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# Application of Composite Shell Lining for Qingdao Metro Xizhen Station

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**Abstract.** Combined with the composite shell lining design of Xizhen station of Qingdao Metro line1, application of composite shell lining in Qingdao Metro station is introduced. The composite shell lining technology is set forth from such aspects as Mix design, characteristic research, construction technology and quality control, test standard and construction matters of structure fibre concrete, as well as good result is obtained in the practice. This paper provides some reference for the design and construction of similar tunnels.

## 1. Introduction

At present, the double lining structure is mostly used in the metro tunnel support engineering. The structure form is: primary support (shotcrete and anchor)+waterproof layer (sheet membrane)+secondary lining (cast in situ). The supporting principle is that the primary support is temporary structure. Secondary lining is used as safety reserve and reinforced concrete is used. Although the design of double lining is used in many projects, there are still many problems in its application: first, after the deformation of surrounding rock is basically stable, and secondary lining does not bear load in theory, only as a safety reserve; the engineering economy needs to be improved; second, the construction of double lining is completed by anchor & shotcrete support, sheet membrane, secondary cast in situ concrete and so on, with many steps, long time. Then, the waterproofing effect is difficult to guarantee. Once the drainage system is blocked, the secondary lining withstands water pressure, which reduces the safety of the structure and easily causes leakage. And the treatment of leakage is difficult and the effect is poor. Fourthly, it is difficult to maintain the leakage waterproof system (construction joints, etc.) and the blocked longitudinal drainage system<sup>[1]</sup>.

In order to solve the above problems, the design concept of Sprayed Concrete Lining has been widely used in Europe, especially in Norway, Sweden and Finland. It has also been used in hard rock tunnels in many countries outside Nordic Europe (Germany, France, Switzerland, USA, Japan, etc.). In recent years, it has also been applied to soft rock strata (such as Cross Rail Project built in London clay). In recent years, with the development of spraying membrane technology, the technology has taken on new vigor. Composite shell lining cancels sheet membrane, spraying membrane is used in better geology area; advanced grouting together with spraying membrane are used in poor geology area. Compared with the double shell lining, composite shell lining structure can be well "close", smooth outline, uniform stress, improve the reliability of the support system, and composite shell lining greatly reduces the amount of excavation and lining, improves the construction convenience, shortens the construction period<sup>[2]</sup> and saves costs and other advantages.



In addition, the upper part of Qingdao stratum is covered by Quaternary system and underlying Mesozoic bedrock. A considerable part of Qingdao metro lines passes through the strata, so drill and blast method for station and tunnel is widely used in the construction of Qingdao Metro. For this reason, this paper introduces the composite shell lining technology of the tunnel in combination with Xizhen Station of Qingdao Metro Line 1.

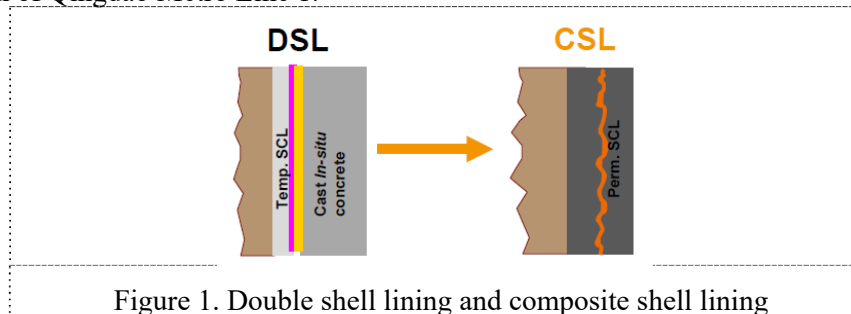


Figure 1. Double shell lining and composite shell lining

## 2. Composite shell lining design

### 2.1. Geological condition

Denudation of debris hills, foothill slope accumulation gentle slope zone. The terrain is flat and the elevation is from 19 to 29m. Quaternary soil layers are mainly Holocene artificial fill, 0-1.5m thick; Upper Pleistocene silty clay, 0-6.3m thick; underlying bedrock is late Yanshanian granite; exposed strata include strongly weathered granite subzone, moderately weathered granite, slightly weathered granite, locally developed massive fractured rocks and joint-intensive zones. The groundwater is mainly Quaternary pore water and bedrock fissure water. Quaternary silty clay and underlying bedrock are generally poor in water-rich. The water-rich zones are good in local tectonic fractured zones and belong to weak-weak permeable zones. The stability of the surrounding rock of the side wall of the station foundation pit is poor, and it is easy to seep and collapse in part during construction.

### 2.2. CSL Cross section design

The composite shell lining is used in the station hall and platform layer, the frame structure is used in the platform layer (frame column is used in the side wall), and the high-performance shotcrete and supporting bolt with good durability are used to meet the structural durability requirements in the service stage. Specific supporting parameters are as follows: system bolt adopts  $L = 4/6$  m, anti-corrosive hollow grouting bolt with a spacing of  $1.5 \text{ m} \times 1.5 \text{ m}$  (ring \* longitudinal), and ultimate pull-out force of bolt is not less than 120 KN. C40 fibre shotcrete, the first layer of shotcrete is 150 mm thick, the content of coarse fibre is  $6 \text{ kg/m}^3$ ; the middle layer is 2 cm sprayed mortar and 6 mm sprayed waterproof membrane; the second layer is 100 mm thick, and the content of fine fibre is  $1 \text{ kg/m}^3$ . The cross-section design of the composite shell lining of Xizhen Station is shown in Figure 2.

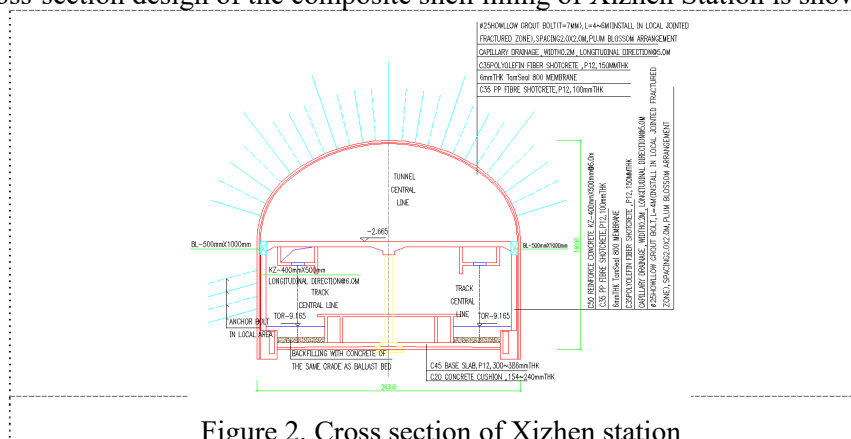


Figure 2. Cross section of Xizhen station

### 3. CSL Mix design

The composite shell lining support system is used as permanent lining structure, and its shotcrete durability is designed as the main index. Its durability index mainly involves impermeability test, electric flux and so on. Specific as follows: 1) shotcrete grade is C40, 7 days shotcrete strength is greater than 30 MPa, 28 days on-site core strength is greater than 40 MPa. 2) The initial setting time of shotcrete is less than 5 minutes and the final setting time is less than 10 minutes. 3) To meet the working performance (and workability) requirements, no segregation, bleeding or fibre agglomeration, etc. Viscosity and water retention meet the relevant requirements. 4) The slump and loss of slump meet the requirement of shotcreting in site, and the slump is about 180-220 mm. 5) The impermeability grade reaches P12. 6) To meet the durability requirements of concrete, the electric flux of C40 concrete in 56d should be less than 1500. 7) The diffusion coefficient of chloride ion meets the requirements of relevant specifications. 8) The maximum content of water-soluble chloride ion in fibre concrete mixtures is not more than 0.06%. 9) To meet the requirements of economic applicability.

#### 3.1. Synthetic fibre

Field tests and engineering experience show that the geometric parameters of coarse fibres used in composite shell lining are generally 15-60 mm in length and 100  $\mu\text{m}$  in diameter. If the length of fibre is too short, the toughness of shotcrete will be affected, and if the length of fibre is too long, the shotcrete will be easily blocked. At the same time, fibre content should meet flexural strength and energy absorption requirements. Therefore, synthetic fibres with a length of 48 mm and a diameter of 0.7 mm are suitable for this project.

#### 3.2. Water cement ratio

Water cement ratio is a decisive factor affecting the quality of shotcrete. In actual shotcrete, the water-cement ratio is relatively constant, because the range of changing water consumption is limited: if too little water is added, excess dust will be generated immediately; otherwise, if too much water is added, shotcrete will not adhere to the base surface, resulting in flow, and affect the strength grade of shotcrete. At the same time, the water cement ratio affects the impermeability and initial and final setting time.

When shotcrete is properly sprayed, the water cement ratio changes slightly, and keeps below 0.5. In the best case (aggregate need low water content, enough cement content), try to use less than 0.4 shotcrete. The water cement ratio used in this project is 0.4.

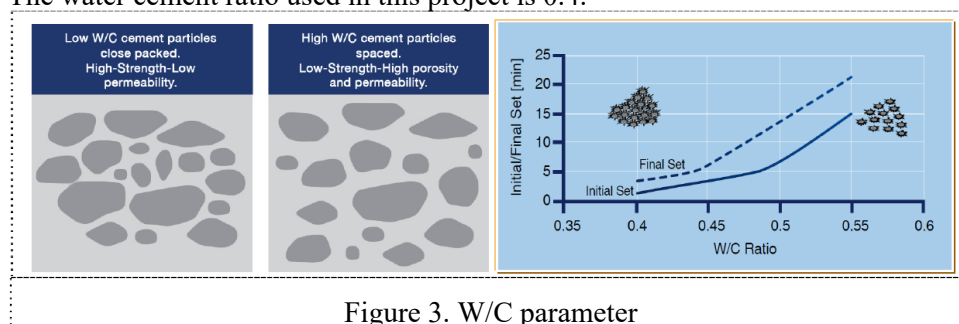


Figure 3. W/C parameter

#### 3.3. Sand ratio

Sand ratio:  $SP = \text{sand amount} / (\text{sand amount } S + \text{stone amount } G) * 100\%$ , which is the percentage of sand and stone quality in concrete. When the maximum size of stone is larger, the gradation is better and the surface is smoother, because the porosity of coarse aggregate is smaller, the smaller sand ratio can be used; when the fineness modulus of sand is smaller, because there are more fine particles in the sand, the cohesion of concrete can be easily guaranteed, and when the peeling effect of sand in coarse aggregate is smaller, the smaller sand ratio can be used; when the water cement ratio is smaller and the cement slurry is thick, the cohesiveness of soil is easy to be guaranteed, and a smaller sand rate can be used. When the liquidity of construction requirements is large, segregation of coarse aggregate often

occurs, so in order to ensure the cohesiveness, a larger sand rate is needed. The sand rate of this project is 60% after testing. If the sand fineness modulus is large due to material supply, the sand rate should be increased appropriately.

### 3.4. Slump

Slump is a quantitative index to measure its degree, which is used to judge whether the construction can proceed normally. This project requires the range of slump from 180 mm to 220 mm.

### 3.5. Accelerator

According to JGJ/T372-2016 Appendix A<sup>[3]</sup>: qualified products require that the initial setting time should not exceed 5 minutes and the final setting time should not exceed 12 minutes. According to the test, the content of alkali-free accelerator is 8% of the cement can meet the relevant requirements.

In order to improve the durability of shotcrete, combined with the characteristics of raw materials in Qingdao, the reasonable and economical mix design of C40 shotcrete is obtained through repeated tests and field verification of the durability, as shown in Table 1.

Table 1. C40 CSL Mix design.

Item	Cement	Water	Sand	Stone	Superplasticizer	Silica fume	Structural fibre	Alkali-free accelerating
Production address	Jimo Zhonglian		Pingdu	Jimo	Normet	Normet	Normet	Normet
Specification	P.O52.5		Medium sand	5-10mm	TamCem 18	TamCem Nanosilica	TamFib SP48	Tamshot 90AF
Mix design	500kg	200kg	930kg	620kg	8.5kg	5kg	6kg	40kg

## 4. Study on Performance of CSL

### 4.1. Compressive strength

The compressive strength of composite shell lining was tested by field water drill core sampling (100 mm high and 100 mm diameter) or spray slab (450mm\*350 mm\*120 mm). The 28-day compressive strength is 46.5 MPa and 42.8 MPa, respectively. Its strength grade reaches C40, which meets the design requirements.

### 4.2. Flexural strength and residual strength value

Testing of flexural strength and residual strength value shall be carried out on beams with dimensions of 75 mm x 125 mm x 600 mm cut from sprayed panels. The beams shall be tested under third point loading. The prisms shall be stored in water for a minimum of 3 days after sawing and immediately before testing, and kept moist during testing. Testing shall normally be performed at 28 days.

The experimental results show that the flexural strength of the concrete is 4.8 MPa, the residual flexural strength is 2 grade of low deformation, 4 grade of ordinary deformation and 4 grade of high deformation.

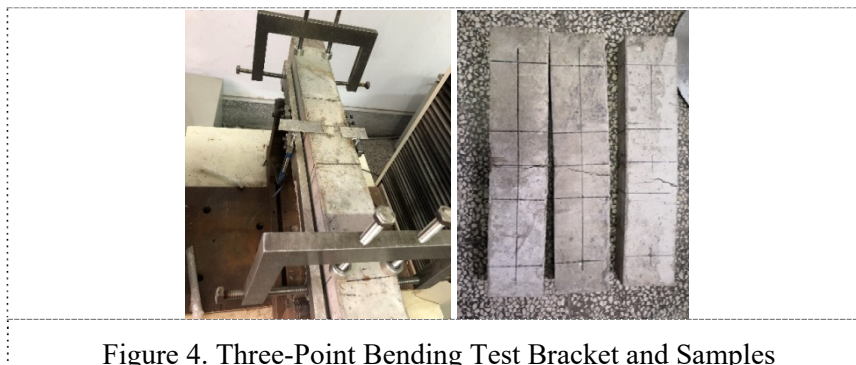


Figure 4. Three-Point Bending Test Bracket and Samples

#### 4.3. Impermeability test

Through field impermeability test, the results show that the maximum water pressure of four of the six specimens in each group without seepage is 1.4 MPa and 1.5 MPa, respectively. According to formula  $P = 10H - 1$  ( $P$  in formula is impermeability label,  $H$  is water pressure of three of six specimens when seepage, unit: MPa), the impermeability labels of the specimens are P13 and P14, respectively, which are higher than P12, and have high impermeability.

### 5. Construction technology and quality control of CSL

#### 5.1. Construction technology and process

In the spraying process, mixing should be carried out strictly according to the design mix proportion, and the construction mix proportion should be determined by testing moisture content of sand and gravel according to the requirements. Shotcrete construction process is shown in Figure 5.

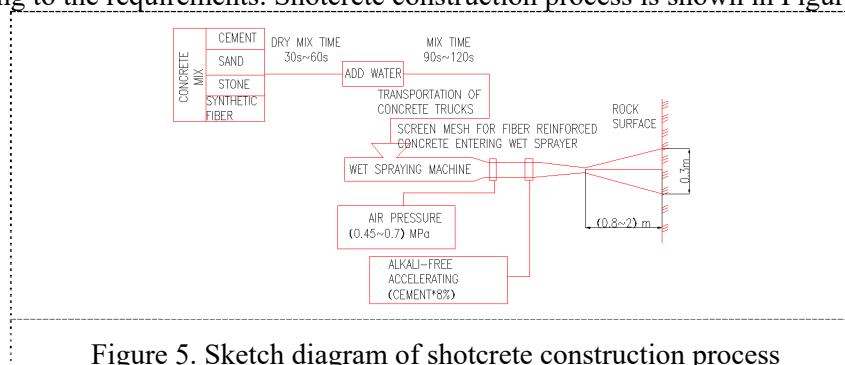


Figure 5. Sketch diagram of shotcrete construction process

#### 5.2. Wet spraying machine

According to the equipment and technical conditions of the construction unit, Normet Spraymec 8100VC is selected to spray high performance shotcrete of the composite shell permanent lining in the test section. The wet sprayer is an automatic spraying machine with a working efficiency of 25m<sup>3</sup>/h. The maximum horizontal and vertical conveying distance is 30 m and 20m.

#### 5.3. Construction quality control and notices

**5.3.1. Concrete mixing.** Mixing station shall be used in the project. When mixing concrete, the order and method of feeding should be correct, and the fibres should be well stirred to ensure the uniform dispersion of fibres. The amount of primary mixing should not exceed 80% of the rated mixing amount. When feeding materials, they are put in the order of stone, sand, cement and fibre. In order to ensure that fibres can mix evenly in concrete, it is advisable to mix stone and sand, fibres and cement together for 30 seconds before mixing water, silica fume and superplasticizer for 150 seconds.

**5.3.2. Concrete transportation.** In transportation, homogeneity should be maintained, stratification and segregation should not occur, and slurry leakage should not occur; slump should be specified at the pouring site, and sufficient time should be guaranteed for shotcreting before initial setting; the transportation road of concrete should be flat, and should be transported from the mixing site to the pouring site with the least number of times and the shortest time; The duration from exit to completion of pouring should not exceed the specification.

#### 5.3.3. Pre-shotcrete conditions:

- After blast and clearing, it is necessary to chisel the roof, clean up the top and side wall dangerous stones, and ensure the safety of the site.
- Surveyors measures the tunnel clearance section; clears and treats the underexcavated parts and all cracked, broken, water outlet and disintegrated damaged rocks, removes pumice and

- corner debris, and flushes the rock surface with high-pressure water or wind to ensure that the shotcrete and the rock are firmly bonded and well stressed together.
- When there are thimble water gushing, line water sprinkling and area water sprinkling in jointed development area, the measures of grouting and drainage should be adopted to treat the situation so as to achieve the condition of no active water.
  - For the fractured areas where the surrounding rock cracks are locally developed, local bolting and installing steel mesh are adopted to strengthen the treatment, so as to prevent the occurrence of block falling in the later stage.
  - After tunnel excavation, it is necessary to meet the Class II waterproofing requirements<sup>[4]</sup>, that is, the total wetted area should not be greater than 2/1000 of the waterproofing area; the wetted area of any 100 m<sup>2</sup> waterproofing area should not exceed 3 places, and the maximum area of a single wetted area should not exceed 0.2 m<sup>2</sup>; the average seepage volume of Tunnel Engineering should be less than 0.05L/(m<sup>2</sup>d), and the seepage volume of any 100 m<sup>2</sup> waterproofing area should not exceed 0.15L/(m<sup>2</sup>d). In the course of tunnel excavation, water quantity should be strictly controlled to ensure the quality of shotcrete.

**5.3.4. Shotcrete.** The spraying operation should ensure that the material supply is continuous and uniform, and the material flow in the hopper is continuous and uniform when the machine is in normal operation; the air pressure of the spraying operation should be 0.55-0.7 MPa; the nozzle should be vertical to the sprayed surface, and the distance between the nozzle and the spray surface should be kept at 1-2 m, as shown in Figure 6; the rebound of sprayed concrete should not be greater than 10% on the side wall and 20% on the arch. When installing steel mesh, the distance and the spray angle should be adjusted to ensure the compactness of concrete between steel mesh and wall.

**5.3.5. Shotcrete sequence.** In the process of shotcreting, high-pressure air and water are used to wash the shotcrete area from top to bottom to ensure the wetness of the shotcrete surface. The shotcrete sequence should move in spiral circles along the horizontal direction<sup>[5]</sup>, from bottom to top, first side wall and then arch, as shown in Figure 7. For areas with broken joints or poor smooth explosion, the concave section should be leveled first to make the shotcrete basically smooth.

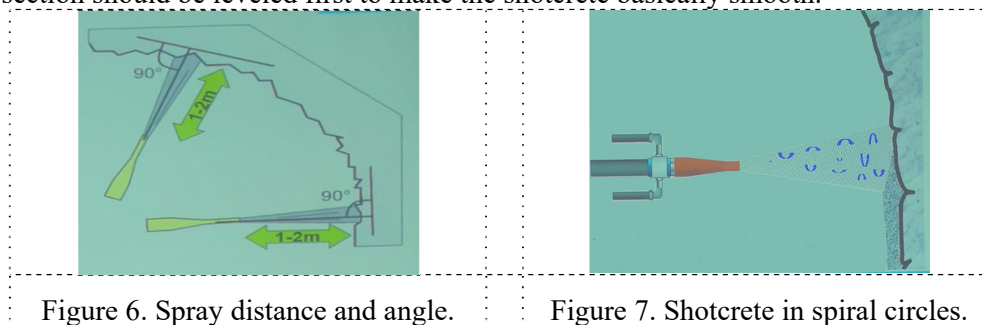


Figure 6. Spray distance and angle.

Figure 7. Shotcrete in spiral circles.

**5.3.6. Concrete curing.** Shotcrete should be cured in time. The curing time of concrete after final setting shall not be less than 7 days, and shall not be less than 14 days for important projects. Tamcem Ibond material can be added to the mixture for concrete maintenance. For shotcrete constructed in winter, when the daily average temperature is below 5 C, water spraying curing is not allowed. The surface of the formed shotcrete is shown in Fig8.



Figure 8. The surface of the formed shotcrete

## 6. Inspection Standards for CSL

The inspection contents of shotcrete include mix properties, thickness, compressive strength, early strength, bond strength, tensile strength, impermeability grade and electric flux, as follows:

### 6.1. Mix properties

- Shotcrete should have good cohesion and meet the requirements of engineering design and construction.
- The slump of wet mixing shotcrete mixture should be 180 mm to 220 mm.

### 6.2. Thickness

The thickness inspection and evaluation of shotcrete should comply with the following requirements: the shotcrete thickness of more than 60% of the inspection points of each section is not less than the design thickness, the minimum value is not less than 1/3 of the design thickness, and the total average thickness is not less than the design thickness.

### 6.3. Compressive strength

The compressive strength of shotcrete should meet the following requirements:

- The compressive strength test of shotcrete at 28 days of age should be carried out in the permanent shotcrete support project.
- The average compressive strength of 28-day-old should be greater than the design value, and the minimum test strength should not be less than 90% of the design strength. The compressive strength of the same batch of shotcrete should be evaluated by the representative value of the compressive strength of the standard blocks in the same batch

### 6.4. Early strength

The early strength of shotcrete should meet the requirements of the following figure<sup>[6]</sup>:

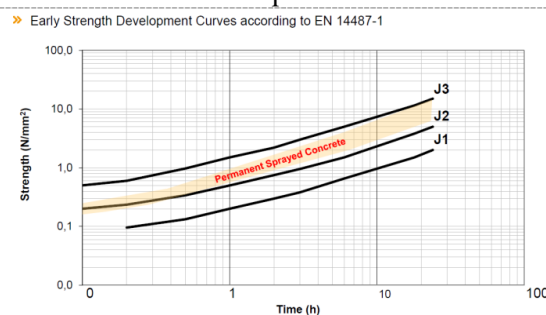


Figure 9. The early strength requirements

### 6.5. Bond strength

The minimum bond strength between shotcrete and rock mass, 1st later shotcrete, smooth layer, 2nd layer shoutcrete and sprayed waterproof membrane should be at least greater than 0.8 MPa.

### 6.6. Tensile strength

The tensile strength test of shotcrete should be carried out in accordance with the current industry standard JGJ/T 221<sup>[7]</sup>. When the strength grade of fibre shotcrete at 28d age is C40, the tensile strength should not be less than 4.8Mpa.

### 6.7. Impervious grade

The strength grade of wet shotcrete is C40 and the impermeability grade is P12. The Impervious grade inspection can be carried out in one group per 200-meter-long.

### 6.8. Electric flux

When the chloride ion penetration resistance of concrete is classified by electric flux, the test age can be 56 days, and the electric flux of C40 concrete is less than 1500 C for 56 days. Electric flux can be sampled from concrete slabs with the same mix ratio of 2 000 m<sup>3</sup> per shotcrete, not less than one group.

## 7. Conclusion

The waterproof composite shell lining of hard rock tunnel adopts C40 shotcrete, which has higher requirements on the dust content, clay lump content and gradation of sand and stone; at the same time, it needs to strengthen the accuracy of additives when mixing; strengthen the construction technology and curing of shotcrete, so as to achieve better results. Based on the project of Xizhen Station in Qingdao, the quality of the project meets the requirements by strengthening the quality control of each link. The composite shell lining of Xizhen Station replaces the double lining, which has good waterproofing effect, relatively small amount of work, simple working procedure and fast construction speed. After two years of construction inspection, the site effect is better.

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