The crucial techniques of water leakage treatment in operating highway tunnel

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Abstract. Tunnel leakage is a common disaster in operating highway tunnel, causing many adverse effects on tunnel stability, cave facilities, traffic safety and the environment. Based on the causes and hazards of operating highway tunnel leakage, the tunnel leakage is divided into four types: construction joints leakage, lining crack leakage, fracture and cavity behind the lining leakage, concrete lining damage leakage. And the related crucial techniques and schemes were proposed. The achievements have been widely applied in Kaiyuan tunnel successfully, which offers a reference for similar tunnels.

1. Introduction
Highway tunnels have vigorously developed with increasing mileage and number in recent years. However, the status of operating highway tunnels is not optimistic. Until the end of 2007, the number of highway tunnel diseases is 4,673 nationwide. Tunnel leakage is one of the most common diseases which owns a direct or indirect relationship with other diseases, which will seriously affect the stability of the lining structure.

Domestic and foreign scholars and experts have conducted related research on leakage of highway tunnels. The generally accepted type division method is to divide the leakage water in the tunnel into points, lines, and surfaces as three forms according to formation and area [1-4]. For the treatment of leakage in operating tunnels, there are mainly buried pipe drainage methods, grouting, and plugging of leaking points [5-6].

However, the current study on the characteristics of leakage water is inadequate, and there are still many shortcomings for most of the treatment methods. Based on the leakage control project of Kaiyuan tunnel in Jinan City, this paper comprehensively considers the cause of leakage water formation, the hazard form and the universality, confirms the type of leakage in the tunnel, improves and proposes the crucial technologies for targeted treatment. Geological radar detection and water injection tests are performed to check the treatment effect. The results show that the water resistance of the surrounding rock of the tunnel has been greatly improved, and the leakage damage has been effectively controlled.

2. Engineering background
Kaiyuan Tunnel is located on Pingding mountain, the west side of the intersection of Tourism Road and Second Ring Road East in Jinan City, which is more than 1,500 meters long. The surrounding rock of tunnel entrance is crushed rock and broken limestone. There are mainly two fault fracture zone. The rock affected by F2 is loose structure with a rock-sand-like shape. The rock affected by F1 is a Crushed stone structure. At present, the drainage system of the tunnel is silted and blocked, the lining
is severely damaged, and there are a lot of cracks and voids in the surrounding rock behind the wall. After the rain seeps on the tunnel in the rainy season, it flows out in the weak area of lining. Many dripping and gushing water appears in the tunnel, which seriously affect the structural safety and traffic safety of the tunnel.

![Common forms of water leakage](image)

**Fig 1. Common forms of water leakage**

### 3. Type and characteristics of the leakage

In order to facilitate the targeted treatment, considering comprehensive cause of the formation of leakage water, the hazard forms and the universality, this paper divides the types of leakage water diseases into four categories, namely leakage from construction joints, leakage from lining cracks, cavity behind the initial support and lining, and leakage due to broken lining respectively.

1. Leakage from construction joints: It is one of the most common typical forms of leakage. The construction joint circumferentially separates the lining. It has a certain width and provides a good water-conducting channel. If it is connected to the groundwater source or when the rainfall in the rainy season is large, the construction joint presents a large amount of water and flows out in a leaching manner.

2. Leakage from lining cracks: The lining cracks are formed after the tunnel completion. The lining force of the tunnel is the main factor for the formation of cracks. In addition, the temperature changes and the tunnel settlement also easily result in cracks (generally 1 ~ 3mm in width). After passing through the weak link of the support, the groundwater is easy to seep slowly from the cracks, and the initial amount of water seepage is small, however if it is not treated in time, it is easy to accelerate the corrosion of the lining concrete and steel bars, thereby affecting the safety of the tunnel structure.

3. Cavity behind the initial support and lining: The cavity after the primary support is caused by construction factors. The voids of the surrounding rock behind the lining are related to the original geological conditions. The excavation of the tunnel also exacerbated the generation of cracks and voids. After the cavity is filled with water, the concrete is deteriorated under the action of groundwater erosion and freeze-thaw cycles, forming a leaking water channel.

4. Leakage due to broken lining: It is caused by many factors, which is more common in operating tunnels, such as weak areas of lining, uncompacted concrete, and honeycomb phenomenon of the concrete. In addition, the long-term effects of crack water, automobile exhaust, etc., cause the concrete and steel bars to corrode, and the concrete becomes crisp and soft, forming a water channel.

### 4. Tunnel leakage water treatment technologies

This paper analyzes the characteristics of the four types of seepage water, conducts research on the treatment of tunnel seepage water according to their causes and hazard forms, and proposes key treatment technologies.

#### 4.1 Construction joints leakage treatment

For the treatment of water leakage in construction joints, grouting is easily to cause slurry running out and the cracks can not be completely closed. If cement mortar is used to apply on the plugging, it is also difficult to completely block the entire construction joint. The fissure water will still leak along
the contact surface of the mortar and the second lining under long-term action. Leakage of construction joints should be sparse and not blocked, and the buried drainage method should be used. The traditional method of diversion and drainage only have one drainage pipe, which are difficult to ensure effective drainage when there is a large amount of water in the rainy season. The new buried drainage method improves the traditional process, adds stainless steel drainage device drainage measures, and uses double-layer drainage to drain leakage water to the drainage ditch.

The specific construction process is as follows:
(1) Tick groove at the construction joint, and place a soft pervious pipe in groove;
(2) Put the PVC wire trough to fix the permeable pipe, and adopt early strength cement on the outside of the PVC wire trough to seal and fix it;
(3) Install stainless steel drains on the outside as preliminary drainage measures;
(4) Apply early strength cement on the outside of the drain.

4.2 Lining cracks water leakage treatment
Lining cracks with a width of less than 2mm have a certain self-sealing and self-healing ability, due to CaCO3 which can slow down leakage generated in the initial period. According to this, sealant is used on surface to assist self-healing. For the treatment of cracks larger than 2mm in linings, water stop needles are adopted to grouting.

Grouting of lining crack requires suitable grouting materials. Chemical slurry owns the better effect on the treatment of lining cracks, but it is more expensive and has problems of toxicity and environmental pollution. Ordinary portland cement slurry is the most commonly used grouting material, but its impermeability is poor, and its volume stability is not ideal; polymer cement has good waterproof and impermeability effects, high bonding strength, can be integrated with the lining, strong corrosion resistance. It is resistant to high humidity, aging, and freezing, and its water-based product is non-toxic, meeting environmental protection requirements.

(1) Clean the cracked surface. After that, use polymer cement slurry to seal the cracks less than 2mm in surface. The closed thickness is 2mm and the width is 30mm.
(2) Drill a hole at a distance of 150mm from the crack, with a depth of 300mm, and bury a water stop needle with a rubber seal. The hole spacing is 300 ~ 500mm.
(3) The grouting material adopts polymer cement. Polymer cement forms a composite network.
structure of polymer cement particles. Compared with ordinary Portland cement, the bonding strength is significantly enhanced, which can effectively plug the lining cracks.

(4) The grouting pressure reaches is about 0.1~0.3 MPa.

4.3 The fractures and cavity behind the first branch and lining treatment

The fractures and cavity behind the first branch and lining are repaired by grouting, aiming to fill the lining fractures and reinforce surrounding rocks. In order to ensure the filling and grouting effect, water glass was added with 5% to polymer cement as the grouting material, which can accelerate slurry solidification and avoid slurry loss.

The concrete grouting process is as follows:
(1) Select grouting points to drill holes, bury hollow grouting anchors and fix by trays;
(2) The grouting material is polymer cement with 5% water glass, the water-cement ratio is 1: 1;
(3) General grouting pressure is 0.2 ~ 0.5MPa;
(4) Seal the grouting holes tightly after the grouting is completed.

4.4 Leakage treatment for lining damage

Leakage water caused by lining damage should be treated according to the amount of leakage and the degree of lining damage.

When the amount of water leakage is large and the lining concrete is damaged only in a small area, dredging water is primary. The specific process is dividing the outline of the leakage area by per 1000mm × 1000mm range, removing the surface concrete along the outline, installing stainless steel pipe at the leakage point as a water-conducting channel, diverting the water to the ring-shaped collecting-water pipe and concentratedly discharging into the drainage ditch.

When the amount of water leakage is small and the lining concrete is corroded and aged in a large area, blocking is primary. The specific process is replacing the lining concrete. Firstly remove the diseased concrete and form grooves; Secondly install wooden formwork fixed with anchor rods under the outer surface, and reserve grouting holes; then fill the formwork with concrete.

When the amount of leakage water is large and the damage on the lining damage surface is serious, the above two methods are used in combination, and it can be grouted behind the lining if necessary.

5. Inspection of leakage water treatment

According to the proposed technologies for leakage control of tunnels in operation, the targeted treatment plan was formulated to treat the leakage in Kaiyuan Tunnel, and the effect of the treatment was checked by radar detection and water injection test.

5.1 Geological radar detection

![Fig 4. spandrel measuring line pseudo-color figure of the north wall, LK3+291~ LK3+391, left cave](image)
Geological radar detection was used at leakage water treatment area in Kaiyuan tunnel. Through analysis of the geological radar detection result map (Figure 4), responses from surrounding rock background fields are normal within the scope of grouting treatment, except for the response of the geological radar corresponding to steel bars, steel arches and tunnel structures. No obvious cracks or abnormal geological radar response of the water-conducting channel are found, which shows that the grouting effect of the leakage treatment is good.

5.2 Water injection test
According to the largest daily precipitation and hourly precipitation in Jinan in the past 50 years, the water injection rate is set at 10m³/h. The water injection area is the surrounding rock outside of the leakage water treatment area, the drilling depth is 10m, and the water injection time is 1 hour. After the water injection test is completed, grouting is performed to block the drilling. The test shows that there is no leakage water in the tunnel, which proves that the tunnel leakage water can be effectively controlled after the treatment.

6. Conclusion
(1) Comprehensively consider the formation causes, the hazard form and the universality of the leakage water, water leakage in tunnel is divided into four types, namely leakages in construction joints, leakages in lining cracks, voids behind the lining and the surrounding rock after lining, and damaged lining respectively.

(2) Aiming at the treatment of four types of leakage water, the buried pipe diversion method, the grouting technique for lining fractures, the grouting technique for surrounding rock fissures and voids and the concrete replacement method for lining failure areas are proposed.

(3) Comparative analysis before and after treatment on geophysical prospecting and water injection test methods are proposed to check the effect of water leakage treatment in the operating tunnel.

(4) The article systematically illustrates the key technologies for treating leakage water from operating tunnels and provides specific implementation procedures and parameters, which has been applied on the water leakage treatment project of Jinan Kaiyuan tunnel and has achieved good results.

References
[1] WANG Hualao, LIU Xuezeng, LI Ning, et al. Safety evaluation of tunnel lining with longitudinal cracks and reinforcement design[J]. Chinese Journal of Rock Mechanics and Engineering, 2010, 1. (in Chinese)
[2] ZOU Yulin, HE Chuan, ZHOU Yi, et al. Statistics and Cause Analysis to Tunnel Leakage Diseases of Operating Highway Tunnels in Chongqing [J]. Journal of Highway and Transportation Research and Development, 2003, 22(1): 117–122. (in Chinese)
[3] CHEN Fenghong, LU Ming. Leakage treatment technology for a highway tunnel in Shanghai[J]. China building waterproofing, 2014 (14): 31-34. (in Chinese)
[4] YUAN Chao, LI shuchen, LI shucui, et al. Study of defects characteristics and repair methods of old tunnel in cold region[J]. Chinese Journal of Rock Mechanics and Engineering, 2011 (S1): 3354-3361. (in Chinese)
[5] WU Mengjun, ZHANG Yongxing, LIU Xinrong. Research on disease treatment technology of highway tunnel[J]. Chinese Journal of Underground Space and Engineering, 2008, 3(5): 967-971. (in Chinese)
[6] DOU Fengguang, LIU Xinrong, SHI Jianxun, et al. Analysis and treatment of Hanghui expressway double-arch tunnel leakage[J]. Chinese Journal of Underground Space and Engineering, 2011, 7(4): 764-769. (in Chinese)