# Design and Optimization of Blasting Scheme for Two Side-Wall Excavation of Shallow-Buried Super Large Cross Section Tunnel in City

Kang Wang [1, a], Chuankui Zhang [2, b]

[1]Research Center of Geotechnical and Structural Engineering, Shandong University, Jinan, China

[2]The First Company of China Eighth Engineering Bureau Ltd, No.89, Gongyenan Road, Jinan, Shandong, China

[a]540179145@qq.com, [b]389881456@qq.com

## Abstract

With the rapid development of urban traffic, more and more large-scale shallow-buried urban tunnels have emerged, and more stringent requirements have been put forward for tunnel construction technology. Based on the detailed study of the failure law of cylindrical charge rock and the related theory and criterion of tunnel blasting, the design of blasting scheme of two side-wall excavation of Longding tunnel was carried out, which is on the connecting line between Jinan and Beijing-Shanghai High-Speed Railway. The blasting scheme was applied to the actual excavation of the construction. Through application in actual excavation and monitoring of relevant vibration of blasting, the results show that the scheme can meet the requirements of blasting vibration for urban tunnels, and realize small disturbances of the surrounding rock and accuracy control of back break. What's more, while ensuring the engineering safety and rapid construction, it has obtained certain economic benefits and can provide reference for similar projects.

## Keywords

Shallow-Buried, Super Large Section, Tunnel, CD Excavation, Blasting.

## 1. Introduction

With the improvement of national economic level, the problem of urban traffic congestion becomes more and more serious, and turns to be the key problem that restricts urban development. The expressway of emerging cities has greatly alleviated the pressure of urban transport. As a key component of urban expressway, more and more urban tunnels are under construction, and the developing trend is ultra-shallow burial and large cross-section, which also puts forward more difficult problems to be solved urgently for engineering construction technology.

The blasting is widely used in mining, underground traffic engineering, water conservancy and hydropower engineering and nuclear power foundation excavation with the characteristics of being economical, efficient and fast. However, the blasting construction will inevitably lead to the disturbance and damage of the nearby rock mass, and the vibration of the rock mass in the medium and farther area while causing smashing and stripping of rock mass in the blasting area. The damage effect of the rock mass is more prominent in the reciprocating blasting operation, such as the disturbance and damage of the surrounding rock when the two side-wall pilot tunnel is used in the large-section tunnel excavation. The mechanical properties of the damaged rock mass are deteriorated, with reduced strength and poor integrity, thus threatening the safety and stability of the rock mass. Therefore, proper analysis of the characteristics of rock mass under blasting load and reasonable control method are the focus of the project [1-4].

The large-section tunnels are flat and their surrounding rock has poor stability after excavation [5]. The stress of surrounding rock is more concentrated and the relaxation pressure is greater [6]. The bearing capacity of supporting structure is relatively reduced. Based on the above characteristics, the major methods applied in the rock large cross-section tunnel at present are single side-wall pilot tunnel method and two side-wall pilot tunnel method [7]. The two side-wall pilot tunnel method divides the entire excavation section into six pilot tunnels to conduct branch excavation, which means after a pilot tunnel is excavated to a few meters, excavation of another pilot tunnel is conducted. Therefore, surrounding rock of the tunnel undergoes reciprocating propelling blasting load.

The above problem is more prominent in the construction process of the city tunnel. Therefore, the paper studies the failure law of the cylindrical charge rock based on Longding tunnel in the connecting line between Jinan and Beijing-Shanghai High-Speed Railway. Besides, design scheme of tunnel trunk excavation and optimization have been carried out and verified in the actual engineering construction. Good application effects have been achieved.

## 2. The study of the failure law of cylindrical charge

According to the analysis and calculation of the cylinder compressive wave and ellipsoidal compressed wave generated by infinitely and finite long cylindrical charge blasting, the damage to rock during cylindrical charge blasting can be divided into crushing zone, shear failure zone, tensile failure zone and vibration zone. As shown in Figure 1.

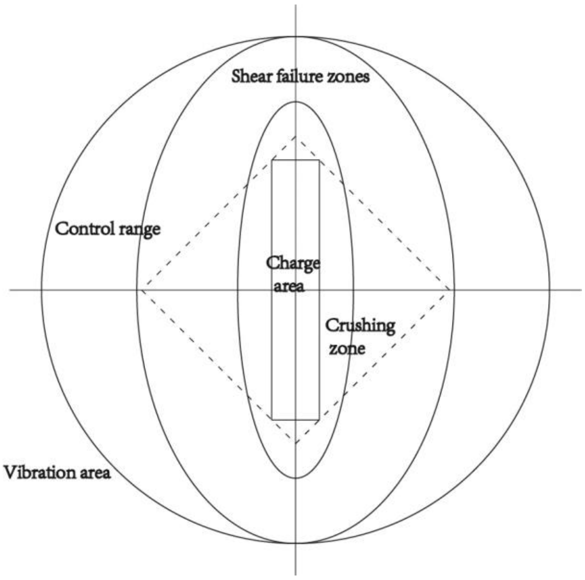



Fig. 1 Rock Blasting Zones

In the crushing zone, the rock is pulverized by strong pressure to form a series of slip surfaces at 45 ° from the radial. This is the same as the spherical charge blasting. In this area, the side of cylindrical charge is about 3.75 ~ 4.75 times length of the cylindrical charge radius; the end of cylindrical charge is about 2 ~ 3 times length of the cylindrical charge radius. This region is where the peak pressure of compressive wave in hard rock is above 20,000 barometric pressure and the pressure of compressive wave in soft rock is above 10, 000 barometric pressure.

Shear failure zone. Radial cracks form in the shear failure zone of the cylindrical charge blasting rock. There are ring cracks between the radial cracks, and shear cracks are also formed. The closer to the crushing zone, the denser cracks and crevices there will be.

In hard rock, the side area of cylindrical charge is 9 ~ 17.6 times of cylindrical charge radius, and the end of cylinder charge is 9 ~ 29.6 times of cylinder charge radius.

In general rock, the side area of cylindrical charge is 10.5 ~ 21.1 times of cylindrical charge radius, and the end of cylinder charge is 10.5 ~ 37.2 times of cylinder charge radius.

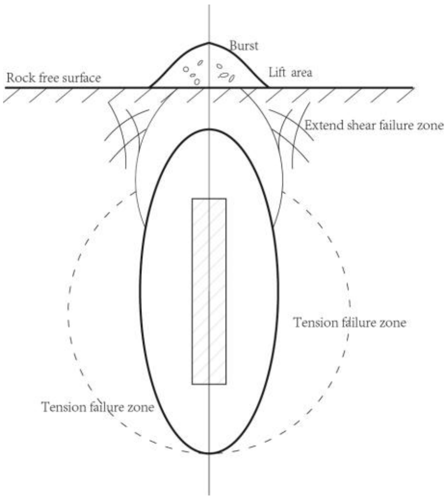
In soft rock, the side area of cylindrical charge is 12.6 ~ 28.3 times of cylindrical charge radius, and the end of cylinder charge is 12.6 ~ 45.1 times of cylinder charge radius. It is the minimum value when the ratio of the length to the diameter of the cylindrical charge is 1; it is the maximum value when the ratio of the length to the diameter of the cylindrical charge exceeds 20 times.

In the tensile failure zone. There is one-way tensile failure zone in the side rock of cylindrical charge with only radial cracks or fissures, which are denser near the shear failure zone. Tensile failure zone is one of the characteristics of cylindrical charge blasting, which should be made full use of in project blasting. In the tensile failure zone at the side of cylindrical charge, the hard rock is 0 ~ 63.4 times of the cylindrical charge radius; the general rock is 0 ~ 76 times; the soft rock is 0 ~ 102 times. It is 0 in the axial direction of the column end. When the ratio of the length to the diameter of the cylindrical charge is 1, it is taken as 0. When the ratio of the length to the radius of the cylindrical charge is larger (larger than 63.4 for hard rock; larger than 76 for general rock and larger than 102 for soft rock), the maximum value is taken.

The vibrating zone is outside the tensile failure zone. In the vibrating zone, the rock is not destroyed but has movement. The range of the vibrating zone in the infinite rock medium is very large.

For general blasting, there must be more than one temporary surface, which is the free surface of the rock. Some temporary surfaces are on the side of the cylindrical charge, some at the end of the cylindrical charge, and some both on the side and at the end of the cylindrical charge.

When the compressive wave reaches the free surface outside the cylindrical charge end, sparse wave is generated immediately. Under the common action of compressive waves and sparse waves, the shear failure zone from the cylinder end to the free surface of the rock will be further enlarged, and a stripping zone will be formed near the free surface. This is because the rock is lifted by the original fracture of the rock. As shown in Fig. 2.



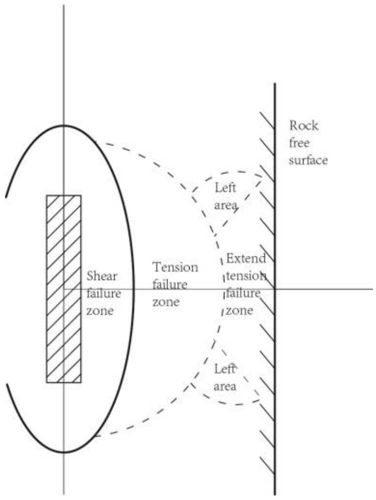




Fig. 2 Grain Axis Perpendicular to the Free Surface Fig. 3 Grain Axis Parallel to the Free Surface

When the compressive wave reaches the rock and free surface on the side of the cylindrical charge, sparse wave will immediately be produced as well. Under the common action of compressive wave and sparse wave, some rocks in the vicinity of the free surface are damaged by tension and connected with the tensile failure of the rock caused by compressive wave. Meanwhile, some rocks near the free surface will be lifted along the original fractures, as shown in Fig. 3.

In the cylindrical charge blasting, according to engineering requirements and specific conditions, making full use of the free surface of rock (temporary surface), is also the key to the design of blasting. The distance from the grain axis to the free surface at the side of the grain is the side resistance line, and the nearest side is the side minimum resistance line. The distance from the end of the grain to the free surface outside the end is the end minimum resistance line. In the blasting design, determine the minimum resistance line and the charge quantity (grain length and diameter) is the key to control the extent of blasting damage, the degree of crushing, the height of accumulation or collapse state, and the distance between rocks.

## 3. Project Overview

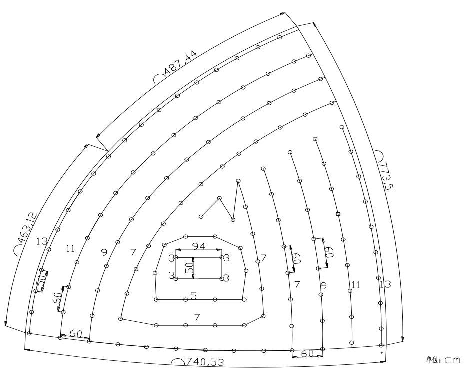
The project of connecting line between Jinan and Beijing-Shanghai High-Speed Railway is an important section of the "three horizontals and six verticals" fast road network planning of Jinan City, Shandong Province, which is also part of the 13th Five-Year Plan of Jinan City, Shandong Province. It will work with the Second-Ring South Road and Jihui Fast Road to build the city's rapid traffic corridor in the southern city connecting east and west. As the key control project of connecting line between Jinan and Beijing-Shanghai High-Speed Railway, Longding Tunnel is located on the west side of Taipingzhuang, Lixia District, Jinan. It is a two-way eight-lane, single-hole four-lane tunnel with a maximum width of 20m and a height of 13.6m. It is the large cross-section highway mined tunnel with the largest span in Shandong Province, which is also rare in the whole country. Currently, there is no related provision about single-hole four-lane tunnel in highway tunnel design and construction specifications.

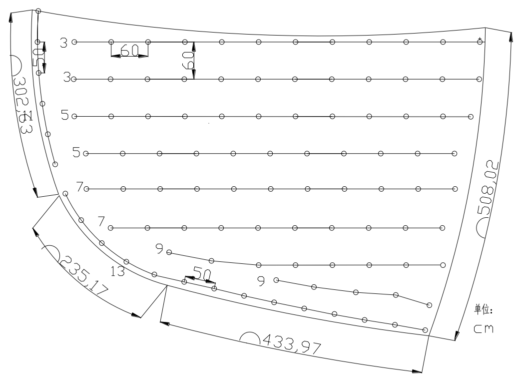
With the whole length of 2183m, Longding tunnel is a large-scale project with complex geological conditions. The minimum thickness covering the tunnel is only 17m, and the minimum distance between the left and right of the tunnel is only 12m. Most of the rock is level V and Ⅳ, and runs through the fault fracture zone and dissolved-fissure karst cave groups. Therefore, it is a super-shallow and small-spacing mined tunnel with large span. If the construction management is not good, it is very easy to encounter unfavorable situations such as large deformation of tunnel surrounding rock and large volume of landslide, which will bring a certain challenge to the construction safety of the tunnel. And due to the location near the village, it is also a serious problem to organize reasonable blasting construction and to avoid "nuisance" and "interference"

## 4. Blasting Scheme Design and Optimization

According to the actual construction, the hole diameter d=40mm; select ordinary emulsion explosives (diameter 32mm, length 18cm, mass 150g); driving footage is 0.8m; borehole utilization is 90%; auxiliary hole spacing is 0.4 ~ 0.8m; peripheral hole spacing is 0.5 ~ 1.0m; the distance between the peripheral hole and the contour line of the tunnel is 0.1 ~ 0.2m; the bottom hole spacing is 0.4 ~ 0.7m; the orifice is 0.1 ~ 0.2m higher than the bottom of the tunnel; the bottom of the hole is 0.1 ~ 0.2m lower than the bottom of the tunnel. According to the blasting requirements of V-class surrounding rock, the design follows the principle of more punching and less charge.

Specific parameters are calculated according to the above formula, and the relevant layouts are as follows:



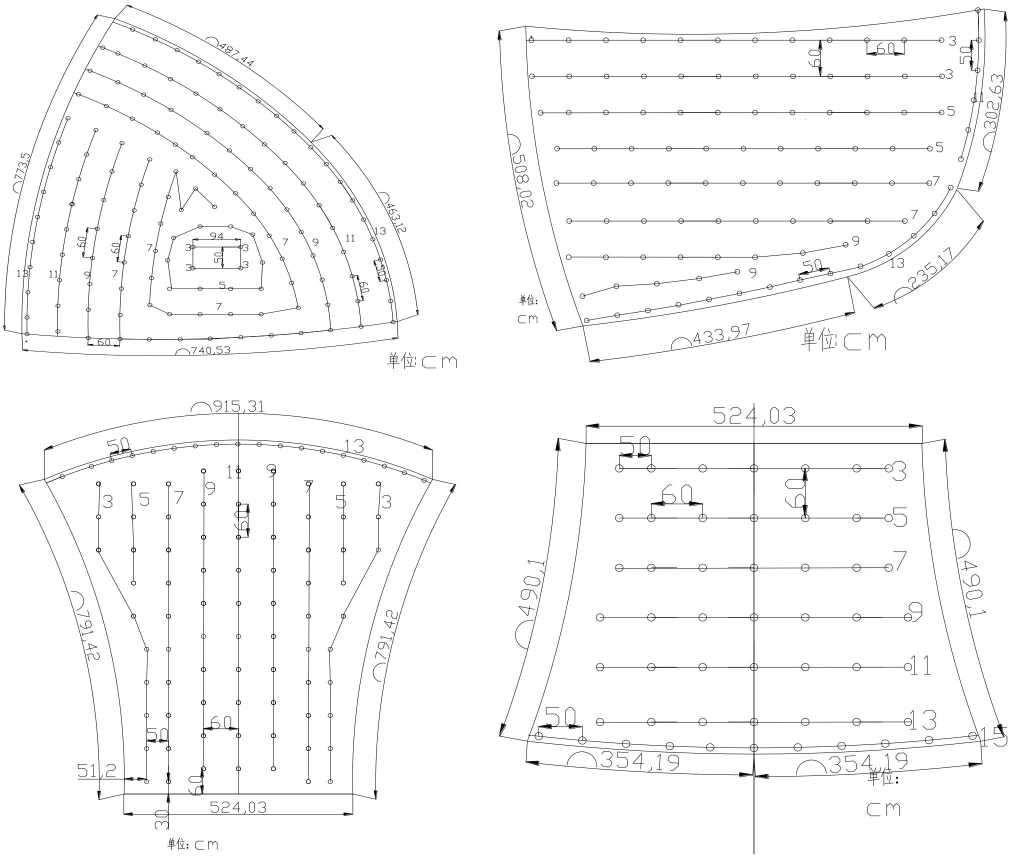



Fig. 4 Sketch Map for Hole Layouts with Two Side-Wall Pilot Tunnel Method

Table 1. Blasting parameters of two side-wall excavation

| Excavation order | Hole type | Detonator section | Hole quantity | Hole depth | Single hole dosage (kg) | Explosive quantity (kg) | Charge mode | Clogging length (cm) | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| I | Drift hole | 3 | 4 | 1.2 | 0.6 | 2.4 | Reverse | 48 | |
| | Auxiliary hole | 5-11 | 52 | 0.9 | 0.375 | 19.5 | Reverse | 45 | |
| | Perimeter hole | 13 | 20 | 0.9 | 0.135 | 2.7 | Drug string | 50 | |
| | Subtotal | | 76 | | | 24.6 | | | |
| II | Auxiliary hole | 3-9 | 34 | 0.9 | 0.375 | 12.75 | Reverse | 45 | |
| | Perimeter hole | 11 | 6 | 0.9 | 0.135 | 0.81 | Drug string | 50 | |
| | Bottom plate hole | 13 | 15 | 0.9 | 0.375 | 5.625 | Reverse | 45 | |
| | Subtotal | | 55 | | | 19.185 | | | |
| III | Drift hole | 3 | 4 | 1.2 | 0.6 | 2.4 | Reverse | 45 | |
| | Auxiliary hole | 5-11 | 53 | 0.9 | 0.375 | 19.88 | Drug string | 45 | |
| | Perimeter hole | 13 | 20 | 0.9 | 0.135 | 2.7 | | 50 | |
| | Subtotal | | 77 | | | 24.98 | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| IV | Auxiliary hole | 3-9 | 33 | 0.9 | 0.375 | 12.38 | Reverse | 45 | |
| | Perimeter hole | 11 | 6 | 0.9 | 0.135 | 0.81 | Drug string | 50 | |
| | Bottom plate hole | 13 | 15 | 0.9 | 0.375 | 5.625 | Reverse | 45 | |
| | Subtotal | | 54 | | | 18.81 | | | |
| V | Auxiliary hole | 3-11 | 86 | 0.9 | 0.375 | 32.25 | Reverse | 45 | |
| | Perimeter hole | 13 | 18 | 0.9 | 0.135 | 2.43 | Drug string | 50 | |
| | Subtotal | | 104 | | | 34.68 | | | |
| VI | Auxiliary hole | 3-13 | 36 | 0.9 | 0.375 | 13.5 | Reverse | 45 | |
| | Bottom hole | 15 | 14 | 0.9 | 0.375 | 5.25 | Reverse | 45 | |
| | Subtotal | | 50 | | | 18.75 | | | |
| Total | | | 416 | | | 141.005 | Unit volume blasted =0.80kg/m3 | | |

## 5. Conclusion

Based on the detailed study of the failure law of cylindrical charge rock and the related materials about design of Longding Tunnel, the design of blasting scheme with two side-wall pilot tunnel for Longding Tunnel was carried out, which is on the connecting line between Jinan and Beijing-Shanghai High-Speed Railway. Through application in actual excavation and monitoring of relevant vibration of blasting, the results show that the scheme can meet the requirements of blasting vibration for urban tunnels, and realize small disturbances of the surrounding rock and accuracy control of back break. What's more, while ensuring the engineering safety and rapid construction, it has obtained certain economic benefits and can provide reference for similar projects.

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