and incorporate complex material models. This formulation is generally used to represent solid materials. However, if the mesh undergoes significant deformation, it may result in problems such as negative volume or excessively small time steps, which will lead numerical errors even terminate the program. In such cases, numerical methods such as mesh re-zoning and element erosion should be employed to correct the problem and perform the following process.

In the Eulerian solver, the numerical mesh is fixed in space and the physical material flow through the mesh. This formulation is generally used to represent fluids and gases. When the mesh moves or deforms, only the material move into the mesh. Its advantages include a non-deforming mesh, which allows for the study of fluid flow problems. However, it requires a larger flow space and extra computational time to accurately understand the flow and cover the physical space described by the problem.

The disadvantage of Lagrangian solver such as mesh distortion or negative volume errors can be overcome by ALE solver. In the ALE method, one or several Lagrangian time steps were calculated first, which the elements will deform with the material flow. Then an ALE time step is performed while keeping the deformed object boundary conditions, and re-mesh the interior elements (called smooth step), then the element variables (such as density, energy, and stress tensors) and node velocities from the deformed mesh were mapped to the re-meshed element (called advection step) for continued computation.

Table 1. Numerical parameters of explosive.

		Explosive [11]
material model	Material	C4
	density ρ $\left(\mathrm{g/cm^3}\right)$	1.6
	detonation speed D$(\mathrm{cm}/\mu\mathrm{s})$	0.8193
equation of state	P P(Mbar)	0.28
	$\mathrm{A}^{(\mathrm{Mbar})}$	6.0977
	$\mathrm{B}^{(\mathrm{Mbar})}$	0.1295
	R_1	4.5
	R_2	1.4
	ω	0.25
	E_0(Mbar)	0.09

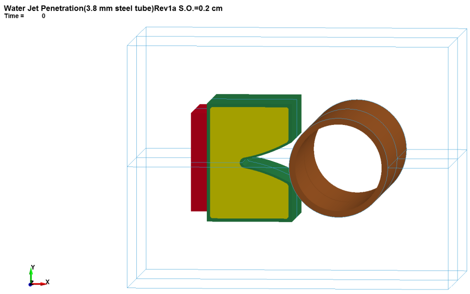


Fig. 4. Water jet device finite element model.

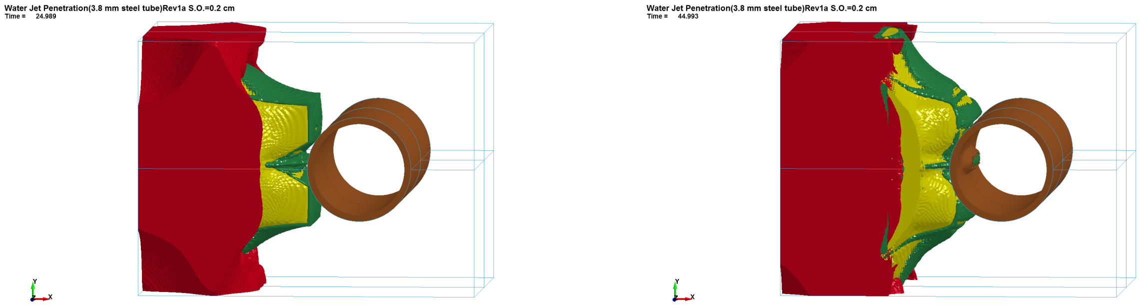
For blast impact structures problems, there were three numerical methods available in LS-DYNA program. The first method is the Fluid-Structure Interaction (FSI) method. The structures were model in Lagrangian mesh, while an Eulerian mesh were used to create the fluid model. The Lagrangian mesh can overlap with the Eulerian mesh, and then both stress coupling calculations can be performed. When using this method, the Lagrangian mesh is used to describe the phenomenon of solid damage, and failure criteria must be employed for the mesh to avoid numerical errors such as mesh distortion or negative volume. Since the failure criteria were related to the mesh size and must be compared with experimental results to determine. Hence, the correct numerical results cannot be obtained before the experiment.

The second method is to use Eulerian meshes to calculate both fluid and solid models. When using this method, an air model must be constructed that covers all other object models, and the air mesh cannot overlap with other model meshes. The interface between air and fluid model must share the same nodes of the element. Using this method, large deformations or numerical errors such as negative volume in the Lagrangian mesh can be avoided. During the calculation, all meshes were fixed, only material of each model flow within the fixed mesh. If there are a large number of objects (parts) in the model, it is difficult to analyze the range of object damage when using Eulerian mesh because the profile boundaries of each material deformation cannot be clearly described within a single mesh.

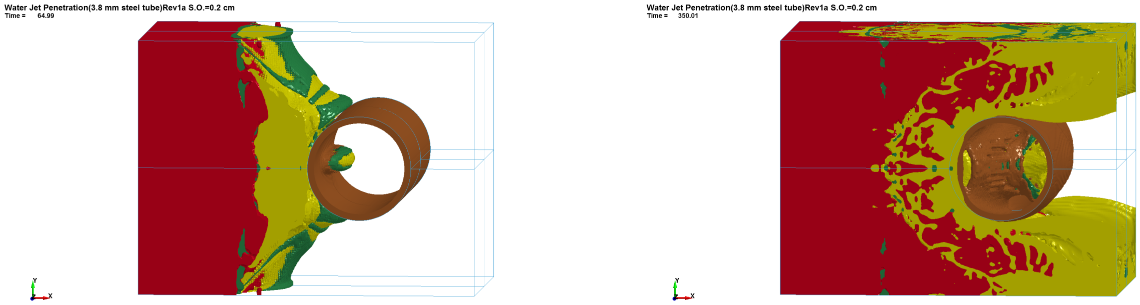
The third method is to use ALE meshes both in fluid and solid models. The method of the ALE mesh is the same as that of the Eulerian mesh, and a single mesh can contain multiple material that exist simultaneously. The profile boundaries of each material deformation can be clearly distributed according to the element force applied to each objects. This method is called the Multi-material ALE (MMALE) method, and the mesh created is called the MMALE mesh. In addition, the MMALE mesh can also perform mesh translation and rotation [13], In this paper, an MMALE mesh is used to establish a numerical model of a water jet device. In addition the MMALE method not only to avoiding the numerical errors that occur in the Lagrangian mesh, but also can improve the shortcomings of the Eulerian mesh description method in multi-material analysis. Since the numerical model contains with explosives, when using the MMALE mesh, after the explosives were detonated, shock wave propagation, water case compression and dispersion, water jet forming, and the contour shape of the target being penetrated all can be displayed in the air mesh.

3.1. Numerical Model

In this study, simulation analysis of water jet cutting of steel pipes was conducted based on the readily available steel pipe sizes in the market. The explosive chamber was loaded with approximately 77 g C4 explosive, with a length of 6.0 cm, width of 8.0 cm, and thickness of 1.0 cm. Single point detonator was used. The case of water was made by Acrylonitrile Butadiene Styrene (ABS) material with a thickness of 0.2 cm. The water chamber was filled with

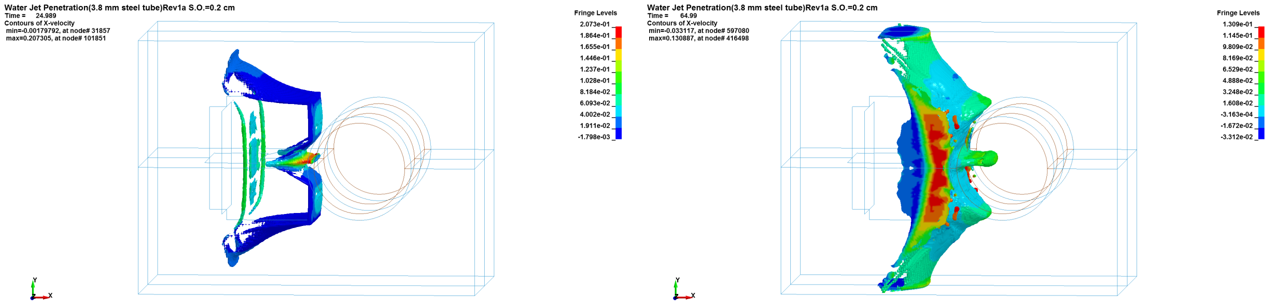


(a) 25 µs. **(b)** 45 µs.



(c) 65 µs. **(d)** 350 µs

Fig. 5. Numerical results of water jet (steel pipe thickness 0.38cm).



(a) Outer shell jet (25 µs). **(b)** Water jet (45 µs).

Fig. 6. Velocity contour of the jet.

Table 2. Numerical parameters of casing and steel pipe.

		Casing [12]	Steel pipe [12]
material model	Material	ABS	304 stainless steel
	density ρ (g/cm^3)	1.06	7.9
	Young's modulus E(Mbar)	0.024	1.93
	Poisson's ratio v	0.35	0.29
	Yield strength σ_y(Mbar)	4.5e − 4	2.15e − 3

Table 3. Numerical parameters of air.

		Air [12]
equation of state	density ρ (g/cm^3)	1.3e − 3
	C_4	0.4
	C_5	0.4
	E_0(Mbar)	2.50e − 6

Table 4. Numerical parameters of water.

		Water [12]
equation of state	density ρ (g/cm^3)	1.0
	$C(cm/\mu s)$	0.148
	S_1	2.56
	S_2	-1.986
	S_3	0
	γ_0	0.5

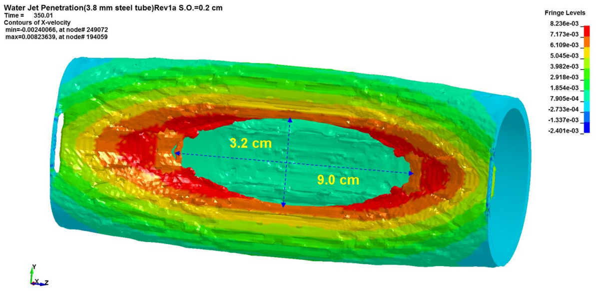


Fig. 7. Steel pipe notch contour (pipe thickness 0.38 cm).

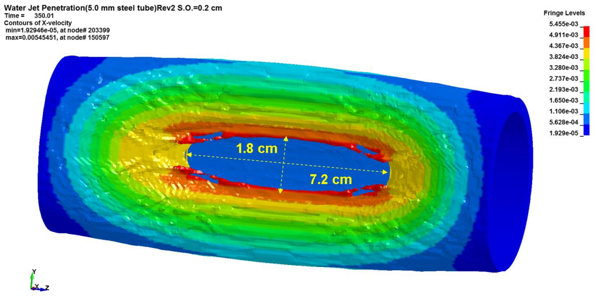


Fig. 8. Steel pipe notch contour (pipe thickness 0.5cm).

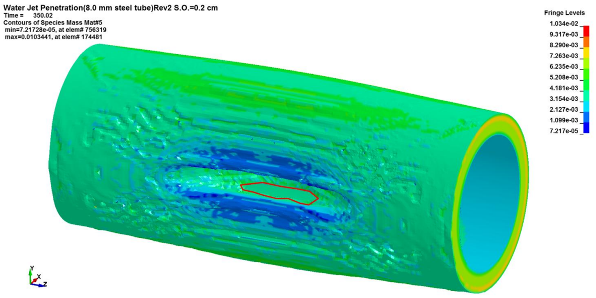


Fig. 9. Steel pipe notch contour (pipe thickness 0.8 cm).

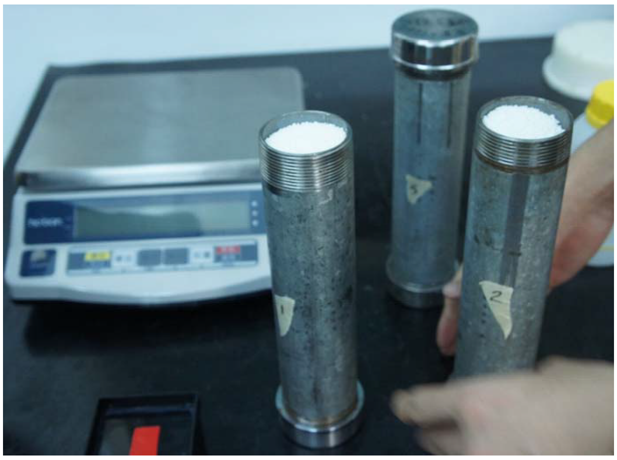


Fig. 10. Steel pipe filled with ammonium nitrate.

approximately 240 g of water. The target object was a cylindrical steel pipe with a length of 26 cm, an outer diameter of 6.0 cm, and a thickness of 0.38 cm, placed in front of the water jet device.

Since the numerical model has a symmetric characteristic, a 1/4 model can be constructed, and constraints can be applied on the symmetric plane to reduce the number of mesh and computational time. Additionally, the water jet in the lateral direction does not contribute to the penetration performance of the cylindrical steel pipe in front. Therefore, the model of water chamber was not created in the lateral direction. In this manner, the formation process of jet also can be observed. The finite element model of the water jet device as shown in Fig. 4. The air model has 20 cm long and 16.4 cm wide. Since the air model is not infinitely large, non-reflecting boundary conditions of stress wave need to be applied to the outer surface of the air model to meet actual physical phenomena. In addition, base on the

(a) Top view. **(b)** Front view.

Fig. 11. Experimental layout of water jetting device.

Fig. 12. Measure ammonium nitrate inside steel pipe using Raman Spectrometer.

dimension of the water jet device, the length of the cylindrical steel pipe target was model 16.4 cm only to save the computational time. The model includes five objects: air, explosive, water, shell, and target, with an average element size of 1.0 mm. The entire model has a total of 1,230,082 hexahedral elements. After the explosive is initiated, the computational time was 350 µs, with data being collected every 5 µs.

3.2. Material Model and Equation of State

Considering the enormous heat energy and shock wave effects generated after detonation, the material behavior has entered the range of plastic deformation. Therefore, a material model consist elastic-plastic behavior were needed. Under high pressure loading, an Equation of State (EOS) was required to describe the relationship between pressure and volume. In this study we use the following Equation of State and describe as below:

Fig. 13. Experimental results :from top to bottom empty steel pipe, two steel pipes filled with ammonium nitrate.

(1) Linear Polynomial Equation of State:

$$P = C_0 + C_1\mu + C_2\mu^2 + C_3\mu^3 + \left(C_4 + C_5\mu + C_6\mu^2\right) E \quad (1)$$

(2) Gruneisen Equation of State

$$P = \frac{\rho_0 C^2 \mu \left[1 + \left(1 - \frac{\gamma_0}{2}\right)\mu - \frac{a}{2}\mu^2\right]}{\left[1 - \left(S_1 - 1\right)\mu - S_2\frac{\mu^2}{\mu+1} - S_3\frac{\mu^3}{(\mu+1)^2}\right]^2} + \left(\gamma_0 + a\mu\right) E \quad (2)$$

In Eq. (2), E is the initial specific internal energy, C is the intercept of the $U_s - U_p$ curve at shock velocity Us and particle velocity U_p, S_1, S_2, and S_3 are parameters of the $U_s - U_p$ curve, γ_0 is the Gruneisen constant, a is the first-order volume correction of $\gamma_0, \mu = (\rho'/\rho_0) - 1$ is the compressibility, and ρ_0 is the initial density of the material. For high pressure condition, the equation of state can be described by the $\mathrm{U_s - U_p}$ relationship, as shown in Eq. (3).

$$U_s = C_0 + S_1 U_p + S_2 \left(\frac{U_p}{U_s}\right) U_p + S_3 \left(\frac{U_p}{U_s}\right)^2 U_p \quad (3)$$

$$U_s = C_0 + S_1 U_p \quad (4)$$

$$C_0 = \sqrt{\frac{K}{\rho_0}} \quad (5)$$

In Eq. (3), C_0 is the bulk sound speed of the material, and S_1, S_2, and S_3 are parameters of the $\mathrm{U_s - U_p}$ curve. If the higher-order terms in the Eq. (3) were difficult to receive, it can be simplified to a first-order only, as shown in Eq. (4), and the bulk sound speed $\mathrm{C_0}$ of the material can be obtain by Eq. (5), where K and ρ_0 are the bulk modulus and initial density of the material, respectively.

(3) JWL Equation of State

The JWL equation of state was developed by Jones, Wilkens, and Lee to describe the characteristics of high explosive detonation, including detonation velocity, the heat of detonation of explosion, and phase transition. It is a mathematical equation used to estimate the explosive pressure generated after detonation, as shown in Eq. (6):

$$P = A\left(1 - \frac{\omega}{R_1 V}\right) e^{-R_1 V} + B\left(1 - \frac{\omega}{R_2 V}\right) e^{-R_2 V} + \frac{\omega E}{V} \quad (6)$$

In Eq. (6), P is the pressure, $\mathrm{A, B, R_1, R_2}$, and ω are constants that depend on the explosive, V is the relative volume, and E is the explosive energy per unit volume.

In this study, the numerical model includes five parts: explosive, air, water, casing, and steel pipe. Base on the LS-DYNA Manual, the explosive adopt the MAT_HIGH_EXPLOSIVE_BURN material model and the JWL EOS. Air model employ the MAT_NULL material model and the LINEAR_POLYNOMIAL EOS. Water utilize the MAT_NULL material model and the GRUNEISEN EOS. Casing and steel pipe use the MAT_PLASTIC_KINEMATIC material model for plastic deformation analysis. The material model and EOS parameters for each part as shown in Tables 1 and 4.

4. Result and discussion

4.1. Numerical Simulation

Based on the requirements of police bomb disposal unit, a water jet device was designed with minimum amount of explosives to penetrate a steel pipe with a thickness at least of 0.38 cm. After ignited the device, the steel pipe must be breakage, and the explosives in the pipe cannot be detonated in order to prevent harm to the surrounding people. A notch of pipe was created in order to provide a clear view for bomb squad and forensic experts for further investigation.

(1) Thickness of steel pipe 0.38 cm.

The numerical analysis results indicated that the water jet device first contact the outer surface of pipe and forms an arc-shaped jet at 25 µs after detonation. At 45 µs, the steel pipe begins to be punctured by the jet. At 65 µs, the initial water jet was formed and starts to penetration the pipe, until 350 µs the water jet penetration the pipe completely, as shown in Fig. 5. The jet velocity contour was illustrated in Fig. 6(a). The numerical results revealed that, the velocity of the outer casing jet is close to 2000 m/s when start contact the pipe, at 65 µs, the water jet begins to penetrate into the steel pipe, with a velocity of about 650 m/s, as shown in Fig. 6(b). When water jet complete penetration the steel pipe, a elliptical notch was found, the dimension of notch were 9.0 cm × 3.2 cm, as shown in Fig. 7.

(2) Thickness of steel pipe 0.5 cm

According simulation results above, the water jet device designed in this study can effectively damage the steel pipe with a thickness of 0.38 cm, producing a nearly 9 cm hole. In order to further analysis the jet penetration performance of current water jet device, the thickness of the steel pipe was increased to 0.5 cm. The cave of the steel pipe with 0.5 cm thickness was close to 7.2 cm × 1.8 cm after water jet penetrated and as shown in Fig. 8.

(3) Thickness of steel pipe 0.8 cm

Previous numerical results revealed that the water jet can complete penetrate the steel pipe with 0.5 cm thickness. In order to find the penetrate limit of current water jet device, the thickness of the steel pipe continue increased to 0.8 cm. Fig. 9 shows the numerical results, indicating that the jet has almost reached its limit in penetrating the steel pipe, only a small notch about 2.8 cm × 0.2 cm was created. Therefore, the penetration limit of water jet device in this study was 0.8 cm thickness of steel pipe.

4.2. Water Jet Penetration Experiment

On the basis of numerical simulation results, the water jet device in this study can penetrate a steel pipe with a thickness of 0.38 cm, producing a hole of about 9.0 cm x 3.2 cm. To verify the accuracy of the numerical model, a water jet penetration experiment was performed.

Three tests has been performed: the first test will use a hollow steel tube as the target, while the second and third tests use steel tubes filled with ammonium nitrate with a purity of 99.5%, which can be mixed with small amounts of other chemicals to become an explosive. Ammonium nitrate is commonly used as a fertilizer and easily obtained, making it a common component in terrorist attacks. The target steel tubes have a length of 26 cm, an outer diameter of 6.0 cm, and a thickness of 0.38 cm, with the weight of ammonium nitrate filling as shown in Table 5. Fig. 10 shows a steel tube filled with ammonium nitrate.

Fig. 14. Detect filled material by Raman Spectrometer.

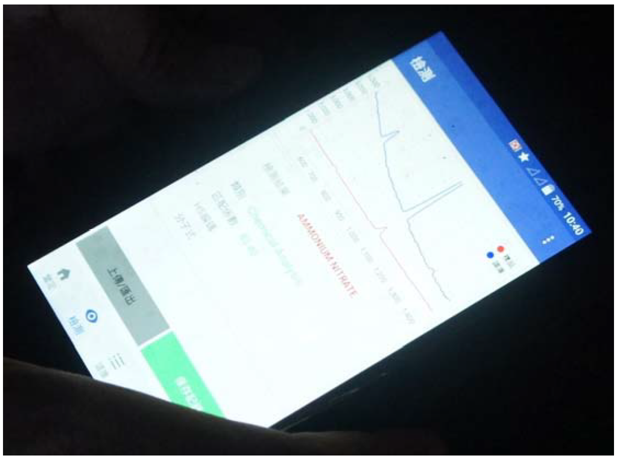


Fig. 15. Ammonium nitrate was successfully measured using the by Raman Spectrometer.

The experimental setup as shown in Fig. 11, target placed on the ground and the water jet device placed on top of the target. A total of three water jet penetration experiments were performed, with two of the targets being steel pipes filled with ammonium nitrate.

To simulate the situation of forensic evidence collection, prior to the experiment, a Raman Spectrometer was used to measure the ammonium nitrate material inside the steel pipe, as shown in Fig. 12, to establish the spectrum data of ammonium nitrate prior test. The Raman spectrometer used in this study was infrared laser with a wavelength of 785 nm. The principle of Raman is to measure the waveform of scattered light. Different substances produce different waveforms due to different molecular structures. After the penetration test, the ammonium nitrate powder inside the damaged steel pipe was successfully measured and confirmed.

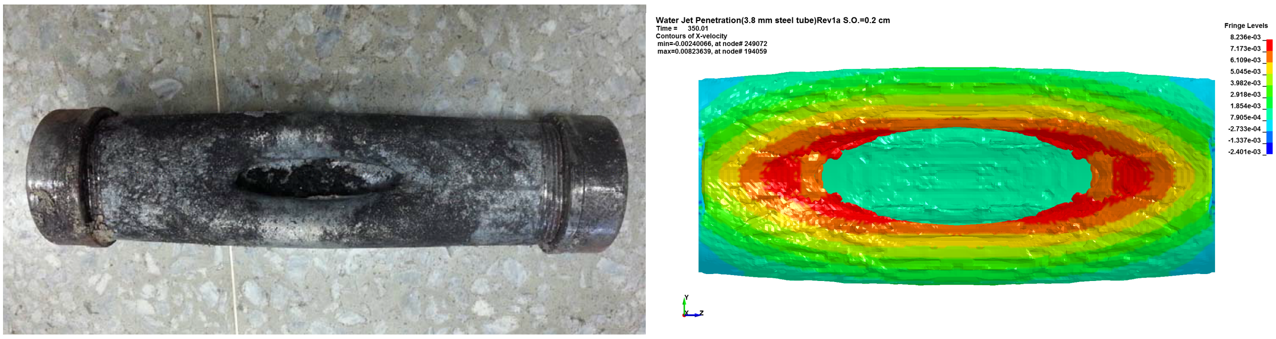
Fig. 16. The steel pipe ruptured by water jet impact (pipe thickness of 0.38cm).

The experimental results were shown in Fig. 13, which includes one hollow steel tube and two steel tubes filled with ammonium nitrate. Fig. 14 shows the powder of ammonium nitrate at the breach point was measured using a Raman spectrometer. The experimental results indicated that the Raman Spectrometer could successfully detect the filled material, as shown in Fig. 15. After the measurement, the water jet device was able to penetrate the 0.38 cm thick hollow steel tube, causing a breach of approximately 9.0 cm × 2.6 cm, as shown in Fig. 16, which is close to the numerical simulation result. Fig. 17 compares the breach shapes of the steel tube, and it can be seen that the numerical results well match with the experimental results, both bring about an elliptical-shaped notch, revealed that the numerical method in this study was correct, which can be used for subsequent analysis.

5. Conclusion

In recent years, terrorist attacks have become more frequent, causing serious harm and casualties to innocent civilians, whether in the form of organized strategic attacks or individual suicide attacks. One of the most common methods of terrorist attacks is the production of pipe bombs, gas cylinder bombs, pressure cooker bombs, and car bombs, among other devices. Among these, the pipe bomb has the lowest production difficulty and can easily pass for ordinary metal components, making it difficult to detect by the public.

In this study, we used the concept of a shaped charge



(a) Experimental results. **(b)** Numerical results.

Fig. 17. Comparison of rupture patterns breach shapes in steel pipes (pipe thickness of 0.38cm).

Table 5. Steel Pipe Weight with Ammonium Nitrate Loading.

	Net weight of steel pipe (g)	Ammonium nitrate weight (g)	Total weight (g)
Steel Pipe (#1)	1691.0	466.0	2157.0
Steel Pipe (#2)	1763.5	473.0	2236.5

warhead used in anti-armor weapons and developed a simple and effective water jet device by using LS-DYNA program. Through experimental verification, we have demonstrated that this device can successfully destroy a cylindrical steel pipe with a thickness of 0.38 cm and filled with ammonium nitrate, producing a8.3 cm x 1.1 cm opening. We have also used a Raman Spectrometer to detect the filling material from the opening, which can provide valuable information for bomb squad and strategy planning. The experimental results have shown that our design can successfully break a hollow steel pipe with a thickness of 0.38 cm, producing an opening of approximately 9.0 cm x 2.6 cm, which is consistent with the numerical simulation results. The proposed methodology is useful and efficient can be further developed for designing the water jet device and other facilities against pipe bomb, gas cylinder bombs and car bombs, ect.

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