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Research on Treatment of Lining Cracks of Small Section Water Diversion Tunnel

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Abstract: *Diversion tunnel is a common project in hydropower construction, in which cracks on concrete lining are common. Often accompanied by the water seepage, the cracks seriously damage the safety of the concrete structure and directly affect the service life of the tunnel. Dealing with the cracks is time-consuming and labor-intensive, so it increases the cost of investment and affects the construction period. Taking the 25 diversion tunnel of the construction of the Yellow River Diversion Project in the central part of Shanxi Province as an example, the cause of the cracks is analyzed based on the construction experience, and the corresponding treatment methods are proposed, which are of great significance to the quality of the project.*

Keywords: *diversion tunnel, lining concrete, circular cracks, cause analysis, treatment method*

1. Introduction

The cracks of concrete lining generated in the process of tunnel construction are irreversible, especially for tunnel projects with impermeable requirements. It not only affects the impermeability of the concrete, causes the corrosion of the steel bars and reduces the durability of the concrete, but also consumes a lot of manpower, material and financial resources and delays the construction period. Therefore, effective technological measures must be taken to control the number and width of cracks of concrete [1-7]. This paper takes the 25 diversion tunnel of the Yellow River Diversion Project (YRDP) in the central part of Shanxi Province as an example, and analyzes the causes of cracks based on construction experience, and proposes corresponding treatment methods.

2. Project profile

The diversion tunnel is one of the important parts of a water transfer project. The 25 diversion tunnel of the YRDP in the central part of Shanxi Province is located in Shilou County, Luliang City, Shanxi Province. The total length of the tunnel project is 29.13km, of which the main diversion tunnel is 22.81km long. The branch tunnel and the main tunnel are both gate-shaped sections. The branch holes have a clear width of 3.65m and a clear height of 3.2m; the main hole has a clear width of 2.5m and a clear height of 3.24m. Among them, the branch tunnel of the 17# tunnel is 605m long and has a slope of 43.71%, with rail transportation as the concrete transportation method. The surrounding rock is mainly interbedded sandstone and mudstone in the T2er2, which is mainly the type IV surrounding rock. According to the design drawings, the strength grade of the lining concrete of the tunnel is C25, the impermeability grade of the rock tunnel section is W6, the frost resistance grade is F50, the longitudinal reinforcement for the type IV surrounding rock is Φ10@200, the circumferential reinforcement is Φ16@200 and Φ18@200, the thickness of the reinforced concrete protective cover is 35mm, and the concrete pouring blocks space 12m. In view of the large longitudinal slope of the tunnel, during the construction of the second lining, the dry materials of concrete is transported to the intersection of the branch tunnel and the main tunnel using a winch. After mixing with water at the intersection, it is transported to the construction site using the tanker.

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3. Crack condition

3.1 Distribution of cracks

The lining concrete cracks of 17# tunnel generally appeared 7 days after the completion of concrete pouring. The cracking location is generally at the side wall close to the bottom plate. As time goes by, the cracks gradually extended to the top, and showed a circular distribution characteristic in about 30 days. The crack development pattern is shown in Figure 1 and Figure 2.

Figure 1: Cracks of the side wall Figure 2: Cracks of the vault

3.2 Crack observations

After the cracks were discovered, the crack width and depth were measured by using a crack tester. The crack depth is basically between 2cm~5cm, with the maximum depth of about 9cm, and the crack width is mainly between 0.15mm~0.5mm, and the maximum 1mm belongs to surface cracks. The observations of some selected cracks are shown in Table 1.

Table 1: Crack observations

Serial number	Crack number	Observation items	Stake number	Crack type	Observation date						Average value
					5.8	5.12	5.16	5.20	5.24	6.5	
1	18s-134-L-1	Crack width (mm)	54+760	Circumferential crack	0.23	0.23	0.25	0.24	0.26	0.28	0.25
		Crack depth (mm)			46.4	46.1	46	46.1	46.1	45.9	46.1
2	18s-139-L-1	Crack width (mm)	54+705	Circumferential crack	0.24	0.25	0.27	0.29	0.31	0.32	0.28
		Crack depth (mm)			21.7	21.5	21.5	21.3	21.2	21.3	21.42
3	18s-144-L-1	Crack width (mm)	54+644	Circumferential crack	0.23	0.24	0.23	0.21	0.22	0.25	0.23
		Crack depth (mm)			35.5	35.7	35.6	35.3	35.1	35.4	35.43
4	18s-149-L-1	Crack width (mm)	54+580	Circumferential crack	0.21	0.21	0.18	0.18	0.16	0.14	0.18
		Crack depth (mm)			48.5	48.7	48.7	48.9	48.6	48.6	48.67
5	18s-154-L-1	Crack width (mm)	54+520	Circumferential crack	0.15	0.15	0.16	0.13	0.14	0.14	0.15
		Crack depth (mm)			28.9	28.8	28.5	28.3	28.4	28.5	28.57
6	18s-159-L-1	Crack width (mm)	54+462	Circumferential crack	0.19	0.21	0.23	0.21	0.2	0.2	0.21
		Crack depth (mm)			46.4	46.5	46.6	46.8	46.9	46.8	46.67
7	18s-162-L-1	Crack width (mm)	54+436	Circumferential crack	0.16	0.16	0.18	0.15	0.12	0.11	0.15
		Crack depth (mm)			20.7	20.5	20.5	20.6	20.7	20.8	20.63

4. Cause analysis

4.1 Analysis of influence of concrete hydration heat

In the early construction of the tunnel, the water-reducing agent was not able to meet the requirements, which is reflected in the hardening of the concrete mixed on site, which causes the pipe blockage. The mixing ratio used in actual construction and production did not involve water-reducing agent. In order to keep the water-binder ratio unchanged, the amount of cement was increased for mixing. Due to the large amount of binding material, the internal temperature of the concrete increased after pouring, which caused cracks. The mix ratio is shown in Table 2.

Table 2: Mix proportion of lining concrete

Mix proportion	Material consumption(kg/m³)						
	Water	Cement	Fly ash	Sand	small stone	Medium stone	high range water reducing admixture
Mix proportion in experiments	175	318	80	786	589	393	4.776
Mix proportion in production	245	436	109	650	640	160	0

Cracks were found in the side poured concrete wall 7 days after the completion of the lining construction, and developed towards the top of the tunnel over time, and circular cracks were formed in about 20 working days. After the cracks appeared, the laboratory staff finally succeeded in the on-site trial mixing through several trial mixing methods and the admixture manufacturer's adjustment of the admixture. The specific mix ratio is shown in Table 3.

Table 3: Mix proportion of lining concrete

After adjustment	Material consumption(kg/m³)						
	Water	Cement	Fly ash	Sand	small stone	Medium stone	high range water reducing admixture
Mix proportion in experiments	100	298	93	947	577	383	4.629

In the successful trial mixing, the cement content was 298kg. After the mix ratio was adjusted, the strength of the standard-cured concrete test block on-site was basically about 35Mpa. After the adjustment, the frequency of cracks in the concrete poured on site was significantly reduced. At the same time, the construction unit purchased an electronic thermometer to detect the internal temperature of the concrete in order to verify the heat of hydration of the poured concrete. Two sets were buried in each block, with one buried 5cm away from the rock surface, and the other buried at the outer steel bar position in the same the concrete stake. The test showed that the temperature difference between inside and outside was basically stable, most of which were 10~15℃, with a maximum temperature difference of 16℃. According to the analysis of the test results, the internal temperature difference of the concrete poured in the mix ratio was not large, and the possibility that the cracks in the concrete were caused by the temperature was relatively small.

4.2 Analysis of the influence of internal and external constraints

The heat of hydration generated by the temperature rise of the concrete results in a higher core temperature and large thermal expansion, which produces compressive stress in the central area and tensile stress on the surface. If the tensile stress exceeds the tensile strength of the concrete, the cracks of concrete will occur. However, the results of temperature test analysis show that the temperature rise of the concrete is too small to form such a large surface tensile stress.

4.3 Analysis of the influence of external temperature changes

The poured concrete is in the main tunnel where the temperature is basically constant. The tests show that the temperature in the tunnel is basically 17~18℃, so the external temperature conditions have no impact on the concrete.

4.4 Analysis of influence of concrete shrinkage deformation

In the concrete, 80% of the water evaporates, and only about 20% of the water is necessary for the hardening of the cement. The initial 30% of free water hardly causes shrinkage. As the concrete dries and 20% of the adsorbed water evaporates, drying shrinkage occurs. Since the drying shrinkage on surface is faster than that at the center, the surface shrinkage is constrained by the concrete at the center. Accordingly, tensile stress is generated on the surface and cause cracks.

In the early stage, no water reducing agent was added to the concrete, and the water consumption per cubic meter of concrete was about 245kg. After adjustment, the water consumption per cubic meter of concrete is about 165kg, with the water consumption reduced by about 80kg per cubic meter.

According to the above theory, the evaporation of the 20% water will cause the concrete to shrink. Each block in the main tunnel consumes about 60 cubic meters of concrete. The evaporation of water in the concrete with the original mix ratio=60×0.245×20%=2.94T, and evaporation of water in the concrete with the current mix ratio=60×0.165×20%=1.98T, with the evaporation of water reduced by nearly 1T, and the shrinkage reduced significantly. The shrinkage of concrete is possibly a cause of cracks.

4.5 Analysis of the influence of subsidence deformation

C15 concrete cushion was poured on the main tunnel bottom plate during the first excavation of the tunnel. After being rolled by vehicles during the excavation and support process, the foundation surface was relatively stable, with strong bearing capacity, so the possibility of subsidence deformation is relatively small.

4.6 Analysis of the influence of trolley length

The length of the main tunnel lining trolley for the main diversion tunnel is all 12m. Based on the consultation result, the length of the trolley is possibly a cause of the cracks. Therefore, the construction unit built a 9m test chamber on the upstream and downstream of the 17#main tunnel. According to observations, cracks still appeared after the age reached about 10 days. At the same time, the construction conditions of other sections shows that the frequency of cracks in the same 12m-long block was relatively low, so the influence of the length of the trolley on the cracks is basically eliminated.

4.7 Analysis of structural stress

In the design drawings, the longitudinally distributed steel bars of the lining concrete are Φ10 plain bars. According to the consultation result, tensile stresses will appear on the side walls and vaults, and cracks will appear if the tensile stresses of the steel bars are insufficient. For this reason, the construction unit conducted a test in the 17#main tunnel. In the two blocks, the Φ10 plain steel bars for the side walls and vault were changed to Φ12 screw thread steel. After the test, cracks were still observed. Therefore, the cause of the side wall and vault tensile stress can be eliminated.

4.8 Analysis of the influence of raw materials

The fine aggregate used in the construction of the lining concrete is manufactured sand, and is coarse sand with the fineness modulus of 3.0, which may be the cause of cracks. Therefore, the laboratory staff conducted tests with adjusted sand, in which the yellow river sand and artificial sand were mixed. The fineness modulus of the mixed sand was 2.46 according to the laboratory test, which met the requirements of medium sand. 7 days later, the block pored on-site with the mixed sand was found to have more cracks than that with the manufactured sand.

5. Preventive measures

After discovering circular cracks in the lining concrete, the supervision and construction unit were organized to take immediate measures. The first measure was to adjust the concrete mix ratio (to reduce the blinding material consumption), that is adjusting the cement consumption from the original 318kg/m³ to 298kg/m³. After the adjustment, the frequency of cracks in the concrete poured on site was significantly reduced, but it was not completely eliminated. After that, the water-reducing agent that meets the requirements was re-selected, the mixing ratio was strictly controlled, the time of template dismantling was extended and the maintenance was strengthened. In view of the fact that the tunnel had been connected and the wind in the tunnel was so strong that the moisture on the surface of the concrete may evaporate faster and may produce shrinkage cracks, a curtain had been installed in the tunnel. After the above measures were adopted, the visible cracks were basically eliminated.

6. Crack treatment methods

In order to further ensure structural integrity and safety, chemical grouting technical measures were taken to treat the cracks after the backfill grouting was completed. During the backfill grouting process, it was found that there was cement slurry flowing out of individual cracks, which were found to be penetrating cracks according to the inspection. Through careful analysis and research of the participating units, comparison with the empirical results of the South-to-North Water Diversion Project, and timely organization of expert meetings, different treatment methods have been formulated for different cracks in the tunnel, and good results have been achieved.

6.1 Crack treatment

(1) Treatment of crack with a width ≤0.2mm (no water)

For anhydrous cracks with a width ≤ 0.2mm, the low-viscosity epoxy resin grout was used for painting and sealing, and the sealing width is 10cm. The material has good adhesion to materials including concrete, and is able to maintain good air tightness and waterproofness under continuous expansion, vibration and temperature changes. With simple construction process, good durability, and non-toxic pollution, suitable for the most of the lining cracks.

(2) Treatment of cracks with width ＞0.2mm and cracks with width ≤0.2mm

For cracks with width> 0.2mm and cracks with width ≤ 0.2mm, polyurethane was used for grouting after polishing. After grouting, the low-viscosity epoxy resin grout was used to paint and seal, and the sealing width is 10cm.

(3) For special cracks, for example, cracks with a width greater than 0.2mm and a large amount of water flow, after the polyurethane grouting was completed, the surface was sealed with a polyurea material, and the sealing width is 10cm.

6.2 Grouting steps

Operation steps of grouting construction: clean up cracks→fix grouting nozzle→seal cracks→mix grout→grouting

In order to ensure the quality of the sealing, the precipitates and other residues around the cracks should be removed, and the surface of the concrete within 5cm on both sides of the cracks should be polished to obtain a uniform fresh surface.

If the crack width is above 0.5mm, the distance between the grouting nozzles should be about 0.5m; for the crack width of 0.4mm~0.5mm, the distance between the grouting hole should be about 0.4m; for the crack width of 0.3mm~0.4mm, the distance between the grouting hole should be about 0.3m; For the crack width below 0.3mm, the distance between the grouting hole should be about 0.2m.

The grouting nozzle was fixed at the position of the drilled grouting hole, and the grouting nozzles were installed across cracks. In addition, they should be more dense for crack tip and the disconnected and bifurcated places.

For impermeable dry cracks, the cracks were first evenly sealed with epoxy putty, and then the surface within the range of 2.0 cm on both sides of the crack was coated with structural adhesive of 2.0 ~ 5.0 mm thick as a second sealing layer to prevent the grout in the crack from leaking during grouting. For wet cracks, a plugging agent was first used for water plugging, and after drying, the surface within the range of 2.0 cm on both sides of the crack was coated with structural adhesive of 2.0 ~ 5.0 mm thick as a second sealing layer to prevent the grout in the crack from leaking during grouting.

The grouting was carried out from bottom to top. During the grouting process, the working pressure should be maintained at 0.1 ~ 0.3mPa. The pressure should be increased appropriately for grouting of

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the last grouting nozzle. During the grouting period, it's necessary to observe whether the mortar suction is still in progress. The grouting end standard is that there is no mortar suction. If the grouting rate is less than 0.01 L/min, and lasts for at least 10 minutes, the grouting can be stopped.

7. Conclusion

In the process of tunnel construction, cracks of lining concrete are very common. Once the second lining concrete cracks, the cracks must be observed in a timely, careful and serious manner. Based on the specific observation data and theoretical analysis, the cause of the cracks in the second lining concrete should be judged and the preventive measures and treatment methods should be further studied and formulated. The studies of the possible causes of cracks during the lining construction of the central YRDP show that the increase in the amount of cement, the high wind in the tunnel after the tunnel was connected, and the faster evaporation of water on the surface of the concrete are the main reason for the cracks of the concrete of the project. In view of these causes, the construction unit put forward crack prevention and treatment methods based on construction experience, which solved the crack problem in a timely and effective manner, which can provide reference for the construction of similar projects.

References

[1] Yang Zhengmao, Nan Yuhong, Zhao Song. Causes of tunnel lining cracks and repair methods [J]. Construction and Engineering, 2014, (45):98.

[2] Lu Zhouxing. Causes and treatment of concrete cracks in diversion tunnel lining [J]. Journal of Zhejiang Water Conservancy and Hydropower College. 2011, 23(1): 29-30.

[3] Ding Jianjun. Analysis of the causes and prevention of concrete cracks [J]. China Science and Technology. 2010, 112(11):117.

[4] Sun Dongqian. Analysis of the causes of tunnel lining cracks and research on treatment measures [J]. Shaanxi Water Conservancy. 2016, 44(2):88-90.

[5] Zhang Zhonghou, Liu Shijie, Zeng Jie. Analysis of causes of circular cracks of intact bedrock tunnel lining and its prevention and control measures [J]. Modern Tunnel Technology. 2011, 48(6):124-129.

[6] Wang Haifeng. Analysis of the causes of and preventive and control measures cracks of tunnel lining concrete [J]. Water Science and Engineering Technology. 2010, (4): 87-88.

[7] Zhao Hibo, Wang Anqi. Causes and preventive measures of cracks of hydraulic tunnel lining concrete [J]. Water Resources Planning and Design. 2016, 41(4):111-113.