

# Double Sidewall Combined Step Method for Ovoid Structured Tunnels with Additional Large Legs at the Lower Steps Research on Construction Technology

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## ABSTRACT

*For weak surrounding rock and poor geology large section tunnel excavation is easy to collapse, tunnel support difficulties and other issues, relying on a V-class surrounding rock up and down double-layer four-center horizontal elliptical structure tunnels, the proposed lower step at the addition of a large arch foot of the double sidewall combined with the construction technology of the step method, through the field experiments show that the technology on the surrounding rock disturbance is small, strong settlement resistance, process alternation, thus greatly improving the construction safety and the degree of machinery, while also saving construction costs. Mechanization degree, but also save the construction cost. This technology has certain reference significance for the construction of similar complex tunnels.*

**Keywords:** Weak surrounding rock; large section; tunnel support; additional large arch foot at the lower step; double sidewall combined with step method

## 1. INTRODUCTION

The stable foundation pit support structure in the process of deep foundation pit excavation and

operation is the necessary premise and foundation to ensure the construction safety, especially in linear engineering, the foundation pit operation surface is narrow and the operator is dense, and the long-term stable support system is more important[1-2]. The traditional foundation pit support system has complex construction process, long construction period, large environmental pollution, can not be recycled, serious waste of resources, high construction cost, long-term accumulation of large deformation, harsh natural environment and complex geological conditions, which is easy to cause engineering stories. The pre-stressed composite steel supporting system can exert sufficient supporting force on the side wall of foundation pit and effectively control the deformation of foundation pit[3-4]. The composite steel support members are connected by high-strength bolts, which is a statically indeterminate structure with full rigid connection, with high stiffness and high redundancy safety. Fast assembly and removal, good stiffness, low bearing capacity requirements for the support. The support system is dug with support and dug with support, and the construction is not affected by the weather, and can be constructed all weather.

Under the background of rapid development of China's economic construction, China's present

engineering construction speed ranks in the forefront of the world, especially China's underground engineering construction, which has many types of projects and huge scale for the world to pay attention to [1]. At the same time, due to the complexity of the geological conditions, especially large cross-section, weak surrounding rock and other tunnel construction, often occurring perimeter rock collapse and surface settlement and other problems, to the tunnel construction has brought great challenges [2]. Therefore, in-depth research on more effective and larger construction technology is needed to ensure the safety and improve the construction efficiency of tunnel construction in complex geological environments.

Many experts and scholars have carried out a large number of studies on tunnel construction in poor geology. Li Wenjiang [3] used numerical analysis means of weak surrounding rock tunnel step method construction process of tunnel arch foot deformation characteristics, the upper step of the bedrock destabilization pattern and arch foot stability control technology for systematic analysis. Jiang Kun [4] established a discrete element numerical simulation model to optimize the construction plan of oversized cross-section and small clear distance tunnel construction in nodular rock body. Gao Feng [5] applied finite element software to study the effect of fast and slow support closure on the stability of tunnels constructed by double sidewall guided pit method using the released load method. Meng Xiangpeng [6] proposed a micro three-step excavation method for shallow buried large section tunnels in water-rich and weak loess strata by combining numerical simulation and on-site monitoring. Xu Yunming [7] used finite element numerical analysis software to study the mechanical characteristics and deformation law of shallow buried tunnel construction process. Zhong Xiaoning [8] combined the commonly used step method of tunnel construction and proposed the application of horizontal transverse support + external tensioning prestressing anchor cable to optimize the deformation control technology of the step method of tunnel construction in upright yielding millimetre rock. Chen Yunjuan [9] proposed a fast construction method based on the step method by using finite difference software, which facilitates the construction of large-scale machinery, thus improving the construction efficiency. Qiao Minglei [10] proposed the five-step single sidewall

guide pit method through numerical simulation to compare and analyze the perimeter rock deformation and steel arch frame stress during the construction process of double sidewall guide pit method, five-step single sidewall guide pit method, traditional single sidewall guide pit method and the step method. Wang [11] monitored and analyzed the tunnel perimeter rock stress, steel frame stress, initial shotcrete stress, anchor axial force, and working face extrusion deformation to provide the best solution for the establishment of a scientific and reasonable support system. establish a scientific and reasonable support system to provide reference. Chen [12] combined the full-function tunneling method and the step method to establish the construction technology of micro-step method for high geostress soft-rock tunnels. Zhao [13] analyzed the perimeter rock pressure, sprayed concrete stress, steel stress and axial stress of anchor rods, and put forward the corresponding technical recommendations for large-section tunnels.

The above studies provide certain reference for tunnel excavation in adverse geology such as weak surrounding rock. However, the research on large-section tunnel excavation construction technology for weak surrounding rocks is not perfect. In this paper, a large section tunnel with a four-center horizontal elliptical structure with upper and lower double layers of V-class surrounding rock is taken as the engineering background, and the double sidewall combined with the step method construction technology with the addition of a large arch foot at the lower step is proposed, and the feasibility of this technology is verified through on-site monitoring and analyzing the support force of the tunnel arch foot and the settlement resistance, and the time for the tunnel's initial support closure to form a ring.

## 2. TECHNOLOGICAL PRINCIPLE

Double sidewall combined with step method overrun support adopts high-pressure rotary spraying piles, with ring spacing of 40cm, inter-pile bite of 20cm, longitudinal length of 20m, and lap of 5 m. After the completion of overrun support, excavation of the left upper guide is carried out, the initial spraying of concrete is closed to the surrounding perimeter rock, steel frames are set up to hang the reinforcement mesh, systematic anchors are set, and sprayed concrete is sprayed to the designed thickness. After the left upper guide is

excavated for 5m, the right upper guide is started, and after the right upper guide is excavated for 5m, the central core soil is excavated. After the whole excavation of the upper step reached 15m, the middle step was started, which was divided into left and right parts, staggered left and right by 3m, and excavated cyclically by 1 m. After the initial support of the middle step was completed, C6 drilling rigs were used to set  $\phi 89$  locking steel pipes, the length of the locking steel pipes was 6m, and 2 sets of locking steel pipes were set in each bays. After the middle step was excavated for 5m, the next step was started. In order to improve the bearing capacity of the arch foot during the construction, the vertical jointing leg was added on the basis of the original design, and then the arc-shaped steel frame was restored, and the gap between the two operations was backfilled with shotcrete to form a large arch foot to increase the structural bearing capacity. After the completion of the arc-shaped leg, excavation of the back arch, center gutter and initial support work, back arch reinforcement installation, concrete pouring, arch wall anti-drainage construction, reinforcement installation, concrete pouring.

### 3. OPERATION POINTS

#### 3.1 High-pressure rotary spraying pile overrun support

Horizontal directional drilling rig is used to set up horizontal holes, and after drilling to the designed depth, the drilling rod is set out, and at the same time, the prepared slurry is sprayed into the soil by the horizontal drilling rig, drilling rod and nozzle at a pressure of more than 35MPa, and with the help of the flow and the impact force of the body to cut the soil layer, so that the soil body within the range of the spray jet is subjected to damage, and at the same time, the drilling rod rotates at a certain speed (10~20r/min), and pulls out at a low speed (15~30cm/min). At the same time, the drilling rod rotates at a certain speed (10-20r/min) and pulls out at a low speed (15-30cm/min), so that the soil and the cement slurry are fully stirred and mixed, and the cement hardens to form a relatively uniform diameter, with a certain strength (0.5cm). When the rotary piles bite each other, they will form a closed horizontal rotary curtain in the form of concentric circles on the tunnel vault and the surrounding area. Horizontal rotary piles have

the beam effect and soil improvement and strengthening effect, which can play a role in preventing quicksand, anti-slip, and anti-infiltration, and ensure the safety of tunnel boring.

Horizontal rotary piles in the process of high-pressure jetting, only on the radial soil (radius 200-400mm range) to produce cutting, piles are generally in  $\phi 600-800\text{mm}$ , more than the cutting range of the pressure is quickly released, the axial only produce back to the pulp pressure, the stability of the palm face has almost no effect.



Fig.1 High Pressure Spinning Pile Schematic



Fig.2 Drilling rig platform site preparation



Fig.3 Triangle Frame Manufacturing

#### 3.2 Upper guide pit construction

After reinforcing the stratum by over-excavation support, the left side of the upper guide is excavated by machinery, and the manpower cooperates with the renovation, if necessary, spraying 5cm-thick concrete to close the palm surface, applying the initial support and temporary support around the left side of the upper guide pit, i.e., spraying 4cm-thick concrete at the beginning, erecting a steel frame to hang the reinforcement

mesh, laying the systematic anchors, and shooting the concrete to the thickness of the design, and then the left upper guide is excavated for 5m, then starting to excavate the right upper guide, and then excavating for the right upper guide is excavated for 5m. After 5m excavation of the right upper guide, excavation of the core soil in the center will be carried out, and the footage of each excavation cycle will be 0.5m, and the level of the center line will be controlled by the surveyors, so as to ensure that there will be no under-excavation and over-excavation during construction. The excavation contour line is rounded as much as possible to reduce the stress concentration, and the excavation of the upper part of the other side lags behind by 3-5 m. When the overall excavation of the upper step reaches 15 m, the middle step will be carried out.

**Initial spraying:** carried out immediately after excavation, in order to close the exposed surface of the arch as early as possible, spraying concrete thickness of 4cm. clay layer section depends on the stability of the surrounding rock after excavation. The clay layer depends on the stability of surrounding rock after excavation.

**Steel frame:** the steel frame is made in accordance with the design specifications and meets the construction requirements; floating soil is removed during installation, and the foot of the arch is tamped or a mat is set up, and the longitudinal spacing of the steel frame is in accordance with the design specifications. The longitudinal spacing of the steel frame is 0.5m per joist according to the design requirements.  $\Phi 22$  connecting bars are provided in the longitudinal direction with a ring spacing of 1m and staggered arrangement.

**Hanging mesh:** Single-layer laying, using E6 qualitative steel mesh with a grid of 15×15cm, made into 1.5m×0.75m mesh, laid behind the steel frame, close to the surrounding rock, and firmly connected with the steel frame.

**Spraying concrete:** adopt wet spraying machine to spray and protect, after erecting the steel frame, hit into the next cycle of overrun pipe shed from the belly of the steel frame, seal the mouth of the pipe, and re-spray to the next cycle of overrun pipe shed.

Seal the mouth of the pipe and re-spray to the design thickness.

**Anchor pipe:** two  $\Phi 42$  anchor pipes are installed at the foot of the arch, and 22L connecting bars are

set at the end of the anchor pipes. When spraying concrete, pay attention to protect the pipe mouth, and after spraying concrete, press slurry in time.

**Drilling:** the over-the-horizon small conduit is drilled with electric drill first and then inserted. The hole is cleared with high pressure wind before grouting. Over the small conduit selection  $\phi 42 \times 4$ mm hot rolled seamless steel pipe processing and become, the top cut into a pointed boot, the tail welded washer, the length of 4.5m and 5m. over the small conduit according to the design scope along the arch peripheral contour line set up, over the small conduit from the steel frame through the abdominal space, the external insertion angle of  $15^\circ$  or so, and the tail and the welding of the steel frame connected to the integration.

**Grouting:** In order to ensure the quality of grouting, 20cm of concrete is sprayed at the mouth of the hole to seal it before grouting. High-pressure grouting pump is used to inject water slurry, and the pressure is controlled at 0.5~1.0Mpa, and the ratio of the slurry is determined according to the geological condition and the field test to ensure that the slurry spreads and bites each other, so as to improve the stability of the surrounding rock.

### 3.3 Middle step construction

The middle step is divided into left and right two parts of excavation, staggered left and right 3m, cyclic excavation 1m, when the upper step of the overall excavation of 15m, mechanical excavation of the left side of the guide, manually with the refurbishment, if necessary, spraying 5cm-thick concrete to close the palms face, the construction of the middle guide of the left side of the guide pit periphery of the initial support and temporary support, i.e., the first spraying of 4cm-thick concrete, erection of steel frames and temporary steel frames, the completion of the middle step of initial support, the use of C6 drilling rigs to carry out  $\phi 8$ cm concrete drilling, the use of C6 drilling rigs to carry out  $\phi 8$ cm concrete drilling. After the completion of the initial support of the middle step, the C6 drilling rig was used to set  $\phi 89$  steel pipes with a length of 6m, and 2 sets of steel pipes were set in each bay. After lagging behind the left side of the center guide pit for a certain distance, the right side of the center guide pit will be excavated and supported by the same process.

After the construction of the preliminary support of the upper and middle steps in the cave, when excavating the middle and lower steps, due to the poor bearing capacity of the foundation at the foot of the arch, it is difficult to provide enough anchoring force by using the originally designed  $\phi 42$  small conduit as the locking foot, and the preliminary support sinking is more serious. In view of this, we set two rows of  $\phi 89$  steel pipes as locking feet in each joist of the upper and middle steps, and the angle of setting is  $30\text{-}45^\circ$ , which effectively avoided the excessive settlement of the initial support and ensured that the initial support did not encroach on the limit.



Fig.4 Finished photo

Suggestions:

- (1) The construction of the hole section should be carried out according to the geology of surrounding rock and the results of monitoring and measuring, while the pipe shed drilling machine has not retired from the site,  $\phi 89$  The locking foot steel pipe is applied to reduce the mechanical cost.
- (2) By combining with the initial support steel frame to form a beam effect, the self-supporting capacity of the steel frame is greatly improved.
- (3) The construction time is longer than that of general  $\phi 42$  locking foot steel pipe or locking foot anchor, and the excavation of the palm face cannot be carried out when the drilling rig is working.

Excavation work.

- (4) This technology is not suitable for tunnels with small sections and many temporary support measures.
- (5) The process can be optimized according to the geological conditions of the tunnel to further control costs.

### 3.4 Downstage construction

After the middle step is bored up to 5m, the left side of the lower guide is excavated by machinery, and the left side of the lower guide is repaired manually, and if necessary, 5cm-thick concrete is sprayed to close the palm surface, and the initial and temporary support around the left side of the lower guide pit is carried out, i.e., the initial spraying of 4cm-thick concrete is carried out, and the vertical and curved legs of the lower guide are erected, and the spraying of concrete is repeated up to the designed thickness. After lagging behind the left guide pit of the lower guide for a certain distance, the right guide pit of the lower guide is excavated and supported by the same process.

Daluoshan Tunnel is designed as a four-centered round ovoid curved side wall structure, and the curved wall is at the lower step, which has better stability after the initial support closes into a ring. The stability of this structure is better after the initial support is closed into a ring, but it is difficult for the curved wall to provide sufficient vertical support for the upper and middle step arches when the lower step is excavated in the construction, so it will be difficult for the lower step to provide sufficient vertical support. The safety hidden danger after excavation of the lower step is bigger, for this reason, we adopt the construction sequence of first straight and then curved, the lower step is first applied a vertical support, spray protection and then excavation. For this reason, we adopt the construction sequence of straight first and then curved, the lower step first makes a vertical support, and then excavates to restore the original design curved wall after spraying protection, and the triangular area between the curved wall and the vertical wall is backfilled with sprayed concrete. The triangular area between the curved wall and the vertical wall was backfilled with spray concrete to form an enlarged footing, ensuring the stability of the initial support.



Fig.5 Schematic diagram of straight then curved construction

### 3.5 Construction Points

#### 3.5.1 Excavation

- (1) The shape of sidewall guide pit should be similar to oval section, and the section of guide pit should be 1/3 of the whole section;
- (2) The earth excavation is manual excavation with mechanical excavation, 30-40cm from the contour edge line to set up the surface repair layer, manual excavation must be used to ensure that the excavation contour line is smooth;
- (3) The steel frame (or temporary steel frame) at the change of process should be set up with locking anchor pipe, and the locking anchor pipe must be grouted to ensure the stability of the steel frame foundation;
- (4) Dispose of and temporarily support each cave chamber in time after excavation and close it as early as possible to form a ring;
- (5) After excavation, the steel frame of the arch is connected with the steel frame on both sides, and the steel frame position should be accurately positioned in the construction of both sides of the wall to ensure that the steel frames of each section are erected in the same vertical plane to avoid distortion of the steel frame;
- (6) The demolition of temporary steel frame should wait until the initial support construction of the main structure of the cave body is completed and stabilized;
- (7) According to the monitoring and measuring information, the temporary support can be dismantled only after the disposal is stabilized, and the length of one dismantling shall not be greater than 15m, and the length of one casting of the second lining is suitable.

#### 3.5.2 Steel Arch

##### (1) tunnel steel arch installation

- ① steel arch installed after the initial spray, and the surrounding rock must be as close as possible, but must leave a gap of 2-3cm as a protective layer of concrete.
- ② steel arch installation must ensure that both sides of the foot must be placed on a solid foundation. Before installation, the footing must be thoroughly cleaned of scum.

③ When the elevation of the foot of the arch is insufficient, it shall not be backfilled with soil or stone, but shall be adjusted by setting steel plate, and the base shall be reinforced with concrete pads if necessary;

④ The height of the arch foot must be lower than the bottom line of the tunnel section by 15-20cm. When the bearing capacity of the surrounding rock at the arch foot is not enough, the contact area of the arch foot must be increased in the direction of the surrounding rock.

⑤ The steel arch frame must be erected strictly according to the design, and the center line and elevation must be strictly controlled, and the permissible deviation of the steel frame installation is  $\pm 5\text{cm}$  for both lateral and elevation, and the inclination shall not be more than  $2^\circ$ .

⑥ The steel frame is assembled into a whole steel frame in the excavation surface, and the connecting bolts of each section must be screwed firmly. After the steel frame is erected, it is corrected to the correct position according to the center line and level, and then fixed with locating tendons, and the longitudinal connecting tendons are used to connect it with the neighboring steel frames firmly, and the steel frame and the wall surface are tightened with steel wedges or concrete pads.

##### (2) Tunnel steel arch construction

① Production: steel frame according to the design size in the hole outside the material section welding production, production is strictly in accordance with the design drawings to ensure that the curvature and size of each section are in line with the design requirements, each section of the two ends of the welded connection plate, nodes through the connection plate bolted connection securely, processing must be carried out after the test splicing check, peripheral assembling allowable deviation of  $\pm 30\text{mm}$ , the plane should be less than 20mm warping.

Each size meets the design requirements, before mass production. Strictly prohibit the use of substandard products.

② Installation: steel arch must be placed on a solid foundation should be removed under the foot of the virtual slag and other debris, the foot of the over-excavated portion should be filled with spray concrete. The steel frame should be installed in sections, the sections should be connected with

each other according to the design requirements, the plane of the connecting steel plate should be perpendicular to the axis of the steel frame, and the two connecting steel plates should be connected by bolts and welding, and the number of bolts should not be less than four. The two adjacent steel frames shall be connected with longitudinal steel bars, and the connecting steel bars shall be  $\Phi 22$  steel bars with a spacing of not more than 1 m. The steel frames shall be perpendicular to the center line of the tunnel, with no tilting in the vertical direction, no misalignment in the plane, and no twisting. The deviation  $\pm 50\text{mm}$  is allowed for up, down, left and right, and the inclination of the steel frame should be less than  $2^\circ$ . After the steel frame is installed in place, the gap between the steel frame and the surrounding rock should be filled with spray concrete. Spray concrete should be sprayed symmetrically from both sides of the arch foot upward and cover the steel frame, and the thickness of the spray concrete protective layer on the airside should be not less than 20mm.

③ Steel arch positioning: use total station to put sample points every 5m on the sprayed concrete surface, with the same elevation on both sides and in a section. Drill holes on the surface of the initial support, plug anchor inserted  $\Psi 8$  round steel, exposed 10cm, in the head of the rebar with a hacksaw engraved with a predetermined distance from the line mark. Control line in three layers, each layer of control line with the construction progress gradually measured, both sides of the head of the rebar and the design of the elevation of the inner rail surface for the fixed value, its carved on the mark and the left center line distance for the fixed value. From the control point of equal length, equal height extended to the section of the arch to be installed, three points of the common surface, make a marking nailed into the steel nails, so as to ensure that the overall each joist arch in a section. The bottom of the arch footing of each excavation was paved with dry mortar and tapped to make it compact, the size of which was 10cm longer than the flange length and 15cm thick, in order to enhance the supporting force and reduce the sinking of the arch.

### 3.5.3 Spraying Concrete

① spraying concrete using wet spraying process for construction, wet spraying machine work requires system wind pressure control at 0.5 ~ 2.0Mpa, air volume of not less than  $10\text{m}^3/\text{min}$ , the

work of the wind pressure is generally controlled at 0.4-0.5Mpa;

② jetting operation in sections, pieces from the bottom up order, the length of each section should not exceed 6m;

③ The thickness of one spraying must be determined according to the design thickness and spraying parts, and the initial spraying thickness is not less than 4-6cm; the first layer of spraying concrete should focus on filling in and filling up, spraying small pits round and smooth, and when there are pits in the rock surface, the anchor lifting mold spraying concrete should be used to deal with it;

④ The spraying operation must be carried out in layers with appropriate thickness, and the spraying of the next layer must be carried out after the final setting of the previous concrete. If the interval is more than 1h after the final setting and the surface of the first spraying has been covered with dust, the sprayed surface should be cleaned by high pressure wind and water;

⑤ At the beginning of the operation, the air must be supplied first, then the machine must be started, then the material must be supplied, and the quick-setting agent must be supplied after the concrete is sprayed from the nozzle; at the end of the operation, the quick-setting agent metering pump must be shut down first, then the material supply must be stopped, and the small amount of concrete and quick-setting agent left in the nozzle must be completely blown out before the air is stopped;

⑥ The wind pressure for spraying concrete shall meet the pressure at the nozzle at about 0.1 Mpa. When the spraying concrete operation is completed or the spraying is interrupted for any reason, the accumulated materials in the sprayer and the material delivery pipe shall be cleaned up.

⑦ The distance of the nozzle from the rock surface is 0.6-1.2m, and the sprayed surface is basically perpendicular to the sprayed surface, and the sprayed material beam makes an angle of  $5-15^\circ$  with the sprayed surface; when spraying, the sprayed material beam must be made to move in a spiral shape.

⑧ when the rock face general water seepage, can first spray mortar, and increase the amount of quick-setting agent mixing (can be appropriate to increase the amount of cement 6-8%), in order to

ensure that the initial spray according to the original proportion of the construction, when the local water out of a larger amount of buried pipes, chiseling grooves, dendritic drainage blind ditch and other measures, the water will be guided out before spraying. The water will be guided out before spraying concrete.

⑨The gap between the steel frame and the wall is filled with concrete, and the shotcrete must be symmetrically sprayed from both sides of the foot of the arch upward, and the steel frame is covered;

⑩shotcrete operations need to follow the excavation surface, the next blasting from the completion of shotcrete operations at intervals of not less than 4h.

#### 3.5.4 grouting

①Grouting with raw materials must be inspected on site, and can only be used after passing the inspection.

②slurry mixed in strict accordance with the ratio, not to adjust the ratio.

③Slurry strength must meet the design requirements, in accordance with the specification requirements to retain the air pressure specimen.

④The grouting must ensure the backfill is dense, and the radar scanning method is used for inspection after the completion of grouting in each section.

⑤The grouting site is followed and guided by the experimenter in order to deal with the problems arising in the construction and to determine the effect of grouting.

⑥The slurry mixing must be uniform and there shall be no lumps.

⑦Pay attention to the maintenance and cleaning of the machinery after grouting.

## 4. CONCLUSION

The use of this technology for the construction of the initial support arch foot support and settlement resistance enhanced, double sidewall combined with the step method of support method to reduce the weight of the initial support, and in the lower guide frame vertical leg and curved leg, the foot of the arch at the spray anchor area increased, greatly strengthened the arch foot support and settlement resistance. The closing time of the tunnel initial support is shortened, and the double sidewall

combined with the step method support method simplifies the cumbersome support of the middle and lower guides and strengthens it at the foot of the arch, so that the closing time of the tunnel initial support is shortened. Construction safety and mechanization degree is strengthened, double sidewall combined with step method support method reduces the number of times of peripheral rock disturbance and the number of process alternation, the mutual interference between the working faces is also reduced accordingly, and the working space becomes relatively large, which greatly improves the construction safety and mechanization degree.

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