



Application of Green Support Construction Technology in Mining Tunnels

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Abstract: This study investigates the engineering application of green support construction technology in the Changjiu Mining 4# Tunnel (total length 1672.03 m; longitudinal slope 2.99‰). Support schemes were optimized for different rock mass classes (II–V), covering rock bolts, shotcrete, steel arch support, and advanced support. Green materials and processes—including full-length bonded bolts, self-drilling grouting bolts, wet-mix shotcrete, alkali-free liquid accelerators, and silica fume admixtures—were adopted to enhance durability, environmental performance, and construction efficiency. Key technical parameters such as mix proportions, rebound rates ($\leq 25\%$ for arch areas; $\leq 15\%$ for other sections), and grouting pressures (0.5–1.0 MPa) were rigorously controlled. The application achieved significant improvements in support stability, material utilization, and ecological impact reduction. The findings provide technical reference for similar underground engineering projects under comparable geological conditions.

Keywords: tunnel support; green construction; shotcrete and rock bolt support; steel arch support; advanced support

1. Overview

This project is situated in Niutoushan Town, Guichi District, Chizhou City, Anhui Province. The main works involve the Changjiu Mining Logistics Corridor 4# Tunnel, with a total length of 1672.03 m. The invert elevation at the tunnel entrance is 33 m, and at the exit is 28 m, resulting in a longitudinal slope of 2.99‰. The permanent and temporary support for various slope works and underground excavations after rock excavation primarily includes support structures such as rock bolts, shotcrete, slope protection, steel mesh, steel arch support, advanced small pipe grouting, and pipe roofs[1][2].

Class II Rock Mass Support: consists of $\Phi 22$ random mortar rock bolts with a length $L=3\text{m}$, supplemented by steel mesh where necessary, and plain sprayed C25 concrete with a thickness of 5 cm. Class III Rock Mass Support: adopts $\Phi 25$ mortar rock bolts with lengths $L=3\text{m}/4.5\text{m}$; steel mesh ($\Phi 6.5@15\text{cm}\times 15\text{cm}$) is installed in the arch area, followed by sprayed C25 concrete with a thickness of 10 cm. Class IV Rock Mass Support: utilizes $\Phi 25$ mortar rock bolts ($L=4.5\text{m}$, $@1.0\text{m}\times 1.0\text{m}$); steel mesh ($\Phi 6.5@15\text{cm}\times 15\text{cm}$) is installed in the crown; reinforced arch rib supports ($3\Phi 25@100\text{cm}$) are set, and C25 concrete is sprayed to a thickness of 15 cm. Class V Rock Mass Support: Applies $\Phi 25$ mortar rock bolts ($L=4.5\text{m}$, $@1.0\text{m}\times 1.0\text{m}$); steel mesh ($\Phi 6.5@15\text{cm}\times 15\text{cm}$) is installed in the crown; reinforced arch rib supports ($3\Phi 25@100\text{cm}$) are set, and C25 concrete is sprayed to a thickness of 15 cm.

2. Green Support Construction Technology for Tunnels

2.1 Green Construction Technology for Rock Bolts

(1) Bolt Types: Full-length bonded rock bolts are adopted, including cement mortar bolts and fast-hardening cement cartridge bolts[3]. In adverse geological conditions such as severely fractured rock masses, fault zones, and water seepage zones where drilling is difficult and borehole collapse is prone to occur, self-drilling grouting bolts are employed.

(2) Bolt Specifications: The bolt body utilizes HRB400 grade ribbed steel bars with an elongation at break of $\geq 16\%$. Both the allowable and ultimate tensile loads must meet design requirements. Bolt bodies are straightened, derusted, and degreased prior to installation. Specifications for self-drilling grouting bolts are listed in Table 1.

Table 1. Specifications for Self-Drilling Grouting Bolts

Self-Drilling Bolt Spec	Nominal Diameter (mm)	Nominal Thickness (mm)	Nominal Cross-Sectional Area (mm ²)	Mass		Note
				Nominal Mass (kg/m)	Allowable Deviation %	
R25x5	25	5	314.2	2.47	±4	Self-drilling bolt body conforms to requirements for seamless structural steel tubes per GB/T 8162-2008

2.2 Green Construction Technology for Shotcrete

Shotcrete operations include plain shotcrete, bolted shotcrete, and shotcrete with steel mesh and steel support, as illustrated in Figure 1. Materials such as cement, aggregates, and admixtures for shotcrete must comply with the relevant provisions of SL377-2007, Section 6.1, and also meet the following requirements:

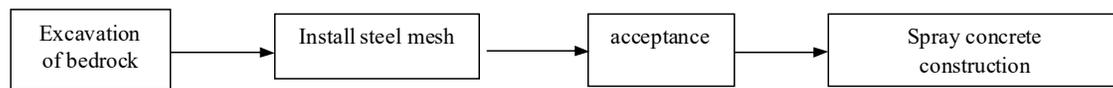


Figure 1. Shotcrete Construction Process Flowchart

2.2.1 Materials

(1) Cement: Cement strength grade not lower than P.O 42.5, produced by new dry process kilns. Specific surface area $\leq 350 \text{ m}^2/\text{kg}$, 28-day compressive strength $\geq 46 \text{ MPa}$, alkali content (calculated as $0.658\text{K}_2\text{O} + \text{Na}_2\text{O}$) $< 0.6\%$, C3A content in clinker $< 8\%$. The temperature of cement delivered to site should not exceed 60°C . The manufacturer’s test report must specify the type and content of mixed materials in the cement. (2) Coarse Aggregate: Use hard and durable crushed stone or gravel, with a maximum particle size $\leq 10 \text{ mm}$, a clay content of $\leq 1\%$, moisture content $3\% - 5\%$. (3) Fine Aggregate: Use medium-coarse sand with a fineness modulus > 2.5 , moisture content $6\% - 8\%$. (4) Accelerator: To prevent alkali-aggregate reaction, alkali-free liquid accelerators are used for wet-mix shotcrete[4].

2.2.2 Mix Proportion

(1) The shotcrete mix proportion, determined through laboratory and field tests, shall comply with the construction drawings, and adhere to SL377-2007, Article 6.3.1.

(2) The dosage of the accelerator is determined through field tests. The initial and final setting times of the shotcrete must meet the requirements of the construction drawings and the field shotcreting process[5].

(3) The selected mix proportion is implemented after approval by the Supervisor. The total alkali content from raw materials per cubic meter of shotcrete should not exceed 3.0 kg . The following requirements must be met: For C25 wet-mix shotcrete, the cement content is $375 - 400 \text{ kg/m}^3$, fly ash is Grade II or above, sand ratio is $45\% - 55\%$, water-cement ratio is $0.4 - 0.45$, chloride ion content in concrete is $\leq 0.06\%$, and alkali-reactive aggregates are not used. To improve adhesion to the rock surface, reduce rebound, and minimize loss, $20 - 30 \text{ kg}$ of silica fume (approx. 5% dosage) is added.

2.3 Construction Technology for Shotcrete and Bolt Support

2.3.1 Bolt Construction

(1) The bolt construction process is detailed in Figure 2.

(2) Bolt Construction Method: Loosened and open rock blocks on the excavation face are removed manually using high-pressure air or steel bars[6]. Holes are drilled using YT-28 leg-type rock drills and cleaned with high-pressure air. Bolts are fabricated in the reinforcement yard, stored in the warehouse, and transported to the working face using 5t trucks for installation.

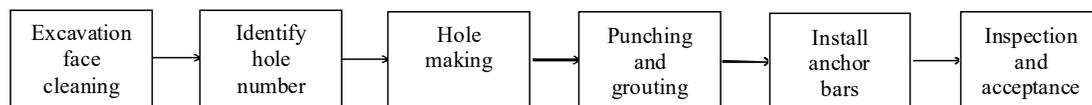


Figure 2. Process flowchart of bolt installation

2.3.2 Shotcrete Construction

Shotcreting: After the excavated tunnel section is safely cleared, bolts are installed as per design drawings to ensure

surrounding rock stability. If abnormal safety monitoring data is detected after bolt installation, additional bolts and/or immediate shotcreting are implemented as directed by the Supervisor. Wet-mix shotcrete is used for underground chambers. The rebound rate for shotcrete in underground chambers should not exceed 25% for the arch and 15% for other sections. Spraying pressure is 0.4–0.6 MPa, spraying distance is 0.6–0.8 m, and the spraying direction is essentially perpendicular to the rock surface.

2.4 Construction Technology for Steel Arch Support

2.4.1 Fabrication and Processing of Steel Arch Support

(1) See Figure 3 for the installation process of steel frame support. Steel arch supports are made from I16 I-beams. Steel arch supports are formed using a cold bending machine, controlled by a 1:1 template based on design dimensions, ensuring accurate processing dimensions and smooth curvature.

(2) Weld height is controlled at 9 mm (12 mm for flanges). Arch fabrication accounts for a 5 cm installation error and half of the deformation allowance. Welding must be sound, without false welds, and the weld surface must be free of cracks, weld nodules, and other defects.

(3) After fabrication, each steel arch unit should be trial-assembled on a level cement floor. The permissible assembly error around the perimeter is ± 3 cm, and the allowable deviation for planar warpage is 2 cm.

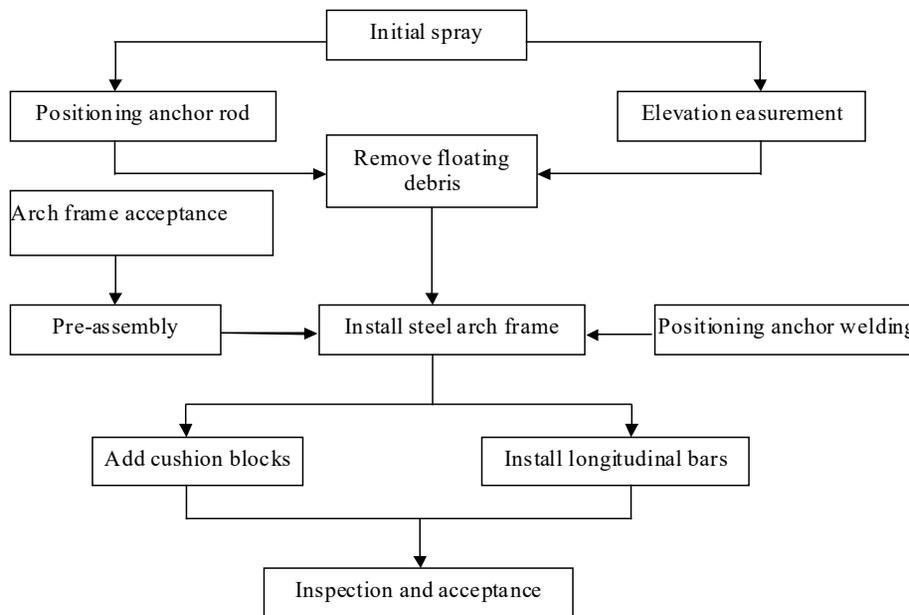


Figure 3. Steel Arch Support Installation Process Flowchart

2.4.2 Steel Arch Support Installation Process

(1) Steel arch support I16 is installed for initial support in Class IV and V rock masses. The steel arch support cross-section is shown in Figure 4. Steel arches are centrally fabricated in the processing yard and manually installed on-site after transportation.

(2) Steel arch supports should be erected promptly after excavation or initial shotcreting.

(3) Before installation, loose debris and obstructions at the base must be removed. The base of the steel arch must rest on a firm foundation. A 0.15–0.20 m thick layer of original ground is reserved at the arch base; a trench is excavated for positioning during erection. Base plates are installed as required during the splicing of each steel arch section. Allowable installation deviations: spacing, lateral position, and elevation of steel arches is ± 5 cm; verticality is $\pm 2^\circ$. After the arch passes inspection, longitudinal $\Phi 25$ connecting bars are installed. Lock-foot bolts ($\Phi 25$) are installed at the arch springing line, inclined downward at an angle of 15° to secure the base.

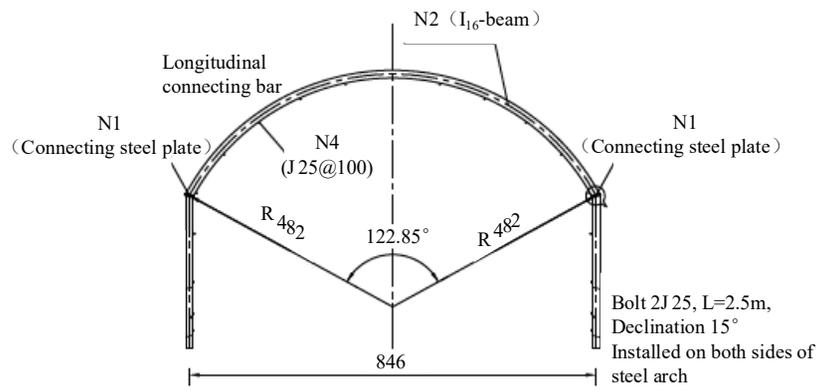


Figure 4. Steel frame support cross-section

2.5 Construction Technology for Advanced Support

Advanced support is implemented during construction in special adverse geological sections, including weak and fractured rock masses with short self-stability time, karst areas, fault fracture zones, and sections with significant water seepage or inflow. This primarily includes advanced rock bolts, advanced grouted small pipes, and advanced pipe roofs.

2.5.1 Advanced anchor

Parameters for advanced anchor are detailed in Table 2. The horizontal projection overlap length between two consecutive rows of advanced anchor should not be less than 100 cm.

Table 2. Parameters for Advanced anchor

Rock Mass Class	Bolt Diameter (mm)	Small Steel Pipe Diameter (mm)	Bolt Length (m)	Circumferential Spacing (cm)	Outward Angle (°)
IV	25	42	4.5	40	10° ~ 15°

2.5.2 Advanced Grouted Small Pipe Construction

(1) The construction process for advanced grouted small pipes is detailed in Figure 5.

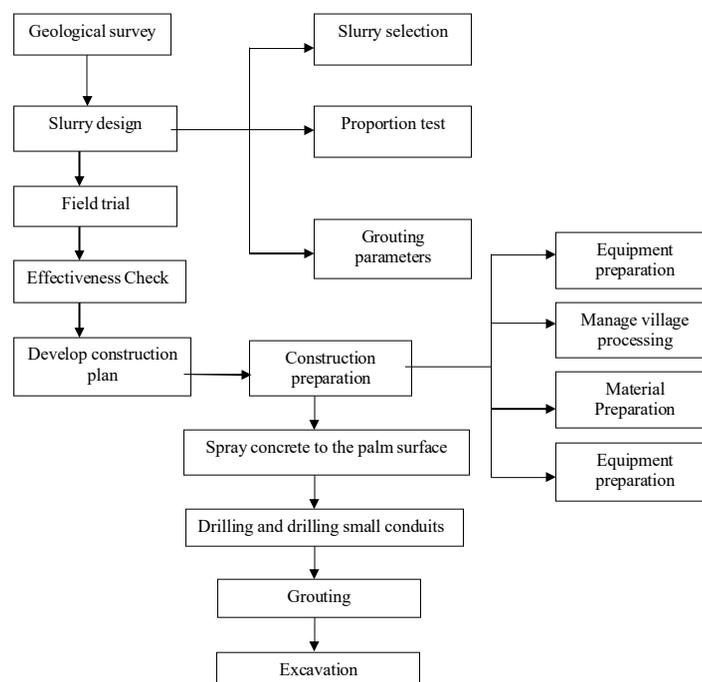


Figure 5. Advanced Small Pipe Construction Process Flowchart

(2) Pipe Fabrication and Installation Requirements: ① Small pipes are made from hot-rolled seamless steel tubes, with diameter $\Phi 42$ mm, length 4.5 m, and wall thickness 4 mm. The tail 100 cm section is not perforated, serving as the grout stop. A 6 mm diameter steel reinforcement ring is welded at the pipe end. ② Advanced small pipes have a circumferential spacing of 0.4 m and a longitudinal spacing of 3 m, with a horizontal overlap not less than 1 m. Holes are drilled along the tunnel's longitudinal excavation profile at an outward angle of 10° – 15° . The embedment length should not be less than 90% of the pipe length. ③ Before grouting the small pipes, the excavation face and the tunnel walls within a 5 m range are sealed with a 50–100 mm thick layer of shotcrete. ④ Grout material is cement slurry. The mix proportion is determined by field tests. Grouting pressure is 0.5–1.0 MPa.

2.5.3 Pipe Roof

Advanced pipe roofs are used in loose, broken weak rock masses, shallow buried sections, and where significant tunnel deformation is expected. The pipe roof scheme is implemented after approval by the Supervisor. (1) Pipe roofs use hot-rolled seamless steel tubes with an outer diameter of $\Phi 80$ mm and wall thickness of 6 mm. The clear spacing between pipes should be about 40 cm. Each pipe section length is 3–6 m. Couplings use thick-walled sleeves, with threaded length at each pipe end not less than 150 mm. Joints should be staggered. The overlap length between two successive pipe roof sets should not be less than 3 m, with an outward angle of 5° – 7° . (2) A concrete grout stop wall should be constructed before pipe roof installation. (3) Pipe roofs are arranged close to the crown. The distance between the pipe roof and the lining layer should be less than 400 mm.

3. Conclusion

(1) Bolt Support Technology: Utilizing $\Phi 22$ – $\Phi 25$ mortar bolts with lengths of 3–4.5 m, supplemented by self-drilling bolts in fractured zones, achieved a grouting compactness pass rate $\geq 95\%$, effectively enhancing the integrity and stability of the surrounding rock mass.

(2) Shotcrete Technology: By optimizing the mix proportion (cement content 375–400 kg/m³, silica fume dosage $\sim 5\%$) and employing alkali-free accelerators and micro-silica fume, the 28-day concrete strength consistently met or exceeded C25, while rebound rates were controlled within 15%–25%, reducing material waste and environmental pollution.

(3) Steel Arch Support Technology: I16 I-beam arches were fabricated with precision controlled within ± 3 cm and installed with deviations within ± 5 cm. Integrated with foot locking bolts and shotcrete, they formed a synergistic load-bearing system, significantly improving the initial support capacity in Class IV and V rock masses.

(4) Advanced Support Technology: In adverse geological sections, advanced small pipes ($\Phi 42$ mm) and pipe roofs ($\Phi 80$ mm) were employed with grouting pressures of 0.5–1.0 MPa and overlap lengths ≥ 1 m, effectively pre-supporting the rock ahead and preventing collapse and water inflow.

(5) Green Construction Effectiveness: Through optimized material selection, refined processes, and strict procedural control, a support system characterized by low alkali content, low chloride content, low rebound, high strength, and durability was achieved. This approach successfully balanced engineering safety with ecological and environmental protection requirements, demonstrating good potential for widespread application.

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