World Scientific Research Journal Volume 12 Issue 9, 2026
ISSN: 2472-3703 DOI: 10.6911/WSRJ.202609_12(9).0002

# Analysis and Prospect of Blasting Construction Technology Status Quo

Minghui Zeng, Lintai Wang, Xu Fu*

Institute of Civil Engineering, North China Institute of Aerospace Engineering, Langfang, Hebei, China

*Corresponding author E-mail: fuxu431@163.com

## Abstract

**This study focuses on the current status of mechanization and material application in blasting construction. By systematically reviewing the practical application of blasting mechanization in various engineering fields such as tunnels, roadbed slopes, mines, structural demolition, and underwater projects, it analyzes the equipment application characteristics in the drilling, charging, and initiation stages, and explains the performance and applicable scenarios of materials such as emulsion explosives and mixed explosives. The research reveals the current development status of blasting construction in terms of the popularization of mechanization and material selection, and points out key issues such as the need to improve the intelligence level of equipment and the urgent need to improve the standardization system of materials. It also looks forward to future trends from the dimensions of equipment automation upgrade, environmental-friendly material research and development, and full-process digital control. The research results provide theoretical basis and practical reference for the optimization of blasting construction technology, and contribute to the development of the industry towards efficiency, safety, and greenness.**

## Keywords

**Blasting construction; Mechanization; Emulsified explosives; Mixed-loading explosive vehicle; Electronic detonators.**

## 1. INTRODUCTION

Blasting technology, as an efficient means for excavating rocks and soil, dismantling structures, and extracting resources, plays a crucial role in various construction projects. From the tunneling and roadbed excavation in transportation infrastructure construction, to the efficient mining of mineral resources, and the demolition of old structures in urban renewal projects, the presence of blasting construction is ubiquitous. With the continuous expansion of project scale and the increasing demands for construction efficiency, safety, and environmental protection, the development of mechanization in blasting construction has become the key to driving industry progress.

In the early days, blasting construction mainly relied on manual operations, which was characterized by high labor intensity, low efficiency and high safety risks. With the continuous advancement of technology, various mechanical equipment has gradually been applied to the field of blasting construction, ranging from simple drilling tools to automated mixed explosive vehicles, from traditional initiation devices to highly precise electronic detonators. The mechanization level of blasting construction and the performance of explosives have been greatly improved. Mechanized construction not only increased work efficiency, reduced labor

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202609_12(9).0002

costs, but also significantly enhanced the safety guarantee and controllability of the construction. High-performance blasting explosives provide a guarantee for the optimization of blasting effects, such as emulsion explosives, which have good water resistance and explosion performance and are widely used in various complex environments.

However, although significant progress has been made in the mechanization and materials of blasting construction, there are still many problems in its application across different engineering fields. For instance, in tunnel construction, the compatibility and adaptability of mechanized equipment need to be improved, and manual operation is still relied upon in areas with narrow working spaces; in mining, the safety and cost-effectiveness of explosives still require further optimization. Therefore, conducting in-depth research on the current status of blasting construction mechanization is of great practical significance for solving existing problems and promoting the continuous development of blasting technology.

## 2. TUNNEL ENGINEERING

At present, our country is in a period of extensive construction of railways and highways. However, 75% of our territory consists of hills and mountains, so the construction of tunnels is inevitable. As the volume and scale of tunnel excavation continue to increase year by year, more construction workers are considering issues of safety, efficiency and economy [1-2].

### 2.1. Mechanization of Drilling Operations

The blasting holes are special types of drill holes that are drilled in rock and soil using drilling machines or rock drills and then filled with explosives for blasting, or they are used as artificial seismic sources in seismic exploration. According to the depth of the blast holes, they can be classified into shallow blasting (hole depth≤5 m) and deep blasting (hole depth>5 m). Among them, smooth blasting and pre-split blasting require the blast holes to be arranged along the designed contour line to control the blasting effect. Blasting holes are widely used in earthwork projects, mineral extraction, and seismic exploration. Through the sound waves generated by artificial blasting underground and their different wave speeds when reflected or refracted towards the ground, it helps to determine the geological structure and the layer positions of oil and gas reservoirs. During the construction process, technical specifications such as controlling the depth of explosive loading and filling with wooden tools must be strictly followed. Workers must hold relevant certificates and implement safety warning measures.

In tunnel blasting construction, the drilling operation is one of the key steps. In the early stage, when the mechanization level was not high, the drilling operation mainly relied on manual use of hand drills (as shown in Figure 1). C.D. Zhao et al. [3] found during project operations that although the hand drill's horizontal smooth blasting method could meet the current standards for the flatness of the rock surface, it was greatly affected by human factors. If a drilling machine that is easy to operate, has a measurement function, can be close to the rock surface, and has a hole depth of 8 - 10 meters could be developed, it could reduce the human influence on the drilling accuracy, reduce overburden and underburden, and improve the excavation technology of the rock protection layer. Y.L. Li et al. [4] summarized from engineering practice that although the hand drill can meet the requirements, the method is still very traditional and has low accuracy and low efficiency.

To improve the efficiency and quality of drilling, mechanized drilling equipment has been widely adopted. The rock drilling trolley is a typical representative. Its main advantages include: fast drilling speed, good hole formation quality, high mechanization level, and significant increase in production ratio; however, it also has disadvantages: high cost, high requirements for operators, and difficulties in technical support [5]. There are various types of rock drilling trolleys, and they can be classified according to the number of drilling arms as single-arm,

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202609_12(9).0002

double-arm, triple-arm, and multi-arm drilling trolleys. Taking the triple-arm rock drilling trolley (see Figure 2) as an example, C. Ren [6] introduced that the fully computerized triple-arm rock drilling trolley, when used in railway tunnel construction, can increase the construction progress by approximately 1 times compared to traditional pneumatic rock drills, better control over over-excavation and under-excavation, improve hole formation quality, and has significant advantages in terms of safety, environmental protection, and applicability. When applying it, it is necessary to reasonably design the construction process and do a good job in quality control. K.M. Huang [7] proposed that the triple-arm rock drilling trolley has the advantages of fast hole formation, good shape, reducing tunnel construction safety risks, environmental protection, reducing construction costs, and improving construction efficiency. However, it also has problems such as difficult equipment maintenance and high requirements for operating techniques. The following is a part of the parameters of the ZYS113 type triple-arm rock drilling trolley (see Table 1).

Figure 1. Hand Drill


**Figure 2.** ZYS113 Type Three-Arm Rock Drilling Truck

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202609_12(9).0002

**Table 1.** Partial Parameters of ZYS113 Type Three-Arm Rock Drilling Truck

| Project | Organization | ZYS113 |
|---|---|---|
| **Overall weight of the machine** | kg | 52000 |
| **Overall machine size** | mm | 17600×2900×3600 |
| **Total power of electricity** | kW | 325 |
| **Maximum working section: Width × Height** | m | 16.6×11.3 |
| **Minimum working section: Width × Height** | m | 6×6 |
| **Maximum climbing ability** | % | 25 |
| **Minimum turning radius** | m | 12.4 |
| **Drilling machine model** | / | 3XHC110 |
| **Drilling machine power** | kW | 27 |
| **Maximum drilling depth** | m | 5.25 |
| **Drilling diameter** | mm | φ41~φ140 |
| **Cable length** | m | 100 |
| **Length of the water pipe** | m | 100 |
| **Initial water pressure** | bar | 1-10 |

## 2.2. Mechanization of Loading Operations and Explosives

For a long time, tunnel blasting operations have mainly relied on manual methods, which have many drawbacks. The manual blasting process is inefficient, with skilled workers being able to load only 20 to 30 kilograms of explosives per hour. Moreover, the operation is conducted in a narrow space, resulting in extremely high labor intensity. Additionally, the consistency of manual blasting is poor, making it difficult to ensure the uniformity and compactness of the explosives, which affects the blasting effect, increases compliance and management costs, and poses significant safety risks.

To address these issues, mechanized loading systems gradually emerged. The application of mixed explosive vehicles in tunnel loading operations has become a development trend. Mixed explosive vehicles integrate functions such as raw material transportation, on-site mixing, and hole loading. Currently, common types include emulsion explosive vehicles, such as the BCRH series on-site mixed emulsion explosive vehicles (see Figure 3). Y.J. Feng. [8] pointed out that on-site mixed explosive vehicles, as a high-end integrated mechanical and electronic equipment that integrates raw material transportation, explosive mixing, and hole filling functions, have significant advantages over manual filling and packaging of explosives, such as superior safety performance, high operational efficiency, low economic cost, and environmental friendliness, and have been widely used in large-scale open-pit blasting projects. With the continuous development and improvement of the on-site mixed explosive vehicle market, China's on-site mixed explosive production has shown a year-on-year increase trend. As of 2022, its production accounted for 34% of the total industrial explosive production. Z.W. An et al. [9] studied that in today's blasting sites, in addition to construction, other processes have achieved automation and intelligence. However, the blasting site still mainly relies on mechanized operations, and some construction sites even still require manual participation. Therefore, it is particularly urgent to vigorously develop intelligent unmanned mixed vehicles. The main core of this type of vehicle is unmanned driving, automatic hole detection, and intelligent loading, to improve the safety and accuracy of blasting operations. The following is part of the parameters of the HYJ5320THR-BCRH type mixed emulsion explosive vehicle (see Table 2).

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202609_12(9).0002


**Figure 3.** HYJ5320THR-BCRH Type Mixed-Loading Emulsified Explosive Vehicle

**Table 2.** Partial Parameters of the HYJ5320THR-BCRH Type Mixed-Loading Emulsified Explosive Vehicle

| Project | Organization | HYJ5320THR-BCRH |
|---|---|---|
| **Overall dimensions** | mm | 10710×2550×3600 |
| **Total mass** | kg | 32000 |
| **Rated load capacity** | kg | 11980 |
| **Tare weight** | kg | 19890 |
| **Fuel consumption** | L/100km | 38.2 |
| **Maximum speed** | km/h | 80 |
| **Number of tires** | Unit | 12 |
| **Type of fuel** | / | Diesel fuel |
| **Approach/Departure Angle** | ° | 16/18 |

In terms of the use of explosives, emulsion explosives are widely applied in tunnel blasting. N.K. He [10] proposed that emulsion explosives, as a mainstream type of industrial explosives with excellent performance and safety and environmental protection, have seen a continuous increase in production volume. However, their production process is complex, and improper control of each link can affect the quality. Therefore, it is crucial to strengthen the quality control during the preparation process to ensure stable performance, improve production efficiency, and reduce safety risks. Q. Li [11] suggested that the on-site mixed loading of emulsion explosives with density variation and segmented loading technology is an advanced method of explosive preparation. By integrating the characteristics of emulsion explosives and the principle of density variation segmented loading, this technology can precisely control the density of explosives during the preparation process to meet the performance requirements of different blasting scenarios. This technology has the advantages of improving production efficiency, reducing costs, reducing the use of harmful chemicals, and reducing environmental pollution risks, and has been widely applied.

## 2.3. Detonation System

The tunnel blasting initiation system has evolved from the use of fire detonators in the early 20th century, to electric detonators and detonating cord detonators in the mid-to-late 20th century, and now to electronic detonators (digital detonators). With each generation of progress, the safety and accuracy of blasting engineering have been greatly enhanced.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202609_12(9).0002

Detonating tubes have the advantages of simple structure, low cost and ease of use. However, they also have disadvantages such as low ignition accuracy, inability to control the initiation time, and poor safety of manual ignition. Nevertheless, they played a foundational role in early blasting projects and made an indispensable contribution to large-scale engineering.

Until the middle of the 20th century, the emergence of electric detonators solved the problem of low safety of manual ignition present in conventional fuses, enabling long-distance detonation technology. However, they were still susceptible to static electricity and stray currents, carried the risk of premature detonation, required dedicated detonation power sources, and had complex wiring.

The detonating cord initiation system overcomes some of the shortcomings of electric detonators. The detonating cord is a plastic hose with a thin layer of explosive coating on its inner wall. When one end of the detonating cord is triggered, the explosive in the tube will generate a detonation wave that propagates along the tube and detonates the adjacent detonator. The detonating cord initiation system is easy to operate, has a low cost, and is not affected by stray currents. It has been widely used for a period of time. However, the accuracy of the delay time of the detonating cord initiation system is limited, and it is difficult to achieve high-precision millisecond blasting. Moreover, when the detonating cord is inserted into the pipe, an electric discharge occurs, and it is prohibited for use in some special construction scenarios. For example, according to Article 320 of the "Coal Mine Safety Regulations", underground blasting operations in coal mines are strictly prohibited from using detonating cords or ordinary detonating cords, and only coal mine permitted explosives and coal mine permitted electric detonators can be used.

The emergence of electronic detonators has brought a qualitative leap to the blasting initiation system for tunnels. Electronic detonators precisely control the delay time through the built-in electronic chips, with the delay accuracy reaching millisecond or even microsecond levels. The delay blasting technology of electronic detonators, with its significant advantages of adjustable delay time and a delay firing time accuracy of 1ms, has gained wide recognition in the industry [12]. Studies by domestic and foreign scholars through extensive application and practice have shown that electronic detonator technology can reduce tunnel blasting vibration by 30% to 60% [13]. In tunnel blasting, the initiation time of each blast hole can be precisely set according to the blasting design, enabling more accurate differential blasting and effectively controlling blasting vibration and flying debris. For example, in the construction of the Zhengzhou Metro tunnel, due to the complex surrounding environment, strict control of blasting vibration was required. After adopting the electronic detonator initiation system, by precisely designing the initiation sequence and delay time, the blasting vibration speed was controlled within the specified range, ensuring the safety of surrounding buildings and improving the blasting formation quality of the tunnel.

**Figure 4.** Electronic Detonator

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202609_12(9).0002

## 3. ROADBED AND EMBANKMENT SLOPE ENGINEERING

According to statistical data, the mountainous areas in China account for approximately 69.4% of the total land area. Within these vast mountainous regions, numerous natural slopes are distributed. Currently, China is experiencing rapid development, with large-scale infrastructure construction such as railways, highways, hydropower stations, and mines advancing rapidly. This has led to the emergence of numerous high-slope engineering projects. In the road expansion and renovation projects in mountainous areas, slope monitoring is of utmost importance. Only by conducting precise monitoring and reducing the negative impact of construction on existing slopes can the project be guaranteed to be safe and the schedule be ensured. This has also become a key technical challenge that urgently needs to be addressed in road expansion and renovation [14].

### 3.1. Drilling and Blasting Equipment

In the blasting construction of roadbed slopes, the selection of drilling equipment should be determined based on factors such as rock characteristics, slope gradient and project scale. For small-scale roadbed slope projects or areas with complex terrain where large equipment cannot reach, hand-held drills still have certain applications. However, in most conventional roadbed slope blasting operations, submersible drilling rigs are more widely used. Submersible drilling rigs have the advantages of strong mobility and high drilling efficiency, and can operate flexibly in different terrain conditions (see Figure 5). G.Y. Wang [15] proposed that the design of multi-functional drilling trolley should be comprehensively considered in combination with specific projects. After clarifying the overall design scheme, detailed design work can be carried out. Such trolleys not only need to meet requirements such as working space, structural safety and equipment configuration, but also must have features such as convenient assembly and disassembly, strong walking stability and good construction convenience. Common drilling trolleys are equipped with multiple rock drills and can drill multiple blast holes simultaneously. The following are some parameters of the HW-421 drilling trolley (see Table 3).


**Figure 5.** HW-421 Drilling Cart

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202609_12(9).0002

**Table 3.** Partial Parameters of HW-421 Drilling Cart

| Project | Organization | HW-421 |
|---|---|---|
| **Power** | / | YC6J220 |
| **Rated power** | kW | 162 |
| **Drilling depth** | m | 20 |
| **Drill pipe specification** | mm | Φ60×3000 |
| **Drilling diameter** | mm | Φ90×150 |
| **Working torque** | N×m | ≤1258 |
| **Rotational speed** | rpm | 60-120 |
| **Working air pressure** | bar | 15 |
| **Gas consumption** | m3/min | 12 |
| **Speed of travel** | km/h | 2/3 |
| **Climbing ability** | ° | 30 |
| **Level the angle** | ° | ±10 |
| **Total weight** | kg | 6800 |
| **Transportation dimensions** | mm | 6000×2300×2750 |

In terms of blasting equipment, in addition to traditional initiation materials, to control the impact of blasting on the stability of the slope, control blasting techniques such as pre-split blasting and smooth blasting are often adopted. For example, in the final slope control of open-pit talc mines, the pre-split blasting technology forms cracks by arranging pre-split holes along the excavation boundary and detonating them before the main blast holes are detonated. These cracks weaken the propagation of seismic waves from the main blasting area to the slope rock mass, effectively maintaining the stability of the slope. The smooth blasting technology forms parallel rock walls by drilling a row of closely spaced parallel holes along the slope boundary and then blasting after the mining holes are blasted, thereby protecting the slope. R.X. Guo [16] indicated that the smooth blasting technology is often applied to ensure the neat and beautiful appearance of the slope. Compared with ordinary blasting methods, this technology can effectively reduce over-blasting phenomena and has more regular blasting shapes, significantly improving the quality of the slope contour. Pre-split blasting refers to, during stone excavation, blasting along the designed contour line to form a certain-width continuous crack in the main blasting area. The core purpose of this technology is to buffer and reflect the blasting vibration waves through the cracks, thereby controlling the damage to the reserved rock mass caused by pre-split blasting and achieving effective control of the blasting contour. These technologies require precise control of the initiation sequence and delay time. Electronic detonators and high-precision detonating cord detonators play an important role in such blasting. The high-precision delay control of electronic detonators can achieve more precise sequential detonation and effectively reduce the disturbance of blasting vibrations to the slope rock mass.

### 3.2. Selection and Application of Explosives

In the blasting of roadbed slopes, the selection of explosives is of crucial importance. Z. Lin [17] systematically explored the theoretical framework for controlling blasting techniques, combined with numerical simulation analysis using ANSYS/LS-DYNA to investigate the influence of explosive types and charge structures on the stability of the slope. He proposed the principle of choosing emulsion explosives or water gel explosives based on the rock properties (such as compressive strength, joint development degree), suggesting that for soft rocks or rocks with well-developed joints and fractures, explosives with relatively lower detonation velocity and lower impact intensity should be selected to reduce the damage to the surrounding

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202609_12(9).0002

rock. For example, ammonium oil explosives, which have lower costs and certain explosive performance, are often used in some soft rock roadbed slope blasting where the blasting effect is not highly demanded. For hard rock roadbed slope blasting, to ensure the rock fragmentation effect, emulsion explosives or more powerful mixed explosives are often used. The good water resistance of emulsion explosives enables them to function stably under various geological conditions.

In practical applications, depending on different blasting requirements, special treatments for explosives or different charging structures may be adopted. S.C. Wu [18] summarized in the design of a blasting scheme for a certain roadbed project that for smooth blasting, the contour of the new wall surface needs to be precisely controlled, and during construction, the amount of each section of explosives must be determined according to the specifications. Although the non-coupled interval charging structure can effectively ensure the contour accuracy, its charging process is more complex, and the technical requirements for the design of the charging structure and the control of the charging amount are higher. At the same time, it also effectively controls the disturbance of blasting to the slope rock mass, ensuring the stability of the slope. In pre-split blasting, a non-coupled charging structure is often used, that is, the explosives are placed at the center of the blast hole, and the surrounding is separated by air or other media to reduce the direct effect of the explosion pressure on the hole wall, making the pre-split surface more flat.

### 3.3. Impact of Blasting on Slope Stability and Control

The vibration effects caused by blasting operations can have a certain impact on the stability of the roadbed slope. The main manifestation is that blasting vibrations may cause the loosening, displacement, and even landslides of the slope rock mass. T.F. Tang [19] conducted research on the rock properties and pre-split blasting mechanism in a certain open-pit mine, and optimized the blasting parameters to reduce the blasting-induced vibration effects on the slope. To reduce the impact of blasting on the stability of the slope, in addition to choosing appropriate blasting equipment and adopting controlled blasting techniques, it is also necessary to optimize the blasting parameters. The blasting parameters include hole spacing, row distance, depth, and charge quantity, etc. The reasonable setting of these parameters is crucial for controlling the blasting effect and reducing the impact on the slope.

Through on-site vibration monitoring of blasting, using Sadovsky's formula:

$$V = K\left(\frac{Q^{1/3}}{R}\right)^{\alpha} \tag{1}$$

(Here, V represents the blasting vibration velocity, measured in cm/s; Q represents the maximum charge quantity for a single section, measured in kg; R represents the distance from the measurement point to the blast center, measured in meters; K and $\alpha$ are coefficients related to the geological conditions, terrain, and blasting methods, and need to be determined through on-site experiments). The blasting parameters can be adjusted based on the monitoring data to ensure that the blasting vibration velocity is within the allowable range of the slope rock mass.

## 4. MINING ENGINEERING

As a major global producer and consumer of mineral resources, China currently accounts for approximately 12% of the world's total mineral resources. This ranks China third in the world, after the United States and Russia. Since entering the "new era", China's economy has continued

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202609_12(9).0002

to thrive and the demand for mineral resources has been increasing. To enhance the efficiency of mineral resource extraction, enterprises often use blasting methods to instantly disrupt the geological structure, and then utilize large construction equipment for the extraction and transportation of mineral resources [20-21].

## 4.1. Mechanized Blasting Process in Open-Pit Mines

The main process of open-pit blasting construction is as follows:

1. Site clearance: Remove debris and obstacles within the construction area.

2. Measurement: Use measuring instruments to determine relevant control points and baseline for the construction, providing precise data for hole layout, etc.

3. Measurement and hole layout: Based on the measurement results and in combination with blasting design, reasonably arrange blasting holes on the construction surface, precisely locate the hole positions and determine their depth and other related parameters.

4. Drilling operation: Use drilling equipment to drill blasting holes according to the hole layout parameters. During the drilling operation, strictly control the drilling quality to ensure verticality and the accuracy of hole depth and other key indicators.

5. Sampling and testing: After drilling, take samples from the holes or related rock and minerals to detect and analyze their composition, grade, etc., providing a basis for subsequent mining circle and other operations.

6. Loading and blasting: According to the designed loading structure and loading quantity, fill explosives into the blasting holes, then use an appropriate initiation method to detonate the explosives, crushing the rock; in the mining circle process, it will provide a basis for distinguishing the minerals and rocks during the blasting, ensuring a more reasonable subsequent processing of the mined rock.

7. Mining by mining line: After blasting, based on the distribution of rock and minerals and the mining line, use excavation equipment to dig and load, and transport the rock to the designated discharge point using transportation tools; if there are large pieces of rock, they need to be subjected to secondary crushing.

8. Rock and mineral transportation: Transport the ore to the beneficiation plant for subsequent processing; transport the rock to the dump site for storage.

9. Rechecking and measuring the mining boundary line: During the process, recheck and measure the mining boundary line to ensure it meets the design requirements. If there are deviations, make timely adjustments.

10. Completion acceptance: After the completion of the construction, when all indicators meet the design and specification requirements, organize relevant units to conduct completion acceptance, confirming that the project is qualified for delivery [22]. The attached flowchart (see Figure 6)

## 4.2. Characteristics and Equipment Materials of Underground Mine Blasting

Compared with open-pit mines, underground mines have the characteristics of limited space, poor ventilation conditions, and high safety requirements. In terms of drilling equipment, underground mines mostly use small rock drills or handheld rock drills. Small rock drills are small in size and highly flexible, and can operate in narrow tunnels. Handheld rock drills are suitable for drilling in some irregular areas or small-section tunnels [23].

In terms of explosive materials, due to the presence of harmful gases such as methane in underground mines, the safety requirements for explosives are extremely high. Usually, coal mine permitted explosives are selected, such as coal mine permitted emulsion explosives. During the explosion process, the flames and high temperatures produced by these explosives

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202609_12(9).0002

can be effectively controlled, thereby reducing the risk of methane explosion. At the same time, to improve the loading efficiency and safety, underground mines have gradually adopted mechanized loading equipment, such as the BJC-4(I) type mixer vehicle. Y.J. Zhang, P. Ma. [24] detailedly introduced the BJC-4(I) type mixer vehicle combined with the emulsion matrix ground station, forming a safe and reliable on-site emulsion explosive mixing technology for underground mining blasting. This technology overcomes the problems of long-distance transportation of emulsion matrices and automatic filling of upward deep holes in underground mining blasting, and the resulting emulsion explosives have better performance.

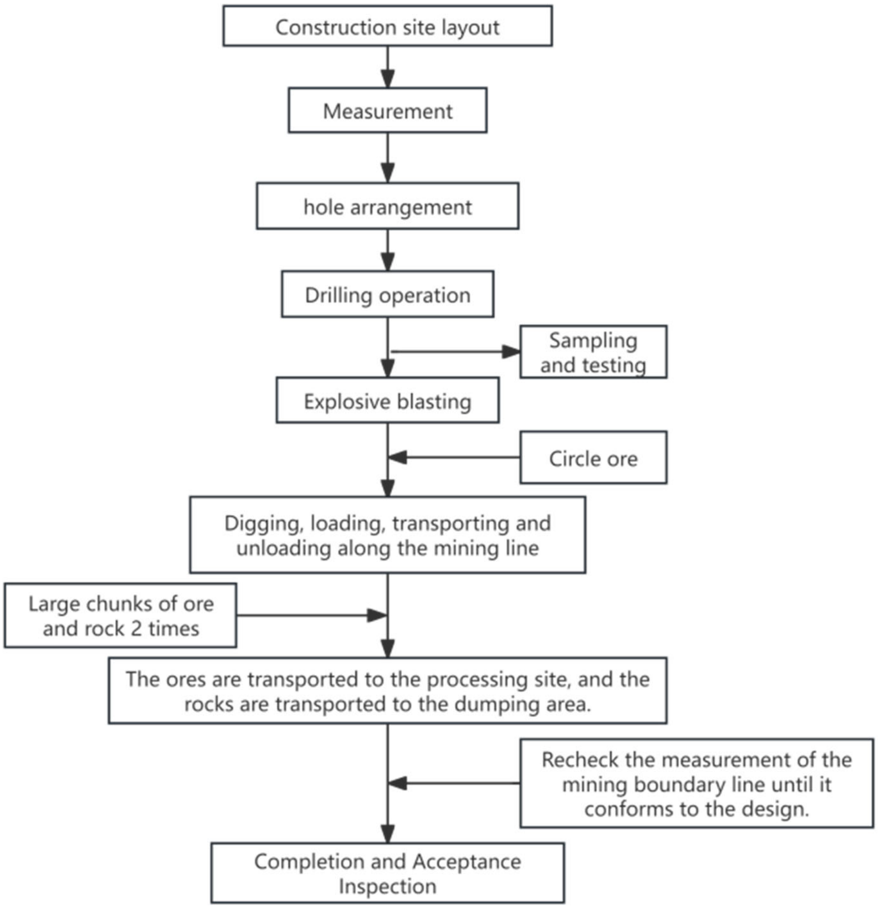


**Figure 6.** Process Flow Chart of Open-pit Mine Blasting

## 5. STRUCTURAL DEMOLITION

Since the reform and opening up, China's urbanization process has accelerated. The urbanization rate has risen from 19.7% in 1978 to 60% in 2020. According to the data from the National Bureau of Statistics in 2022, as of the end of 2022, the urbanization rate in China has reached 65.22%. It is expected that by 2025, the urbanization rate will reach 65.5%, and by 2050, it is expected to reach around 80%. The Fifth Plenary Session of the 19th Central Committee of the Communist Party of China and the 20th National Congress of the Communist Party of China clearly deployed and implemented the urban renewal action, continuously strengthening urban infrastructure construction. With the deep development of urbanization and the upgrading of urban renewal and renovation, in the future, a large number of buildings (structures) will gradually enter the demolition stage, which will bring broad development and application space for demolition blasting technology [25].

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202609_12(9).0002

## 5.1. Classification of Demolition Blasting Techniques

Structural demolition blasting technology mainly includes directional collapse blasting, controlled blasting and static crushing, etc. Directional collapse blasting is suitable for the demolition of tall buildings or structures. By reasonably arranging the blast holes and controlling the detonation sequence, the building collapses in the predetermined direction. Due to the increasingly aging ground infrastructure, numerous residential buildings, chimneys, and water towers urgently need to be demolished. In the past, the demolition of brick-concrete buildings, large brick-concrete chimneys, and water towers mostly relied on the construction of scaffolding, but this method had drawbacks such as long construction time, high operational difficulty, and high risks of working at heights. Nowadays, directional blasting construction methods have gradually become the mainstream. With advantages such as short construction period, low operational difficulty, and controllable costs, it effectively solves the problems of traditional demolition methods [26].

Controlled blasting focuses on precisely controlling the extent and intensity of the blast damage, and is often used for the demolition of structures with high requirements for the surrounding environment. When demolishing abandoned buildings in urban downtown areas, the controlled blasting technique is adopted. By precisely calculating the amount of explosives and the position of the blast holes, combined with the micro-differential blasting technology, the blasting vibration and flying debris are controlled within an extremely small range, ensuring the safety of surrounding traffic and pedestrians. Static crushing utilizes the expansion effect of static crushing agents to cause the structure to break. This method is suitable for environments with extremely high requirements for vibration and noise, but the crushing speed is relatively slow.

## 5.2. Selection of Blasting Equipment and Explosives

In the structural demolition blasting (as shown in Figure 7), the drilling equipment is selected based on the material and thickness of the structure. For concrete structures, commonly used drilling equipment includes hydraulic drilling machines and pneumatic drilling machines. Hydraulic drilling machines have the advantages of fast drilling speed and high precision, and are suitable for drilling in large areas and thick concrete structures. Pneumatic drilling machines, on the other hand, are small in size and flexible in operation, and are more commonly used in narrow spaces or for drilling in small structures.

The selection of explosive materials depends on the nature of the structure and the demolition requirements. For concrete structures, emulsion explosives are often chosen due to their good plasticity and explosive performance. When demolishing some ancient buildings or surrounding structures of cultural relics that are sensitive to blasting vibrations, low explosive velocity and low power explosives, such as special powdered explosives, are selected to reduce the impact on the surrounding environment.

**Figure 7.** Demolition by blasting

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202609_12(9).0002

### 5.3. Selection of Detonating Devices

In the selection of initiation devices for structural demolition blasting, electronic detonators and detonating cord detonators hold a dominant position. Industrial electronic detonators demonstrate significant technical advantages: 1. They can flexibly set the delay time, which can meet the multi-stage precise control blasting requirements for complex building structures; 2. They simplify the blasting network networking process and do not require external relay detonation networking operations; 3. They have a reliable blasting network detection function, significantly improving the efficiency of network inspection and the success rate of initiation; 4. They have a classified management and authorized initiation mechanism, which is particularly suitable for scenarios with high safety control requirements such as urban complex environments and densely populated areas [27].

## 6. UNDERWATER BLASTING

When at least one of the blasting media's free surfaces is below the water surface, such blasting operations are referred to as underwater blasting. As an important branch of blasting engineering, underwater blasting can be classified into various types such as deep-water blasting, shallow-water blasting, near-water surface blasting, underwater exposed rock blasting, underwater drilling blasting, underwater chamber blasting, and dam body blasting, depending on the different loading forms and water conditions [28-30].

### 6.1. Underwater Blasting Equipment

The most commonly used equipment for underwater drilling and blasting mainly includes self-elevating drilling and blasting platforms and floating drilling and blasting vessels. The floating drilling and blasting vessels are also known as drilling and blasting ships or blasting reefing ships; the self-elevating drilling and blasting platforms are also called drilling and blasting platforms or blasting reefing platforms. The drilling and blasting platform can use its own lifting system to lift the hull above the water surface, allowing the main body of the platform to be largely free from interference from external factors such as water flow and wind waves, thus enabling integrated construction operations for drilling and blasting. In the past, it was always the core equipment for underwater drilling and blasting operations, but now only the No. 1, No. 2, and No. 3 drilling and blasting platforms of China Railway Port and Navigation remain. Nowadays, the drilling and blasting vessels have gradually replaced the drilling and blasting platforms and have become the main force of underwater drilling and blasting equipment. They are also steadily moving towards the development path of modernization, modularization, and integration. The drilling and blasting vessels have advantages such as convenient operation, rapid ship position movement, and outstanding navigation performance. Except for some special scenarios in the internal river areas where ordinary barges are still modified into drilling and blasting vessels, current drilling and blasting vessels have fully shifted to standardized construction mode, and their construction equipment is also undergoing iterative upgrades towards modernization, automation, and informatization [31].

Taking the "Changlu 2" drilling and blasting vessel as an example (see Figure 8), the "Changlu 2" was built by Hunan Yiyang Zhonghai Shipbuilding Co., Ltd. It is equipped with 5 SWDW165 integrated hydraulic submersible drilling rigs, and the 5 rigs move along the longitudinal tracks. They can be positioned and drilled at any location according to the predetermined hole spacing. In an inland river channel with a water depth of about 10 meters, the pure drilling efficiency of a single drilling rig for 10 levels of granite rock is approximately 0.6 to 0.8 meters per minute, and the production efficiency can be increased by more than 40%. This vessel can also be used for construction operations in coastal navigation areas. The maximum operation water depth of the steel piles is up to 25 meters, and the maximum drilling depth of the rigs can reach 40

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202609_12(9).0002

meters below the water surface. The operation of the "Changlu 2" can realize the construction of waterway projects while maintaining navigation, effectively reducing the impact of construction on navigation, and providing a reliable guarantee for the protection of aquatic fishery resources. The Chongqing Waterway Engineering Bureau of the Yangtze River has thus formed a cluster of underwater drilling and blasting equipment and technical strength, which will provide stronger technical support for solving the underwater drilling and blasting construction problems in the Yangtze River Golden Waterway construction.

**Figure 8.** Changlu 2 Drilling and Blasting Vessel

## 6.2. Submarine Blasting Agents and Detonators

Underwater explosive charges are generally divided into two types: single-component explosives and mixed explosives. Single-component explosives mainly include nitroglycerin, TNT, etc. Crystalline powdered TNT, although having a high density and power, becomes insensitive when exposed to water, and in severe cases, even fails to detonate; flake-shaped TNT, although the water sensitivity is not obvious, has a low explosion power and low density; granular TNT, although having a high density and sufficient explosion power, has an excessively high production cost. Nitroglycerin, although hardly affected by water, has excessively high mechanical sensitivity and explosion sensitivity, and is prone to explosion upon impact and vibration, so it is used less. Mixed explosives commonly use nitramine and nitroglycerin types. Among them, nitramine mainly includes ammonium nitrate-fuel oil explosive, paste explosive, and emulsion explosive. Ammonium nitrate-fuel oil explosive has been phased out in China due to its pollution to the environment. Paste explosive has excellent water resistance and explosion performance but has high cost and complex process. While emulsion explosive and water gel explosive have high power, low cost, no insensitivity, and good water resistance, they have gradually become the mainstream underwater blasting explosives [32].

Underwater blasting requires extremely strict standards for the water resistance and explosive performance of the explosives. Emulsified explosives are commonly used in underwater blasting. Their unique water-in-oil structure gives them excellent water resistance, and they can maintain stable explosive performance even when immersed in water for a long time. Additionally, to enhance the underwater blasting effect, some special underwater-specific explosives are used. These explosives improve the detonation performance and energy utilization in water through optimized formulations.

In terms of initiating devices, underwater electronic detonators and waterproof detonating cord detonators are widely used. Underwater electronic detonators undergo special waterproof treatment, enabling reliable detonation in underwater environments and maintaining their advantages in high-precision delay control, which helps achieve precise underwater blasting. Waterproof detonating cord detonators use enhanced sealing measures to prevent water from

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202609_12(9).0002

entering the internal part of the detonator and affecting the detonation performance, providing reliable initiation guarantee for underwater blasting.

## 7. SUMMARY AND OUTLOOK

### 7.1. Summary

This paper systematically studies the current status of mechanization and material application in blasting construction in fields such as tunnel engineering, roadbed slope engineering, mining engineering, structure demolition, and underwater blasting. In terms of mechanization, from drilling equipment such as rock drilling trucks, drilling trucks, and drilling-blasting ships, to loading equipment like mixed explosives vehicles, and various initiation devices, the degree of mechanization has continuously improved, significantly enhancing the construction efficiency and safety. In terms of materials, emulsion explosives, due to their excellent water resistance and stable explosion performance, are widely used in various complex environments; the combination of mixed explosives and mixed explosives vehicles enables on-site mixing and filling of explosives, improving the operational flexibility.

However, the current application of mechanization in blasting construction still has shortcomings. Some equipment's adaptability to different geological conditions and engineering scenarios needs to be strengthened, and the coordination and collaboration level among equipment is relatively low. In terms of explosive materials, their safety, environmental friendliness, and cost-effectiveness still need to be further optimized to meet increasingly strict safety and environmental protection requirements and engineering cost control needs.

### 7.2. Outlook

The mechanization of future blasting construction will develop towards the direction of intelligence and automation. With the integration of Internet of Things, big data and artificial intelligence technologies, drilling equipment can achieve automatic positioning and intelligent adjustment of drilling parameters, improving the drilling accuracy; mixed explosive vehicles can automatically optimize the explosive formula and mixing process according to different engineering requirements; the initiation system can intelligently adjust the initiation sequence and time through real-time monitoring of environmental parameters, achieving precise blasting.

In the blasting construction process, the focus will be on optimizing and enhancing the efficiency of construction connection. By building a collaborative management platform based on BIM and IoT, real-time monitoring of the dynamic progress of drilling, loading explosives, warning, and initiation processes will be carried out. Intelligent algorithms will be used to predict the time difference of process connection, and personnel and equipment resources will be allocated in advance. Standardized operation modules and digital twin technology will be introduced to simulate the entire construction process, optimize the process logic and resource allocation, reduce connection breaks caused by information lag and resource mismatch, form an efficient and orderly construction chain, and promote the development of blasting construction connection towards the direction of intelligence and seamless integration.

In the development of high-performance explosives, new environmentally friendly, safe and efficient explosive materials will become the key development direction. Researchers will strive to reduce environmental pollution during the production and use of explosives, improve the safety and explosion performance of explosives during transportation and storage. At the same time, the research on performance parameters such as "wave impedance" of explosives will be more in-depth. By optimizing the wave impedance matching between explosives and rocks and other media, the utilization rate of blasting energy will be further improved, and the blasting cost will be reduced. In addition, initiation equipment will also develop towards higher

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202609_12(9).0002

precision and stronger reliability, providing a more powerful guarantee for the safe and efficient blasting construction.

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