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Key Technology of Cloud Platform for Intelligent Design of Tunnel Blasting Program under Complex Geological Conditions

Luyu Zhang[1,*]
[1] Qilu Transportation School, Shandong University, Jinan, Shandong, 250100, China
Corresponding authors: (e-mail: luyu84667237@163.com).

Abstract Tunnel blasting design is an important part of tunnel construction, and a reasonable blasting program can not only improve the construction efficiency, but also ensure the stability and safety of the surrounding rock. In this study, an intelligent design platform for tunnel blasting program is developed, which aims to solve the limitations of traditional blasting design methods under complex geological conditions. The platform is developed in JavaScript language, combined with React, Nest and other technologies to support efficient interaction and data processing between the front-end and the back-end. By designing an automated blasting parameter calculation module, the platform is able to automatically generate a blasting plan based on the specific parameters of the tunnel project (e.g., geological conditions, tunnel dimensions, etc.), and provide key contents such as the arrangement of the gun holes, the calculation of the charge amount, and the sequence of detonation. The unit consumption of explosives designed by the system is 0.96, which is lower than the 1.04 of the traditional design system, showing good optimization effect. In addition, on-site application verification shows that after adopting this system, the blasting effect is better than the traditional design, the over and under excavation is controlled within 12cm, and the utilization rate of the shell hole is increased to 86%. The application of this system not only improves the design efficiency, but also reduces the construction cost and resource consumption, which has a wide engineering application prospect.

Index Terms Tunnel Blasting Design, Intelligent Platform, Automated Design, Blasting Optimization, Borehole Layout, Explosive Unit Consumption

I. Introduction

With the development of China's economy and society, the increasing number of infrastructure construction projects such as highways, railroads, urban subways, water conservancy and hydropower, the tunnel engineering construction task is heavy [1], [2]. And in the process of tunnel excavation construction, blasting technology has become a commonly used method, blasting technology by placing explosives inside the tunnel, the use of shock waves generated by the explosion and high temperature gas to destroy the rock and soil, to achieve the tunnel excavation, it is not only work efficiently, but also can adapt to a variety of complex geological conditions [3]-[6]. At present, tunnel construction mainly adopts drilling and blasting method, mechanical excavation method (TBM machine and shield machine), machinery combined with drilling and blasting and other methods [7], [8]. Because mechanical excavation method is greatly restricted by geological conditions, and the project cost is high, it is difficult to promote the application of the full range in China, while the mechanical combination of drilling and blasting method is still immature, the application is even less [9], [10]. Tunnel excavation and blasting technology after many years of development, basically able to meet the needs of tunnel construction and safety, but also the current tunnel construction is the most used method [11], [12].

However, with the improvement of the level of construction technology and equipment, tunnel construction speed requirements are getting faster and faster, coupled with the changes in the organization mode of the construction workforce, the traditional manual tunnel blasting design method can no longer meet the construction needs [13]-[15]. Existing tunnel blasting design system is realized by CAD software to draw and print the borehole layout, detonation network diagram, charging structure diagram, blasting design manual, the position of the borehole on the palm face has not yet been completely adaptive layout by the computer, the design of the human factor is more [16]-[19]. With the development of automation and intelligent technology, blasting engineering also develops in the direction of automation and intelligence, for example, the introduction of drones and remote sensing technology, which realizes the remote monitoring and control of the blasting process, while the development of a reliable intelligent cloud platform for tunnel blasting design, and the use of computers to carry out the blasting design is one of the important development directions of tunnel blasting construction technology [20]-[23].

This paper takes tunnel blasting design as the research object, and proposes a design scheme based on intelligent platform by analyzing and comparing the existing design methods. Through embedded blasting design algorithm and visualization interface, the platform realizes the automatic calculation and display of the parameters of the borehole, charge amount and detonation sequence. Through experimental data verification, the platform can provide more accurate design solutions under complex geological conditions, which significantly improves the efficiency and effectiveness of blasting operations.

The platform can not only be applied to conventional tunnel blasting design, but also be extended to other underground engineering fields. By comparing the effects of traditional design and intelligent design, this paper verifies the feasibility and advantages of the platform in actual projects, and provides a theoretical basis for the subsequent development and popularization of technology.

II. Blasting Intelligent Design System Development

II. A.Key Technology for R&D of Blasting Intelligent Design System

The Blast Intelligent Design Platform is developed using the JavaScript visual programming language, and in the development process, Canvas, React, Nestjs, PostgreSQL database, etc. are applied to assist in the development, and the editor used is VS. Next, the relevant computer technologies involved in the development process of the platform are briefly introduced.

II. A. 1) Selection of system development language

Currently computer programming languages can be divided into two main categories: non-visual programming languages and visual programming languages. Visual programming language is more suitable for the platform as the system development language. In determining the use of visual programming language as a tunnel blasting intelligent design platform development language, according to the actual situation of the development of the platform, from the many visualization languages to choose the most appropriate programming language.

JavaScript has the following characteristics and advantages:

(1) JavaScript is a direct translation, interpretive scripting language, its code does not need to be pre-compiled, can be directly embedded in the HTML, loaded by the browser to interpret the execution.

(2) JavaScript has cross-platform characteristics.

(3) JavaScript is dynamic.

Therefore, JavaScript visual programming language is used for the development of blasting intelligent design platform, and TypeScript is used for the back-end development of blasting intelligent design platform.

II. A. 2) Canvas

In the tunnel blasting intelligent design system, it is necessary to display the design of the borehole in the browser in real time, so the Canvas of JavaScript is used to display the design of the borehole.

II. A. 3) Front-end framework React

React is essentially a JavaScript library that can be used to build user interfaces.The advantage of the React framework over other frameworks is that it has the characteristics of high performance and high efficiency.The reasons why React has higher development efficiency and performance are: ① virtual DOM, ② componentization.

Because React framework has the two advantages of virtual DOM and componentization, combined with the development requirements of the intelligent design system, it is chosen as the front-end development framework of this platform.

II. A. 4) The Nest framework

Nest is a development framework for building efficient and scalable Node.js server-side applications.Nest is also a module-based framework, its code can be reused, each of its implementation of the functionality can be used as a module, each module can be called by itself, but also allows other modules to call.

Nest supports TypeScript language for programming and also allows developers to use pure JavaScript for development, which can be used to create highly testable, scalable, loosely coupled and easy to maintain applications.

Based on the features of Nest, the back-end development of the Blast Intelligent Design Platform is carried out using the Nest framework.

II. A. 5) Database

This system uses PostgreSQL, an open source object-relational database management system with open source code. It is powerful enough to allow retrieval of requests as they are processed, and it is cross-platform, running on most everyday operating systems.

The database of Tunnel Blasting Intelligent Design System mainly contains information, parameters and other related data involved in the tunnel blasting design process, including user's account information, information on tunnel engineering conditions, borehole design parameters, charge design parameters, blasting optimization parameters and so on.

II. B.Functions of Blasting Program Intelligent Design Module

II. B. 1) Basis for Tunnel Blasting Design

Tunnel project before construction, should be based on engineering geological conditions, rock explodability, tunnel section size, excavation methods, cyclic footage, drilling equipment and blasting equipment to do a good job of drilling and blasting design, reasonably determine the number of holes out of the gun, spacing, depth, angle, to determine the explosives unit consumption, charge, charging structure, detonation methods, detonation sequence, and arrange for a good cycle of operations, in order to correctly guide the construction of the tunnel drilling and blasting to achieve the expected blasting effect [24]-[26].

(1) The basic requirements of drilling and blasting method of construction:

a) blasting on the surrounding rock disturbance damage is small, to ensure the stability of the surrounding rock.

b) after blasting to meet the design requirements of the section and the tunnel profile is relatively flat, over and under excavation in the maximum allowable value of over-excavation within the scope, and try not to undercut the situation.

c) After blasting, the tunneling footage reaches the construction design requirements, the working surface is smooth, and the root of the gun is short and shallow.

d) The rate of large pieces after blasting is controlled within a reasonable range, and the throwing position is relatively centralized to meet the requirements of slag loading.

e) In the case of ensuring the blasting effect, minimize the number of holes, reduce the workload of drilling, explosives and other blasting materials consumption.

f) to avoid blasting on the surrounding machinery and other equipment damage, reduce construction pollution of the surrounding environment.

(2) Gunhole arrangement

The order of the arrangement of the gunhole is hollowing eye, peripheral eye, auxiliary eye. Hollowing eye is generally arranged in the excavation surface of the central part of the lower part, the purpose is to create a new air space for the blasting of the other holes, the depth of the hole is usually deeper than the other holes 12 ~ 18 cm. In addition to hollowing eye and the bottom of the hole, all the other eyes of the eye should fall on the same vertical plane. The depth of the bottom eye is usually the same as that of the trenching eye. The peripheral eyes should be arranged in strict accordance with the design position. In order to facilitate mechanical drilling, reduce over- and under-excavation, and form a flat and smooth contour surface, the peripheral eye should be designed with an interpolated slope rate of 2.6% to 6.1%. The auxiliary eye is set in the position between the peripheral eye and the hollowing eye, and is arranged from inside to outside, layer by layer.

(3) Calculation and distribution of charge. Reasonable charge volume should be determined according to the performance of the explosives used, combined with the engineering geological conditions, the diameter and depth of the borehole, the volume of the blasting burden rock and the requirements of the blasting effect and other conditions. At present, usually through the blasting volume formula to calculate the total amount of a cycle footage of the charge, and then according to the blasting characteristics of each type of borehole and the requirements of the allocation, in blasting practice to test and amend, until a good blasting effect.

II. B. 2) Automated Design of Tunnel Blasting Programs

The automated design of the tunnel blasting program is shown in Figure 1.

The project profile includes tunnel type, tunnel mileage, engineering geological conditions, perimeter rock classification, perimeter rock uniaxial compressive strength and burial depth. Tunnel geometric parameters include section size, shape, excavation method and sub-section division. Borehole parameters include type, number, depth, spacing and inclination. Charging parameters blasting single-hole charge, total charge and charge structure. The automatic generation of blasting plan includes the process of exporting and editing the project overview, the parameters of gun holes and the parameters of charging, and the system realizes the image display of the parameters of gun holes and the statistics of the charging parameters through the embedded charts of gun holes and charging design, and finally generates the document of blasting design plan.

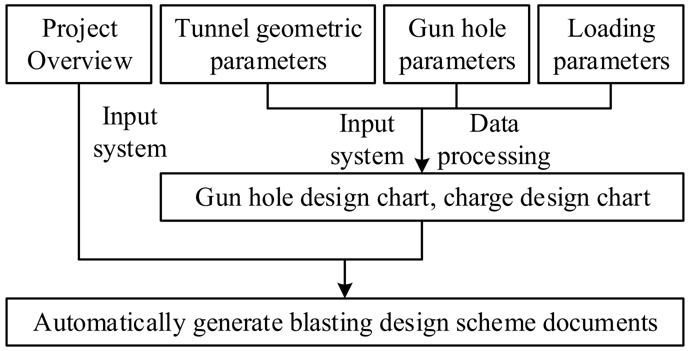

Figure 1: Automatic design of tunnel blasting scheme

II. B. 3) Overall design of the Blasting Program Intelligence System (BPIS)

The design process of the intelligent system for blasting program is shown in Figure 2. The system design process is mainly for the input of the operating platform, tunnel contour line, explosives and surrounding rock and other parameters, according to the input parameters to calculate the borehole layout parameters, detonation sequence and the amount of charge, the results of the calculations are displayed in the form of the borehole layout map, detonation sequence map and the amount of charge map.

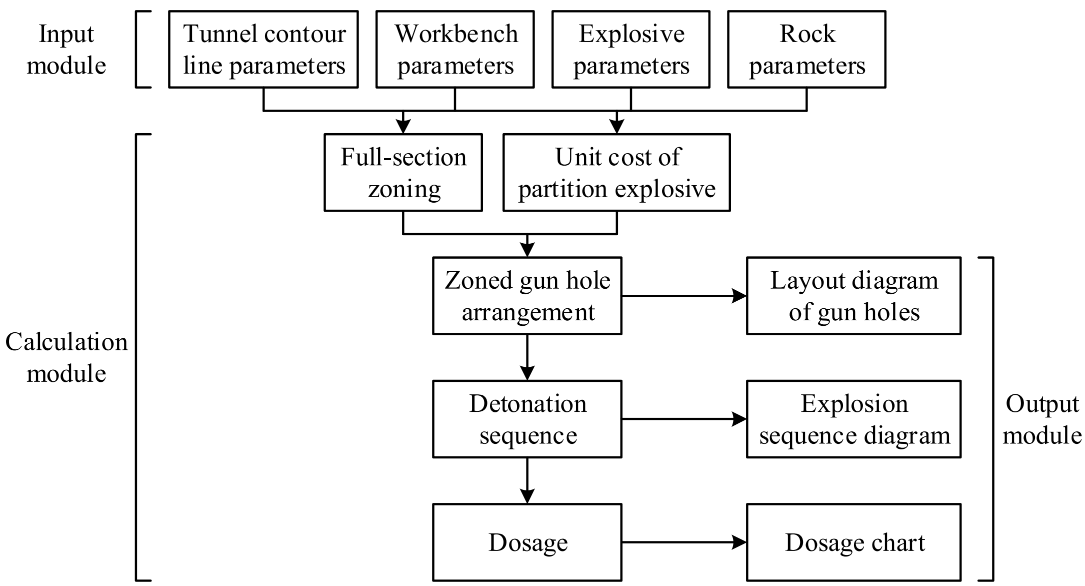

Figure 2: The design process of the blasting scheme intelligent system

II. C.Algorithmic Implementation of Intelligent Design Module Functions

II. C. 1) Tunnel Profile and Zoning Design

When building a project using the Intelligent Design System for Blasting Solutions, the first step is to determine the profile line of the tunnel section before the next automated design can be carried out in the profile line.

This describes the algorithm for depicting the contour line of the city gate cave type. The shape and parameters of the contour line of the city gate are shown in Fig. 3, where the point E is the origin of the coordinate system, where the right direction of the origin is the positive direction of the X axis, and the upper direction of the origin is the positive direction of the Y axis, and the establishment of the local coordinate system of X and Y is shown, and the control points of the contour line can be expressed in local coordinates. Among them, the height of section H, the radius of the arc of the arch R and the width of section W are input values.

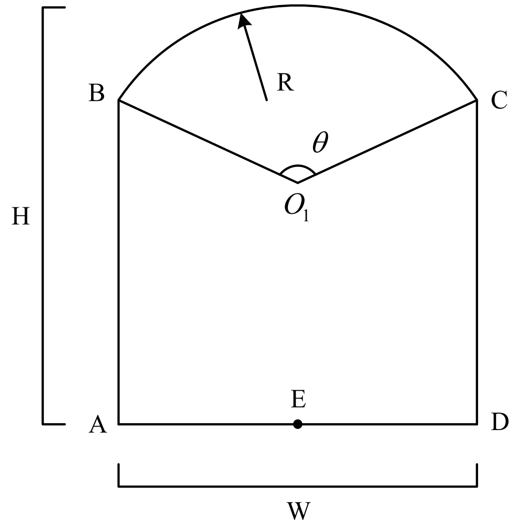

Figure 3: The contour lines and parameters of the gate

Then the coordinates of the center of the circle O_1 are:

$$x_1 = 0, \quad y_1 = 0 \tag{1}$$

The coordinates of the endpoints A, B, C, and D are:

$$x_A = -0.5W, \quad y_A = 0 \tag{2}$$

$$x_B = -0.5W, \quad y_B = H - R + \sqrt{R^2 - 0.25W^2} \tag{3}$$

$$x_C = 0.5W, \quad y_C = y_B \tag{4}$$

$$x_D = 0.5W, \quad y_D = 0 \tag{5}$$

Angle θ for:

$$\theta = \sin^{-1}\left(\frac{0.5W}{R}\right) \tag{6}$$

In the design of the program, the geometric parameters of the profile line should also be calculated based on the profile line of the tunnel section in order to meet the requirements of the borehole layout, so the corresponding algorithms need to be designed to derive the area and perimeter of the defined profile line.

II. C. 2) Automatic placement of holes

After using the computer to draw the profile line of the section, it automatically enters into the module of gun hole arrangement. To realize this function, it is necessary to input the site surrounding rock conditions, hollowing type and blasting method into the platform interface. According to the input information, the computer algorithm selects the corresponding layout principles for automated hole design, and the designers can also make personalized adjustments to the arranged holes, so as to design a blasting program in line with the actual project.

In the process of surface blasting, according to the location and role of the different gun holes can be roughly divided into three kinds of hollowing holes, chipping holes, peripheral holes.

(1) An example of a Shing Mun Hole-type hollowing hole arrangement for a three-tiered workbench job. The parameters of the hollowing hole of the Shing Mun Hole type section are shown in Fig. 4. Where point E is the origin of the coordinate system, where the right direction of the origin is the positive direction of the X-axis, and the upper direction of the origin is the positive direction of the Y-axis, to establish the X, Y local coordinate system. The width of the two legs of the work platform W, the height of the first floor shelf H_1 and the height of the second floor shelf H_2, and the cyclic footage L are all input values.

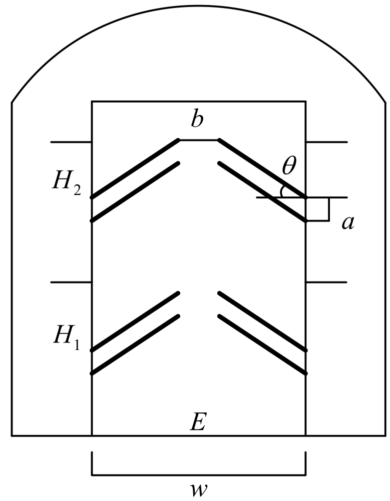

Figure 4: Channel hole parameter

The spacing a of hollowing holes within a zone is:

$$n = \frac{H_2}{a_{\text{Theory}}} - \left(\frac{H_2}{a_{\text{Theory}}} mod?\right) \tag{7}$$

$$a = \frac{H_2}{n} \tag{8}$$

The theoretical spacing of the trenching holes a_{Theory} is obtained from construction experience through the rock grades, and the spacing of the trenching holes under the I, II, IV and V grades of rock in general construction is 35 cm, 45 cm, 55 cm and 65 cm, respectively.

The coordinates of the hole opening of the i th hollowing hole from bottom to top within Zone II are:

$$x_i = 0.5W, \quad y_i = H_1 + (i - 0.5)a \tag{9}$$

The coordinates of the bottom of the i th hollowing hole are:

$$x_{i \text{ bottom}} = \frac{1}{2}b = \frac{1}{2}W - \left(\frac{L}{\tan\theta}\right), y_{i \text{ bottom}} = y_i \tag{10}$$

The hole length L_i of the i th hollowing hole is:

$$L_i = \frac{L}{\sin\theta} \tag{11}$$

Where b is the hole bottom spacing. θ is the hollowing angle, and the parameters are selected according to the experience presented by the blasting project.

(2) For the peripheral hole spacing and number of holes in the straight line section on both sides of the contour line, they are calculated according to the height of each level of the work platform H . For the perimeter holes at the top of the arch, they are calculated according to the average of the arc length S . Firstly, the theoretical value of peripheral hole spacing is selected according to the coefficient of solidity of surrounding rock, and then the number of peripheral holes and the value of hole spacing are back-calculated by the above formula to obtain the spacing of all adjacent peripheral holes on the line of the wheelhouse, so as to realize the automatic arrangement.

It is worth noting that, within the scope of operation one area, the first peripheral hole from the bottom up should be arranged at the foot of the contour line arch and detonated after all the gun holes are detonated, so the peripheral hole spacing c within the scope of one area is:

$$n = \frac{H_1}{c_{\text{Theory}}} - \left(\frac{H_1}{c_{\text{Theory}}} mod?\right) \tag{12}$$

$$c = \frac{H_1}{n - 0.5} \tag{13}$$

(3) The chipping holes are generally located between the perimeter holes and the hollowing holes, and their main function is to further expand the slot cavity and the proximity of the surface after the hollowing blasting, so they are also called auxiliary holes.

Calculation of the two sides of the crash hole row spacing and the number of rows: the right side of the tunnel section planing surface shown in Figure 5.

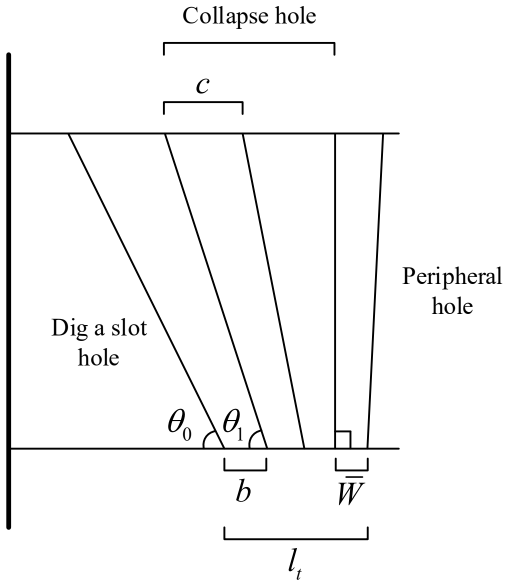

Figure 5: The right plane of the tunnel section

As shown in the figure above, the number of rows of chipping holes on both sides needs to be calculated first since they are generally arranged in multiple rows in the design. The row spacing of the auxiliary holes can be derived using the modified Barron's formula:

$$q_a = \frac{K}{P}\sqrt{\frac{f}{S}} \tag{14}$$

$$b = d_c\sqrt{\frac{\pi(L - L_d)\rho_0}{4\gamma q_a m L \eta}} \tag{15}$$

$$a = mb \tag{16}$$

where q_a is the average explosive unit consumption of tunnel boring blasting. K for the average explosive unit consumption coefficient. P for the explosive force, f for the rock solidity coefficient. d_c is the diameter of the charge coil and ρ_0 is the explosive density. L_d is the plug length and L is the depth of the shell hole. γ is the correction factor. According to experience, the two sides of the collapse hole is usually taken as 1. m is the blast density coefficient. η is the utilization rate of the hole. b is the row distance of the chipping hole, a is the hole distance of the chipping hole.

After obtaining the row spacing of the chipping holes, the number of rows of chipping holes can be obtained:

$$n = \frac{(l_t - \overline{w})}{b} \tag{17}$$

where n is the number of disintegration hole rows, rounded to the nearest whole number. l_t is the length of the side stand, $\overline{w}$ is the thickness of the photo-explosive layer.

According to the number of rows of chipping holes and the angle of the hollowing hole, the row spacing at the bottom of the hole can be determined:

$$c = \frac{l_t + L\cos\theta_0 - \overline{w}}{n} \tag{18}$$

Knowing the row spacing of the hole opening and hole bottom, establish X, Y coordinate system to find out the coordinates of the hole opening and hole bottom of any hole.

The coordinate diagram of the right side of the tunnel section is shown in Fig. 6, and it is known that the coordinates of the hole opening of any chipping hole are (x_2, y_2), and the coordinates of the hole bottom are (x_1, y_1), then the inclination angle of this shell hole θ_1 is:

$$\theta_1 = \tan^{-1}\frac{y_1 - y_2}{x_1 - x_2} \tag{19}$$

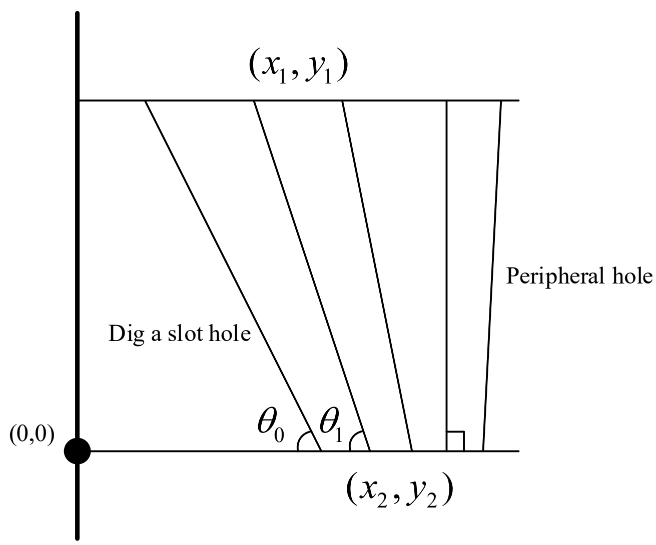

Figure 6: The right coordinate diagram of the tunnel section

II. C. 3) Sequence of detonation and differential timing

In order to reduce the impact of vibration and shock, as well as reduce the possibility of rock splashing and falling, and to ensure that the explosives can produce the desired effect after the explosion, a reasonable sequence of detonation must be designed to maintain the stability of the blasting project when carrying out surface blasting detonation.

The different parts of the holes are categorized: hollowing holes, chipping holes, inner ring holes, perimeter holes, base plate holes and sharp point holes, of which the sharp point holes are perimeter holes at the foot of the arch.

The overall order of detonation of the holes: hollowing holes before the chipping holes, chipping holes before the inner ring holes, the inner ring holes before the base plate holes, the base plate holes before the perimeter holes, the perimeter holes before the cusp holes.

In accordance with the order of detonation, all holes segmented, when a section of the charge exceeds the safe and permissible value, the design section should be divided into smaller areas, but also based on experience or requirements of the section to be adjusted. After the end of the segmentation of the holes, should also set the differential time between the segments, the system generally defaults to 60ms, can be adjusted.

II. C. 4) Fine design of the charge of the shell hole

In the tunnel blasting design, the design of the gun-hole charge is a very important part of a reasonable charge can greatly improve the rock-breaking efficiency and energy utilization.

(1) Calculation of the blast volume of the blast holes

In this paper, the idea of calculating the blast volume of the blast holes is based on the arrangement of the holes to calculate the impact area of each hole, combined with the lithological distribution of the holes can be obtained from the blast volume of each section of the surrounding rock of each hole.

Based on the free surface theory, the blast volume of the blast holes is determined.

Then optimize the palm face after sectioning. For the hollowing hole area, the triangle generated by the innermost two rows of gunholes is poor due to the large spacing between them. Therefore, the triangles formed by the innermost two rows of holes symmetrically along the central axis are canceled, and a new Tyson polygon is formed by making a vertical line directly over the center of the outer circle of the triangle near the central axis to the central axis. For the peripheral hole area and the bottom plate hole area directly to the extension of the Tyson polygon, with the contour line adjacent to the center of the triangle of the outer circle as a starting point to do with the contour line of the plumb line can be obtained from the peripheral holes in the area of influence. The auxiliary hole area is taken directly from the original Tyson polygon.

Calculating the area of influence of a gunhole first requires determining the coordinates of the vertices of the Tyson polygon. Then select one vertex as the reference vertex and use that vertex as the center to order the other vertices of the polygon in a counterclockwise direction. Then connect the datum vertex with two neighboring vertices to form a number of triangles, and calculate the area of each triangle S_n by the method of fork multiplication. Finally, the area of each triangle can be added together to obtain the impact area of each shell hole S_i, and establish the shell hole impact area set S, the calculation formula is as follows:

$$S = \sum_{1}^{n} S_n \tag{20}$$

$$S_n = 0.5 \times |(x_1y_2 - x_2y_1) + (x_2y_3 - x_3y_2) + ... + (x_{n-1}y_n - x_ny_{n-1}) + (x_ny_1 - x_1y_n)| \tag{21}$$

where $(x_1, y_1), (x_2, y_2), (x_n, y_n)$ is the vertex coordinates of the triangle.

After obtaining the set of impact area of the gun holes, the blasting volume of each gun hole can be obtained according to the impact area of each gun hole and the depth of the gun hole. The formula for calculating the blasting volume of each gunhole is as follows:

$$V = \sum_{1}^{i} V_i = \sum_{1}^{i} SL_i \tag{22}$$

where V is the blast volume of the blast hole, m^3. V_i is the blast volume of the i th section of the blast hole segment, m^3. S_i is the area affected by blasting of the i th blast hole, m^2. L_i is the length of the i th blast hole section, m.

Explosives unit consumption refers to the amount of explosives consumed per cubic meter of rock crushing, which is an important index for evaluating the economy and effectiveness of blasting.

In actual engineering, it is usually selected by engineering analogy or empirical method. According to engineering experience, the value of explosive unit consumption k ranges from 0.6 to 2.3 kg/m^3. The explosive unit consumption can also be calculated by the following formula:

$$k = 1.1k_0\sqrt{\frac{f}{S}} \tag{23}$$

where k is the unit consumption of explosives, kg/m^3. k_0 is the correction factor for explosive bursting force, k_0 =525/P, and P is the selected explosive bursting force, ml. f is the rock solidity coefficient, S is the tunnel section area, m^2.

According to the results of gunhole modeling, the explosive unit consumption of each level of surrounding rock and the charging coefficients of different types of gunholes at each level of surrounding rock. A new idea of charge calculation is proposed in this paper, which provides certain ideas for refined blasting design. The formula for calculating the charge of the gunhole is as follows:

$$Q_n = \sum_{1}^{i} \xi_i k_i V_i = \sum_{1}^{i} \xi_i k_i L_i S \tag{24}$$

where Q_n is the charge for the n th gunhole, kg. ξ_i is the charge coefficient of the i th gunhole section of that gunhole. k_i is the unit consumption of explosives in the i th section of the borehole, kg/m^3.

According to the formula proposed in this paper for calculating the charge of each gunhole, the charge of each gunhole can be obtained, in order to facilitate the loading, the calculated charge results are normalized to the tenths place, so as to facilitate the division of explosives.

III. Field engineering application validation

III. A. Summary of works

The project adopts 4-lane highway standard, in which the Ping'an Tunnel is a separated tunnel. The length of the left tunnel is 1526m, the length of the right tunnel is 1510m, the tunnel excavation span is 14.2m, the excavation height is 11.55m, the minimum clear distance between the left and right lines is 22m, and the surrounding rocks in the tunnel site area are mainly composed of strongly-weathered~moderately-weathered dolomitic greywacke.

III. B. Blast Automatic Design Output

The excavation was carried out by two-step blasting, the height of the upper step was 8.6m, and the perimeter rock was class III. The cyclic feeding was 3m, and the saturated compressive strength of the perimeter rock was 55MPa. Circular footage is 3m, the height of the upper step is 7.2m, the saturated compressive strength of the surrounding rock is 55MPa. 2 rock emulsion explosives are used, the minimum loading unit of the peripheral holes is 0.6 sections, the diameter of the roll is 35mm, the length of the roll is 50cm, and the quality of the roll is 500g.

The blasting parameters are shown in Table 1. This system is designed for the explosive unit consumption of 0.96 kg/m^3, without the use of this system, the actual total amount of drugs on the site is 176 kg, the explosive unit consumption in 1.04 kg/m^3, compared with the site is not much difference.

Table 1: Blasting parameter

Hole type	Number	Hole depth/m	Cartridge diameter /mm	Cartridge length /mm	Charge length /m	Single hole loading /kg	Total dosage /kg
Peripheral hole	58	2.35	35	180	0.51	0.56	27.63
Slot hole	23	2.86	35	500	2.35	2.24	35.42
Auxiliary cut hole 1	20	2.53	35	500	1.96	1.89	22.35
Auxiliary cut hole 2	17	2.27	35	500	1.53	1.52	18.65
Bottom hole	15	2.21	35	500	1.42	1.53	20.33
Auxiliary hole	16	2.21	35	500	1.36	1.35	45.52
Summarizing	149	-	-				169.9

III. C. On-site blasting effects

According to the blasting parameter table and hole arrangement output from the blasting design auxiliary system, after the on-site drilling and charging blasting, the half-hole rate can be clearly seen in the sidewalls and vaults, etc. The whole rock face did not show large bumps and unevenness. The entire rock face did not appear large bumps, tunnel excavation unevenness within 12cm, over and under excavation is well controlled, a single cycle of blasting footage is basically about 2.5m, the utilization rate of the gunnel hole reached more than 86%.

On-site statistics of construction labor efficiency and construction costs are shown in Table 2. Data show that the original blasting design per cycle of 182kg of explosives, detonator 123 rounds, the average linear over-excavation of 30cm. 169.9kg of explosives per cycle of system blasting design, detonator 149 rounds, the average linear over-excavation of 16cm.

According to the explosives 30,500 yuan / t, detonator 30 yuan / hair, concrete 420 $yuan/m^3$ Consideration, in each cycle of time is basically the same, the cost reduction of about 5 to 12%.

Table 2: Site statistics construction and construction cost

Analogy	Ergonomic analysis/h		Cost analysis/yuan	
Original blasting design	Drilling time	2.75	Blasting equipment	7862
	Drug initiation	1.13	Backfilling concrete	2930
	Spray time	2.04	-	
	Total	5.92	Total	10792
System blasting design	Drilling time	3.05	Blasting equipment	8125
	Drug initiation	1.46	Backfilling concrete	2074
	Spray time	1.75	-	-

	Total	6.26	Total	10199

In order to verify the vibration effect of this blasting design on the buildings under the surface, in the tunnel blasting construction, using TC-4850 blasting vibration monitor for each blasting construction of the surface building vibration monitoring. The monitor is arranged on the outside wall of the building above the tunnel vault, and the waveform of blasting vibration monitoring is shown in Figure 7 for a certain blasting cycle when the tunnel goes through the building. The vibration waveform is large at the beginning to 0.4s, and after 0.4s, the blasting vibration waveform shrinks steadily and the vibration decelerates.

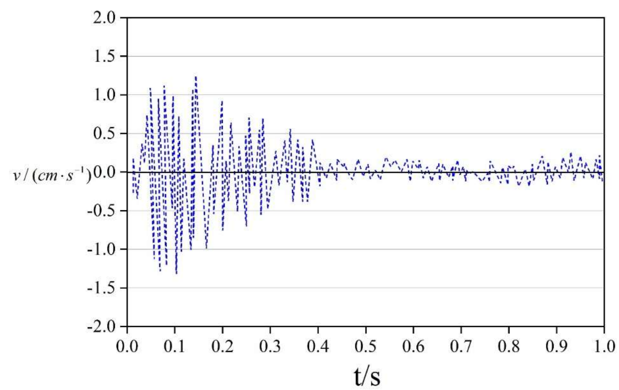

Figure 7: Field blasting vibration monitoring waveform

In order to effectively control the effect of blasting construction on the vibration of surface buildings, the maximum blasting vibration speed data of 120 consecutive cycle feeds of the interval tunnel under the building are collated and analyzed, and the relationship between the maximum vibration speed of each blast v and the number of excavation cycles n is derived.

The relationship between blasting speed and excavation cycles is shown in Figure 8. The average value of the measured blasting velocity of the tunnel under the building was 1.275cm/s, and most of the measured values of blasting velocity fluctuated up and down in the blasting design velocity check value of 1.342cm/s, which were all controlled within the safety vibration velocity of 1.5cm/s required by the building. There is no blasting vibration speed exceeding the standard in the process of blasting excavation, and the interval tunnel also passes through the nearby commercial buildings smoothly. It can be seen that the blasting design program is practicable to meet the safety requirements of blasting vibration of the tunnel through the building, and has certain practical significance of the project.

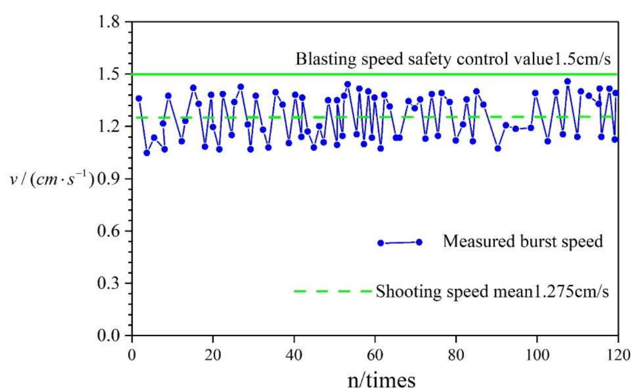

Figure 8: The relationship between the burst speed and the excavation cycle

IV. Conclusion

This paper draws the following conclusions through the research and application verification of the intelligent design system for tunnel blasting program:

The intelligent design platform is outstanding in improving blasting design accuracy and construction efficiency. In this project, the unit consumption of explosives after adopting the platform is 0.96, which reduces the use of explosives by about 8% compared with the traditional design of 1.04, fully reflecting the optimization effect of the blasting scheme.

The platform is able to automatically generate a reasonable gunnel arrangement and charging scheme according to the specific parameters of the tunnel under complex geological conditions, reducing human intervention and improving the accuracy and reliability of the design. Field tests show that the progress and quality of tunnel excavation after using the intelligent design system have been optimized, with the over- and under-digging controlled within 12cm, and the utilization rate of the boreholes reaching more than 86%.

The platform was verified through on-site engineering applications, which not only reduced the impact of blasting vibration on the surrounding buildings, but also saved in construction costs, demonstrating its practical application value in tunnel blasting construction.

The successful development and application of the system in this study lays the foundation for the extensive promotion of intelligent technology in the field of tunnel blasting, and provides valuable experience for subsequent technology optimization and engineering application.

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