A Research on Tunnel Lining Water Leakage from the Aspect of Operation Influence

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Abstract: In the early times, restricted by the tunnel construction technology and technical difficulties, tunnel diseases, especially water leakage of lining are widespread in the tunnel engineering of China. Leakage disease would adversely affect the lining structure and operation environment, which may endanger the normal operation of tunnel projects. Existing leakage classification standards for tunnels are mainly based on the apparent view state, and the impacts of the actual operating environment are not fully taken into consideration. Based on the characteristics of leakage influences on tunnels, leakage in tunnels is analysed from the perspective of traffic safety, including the influence on driving safety and the influences of tunnel operation. Through investigation, point out the shortcomings of existing leakage classification methods, such as criteria are not complete, quantitative criteria are insufficient, disease treatment are not considered, and so on. The research results will provide important ideas for future research of tunnel lining leakage.

1. Introduction
With rapid development of highway tunnel construction, the number of long tunnels is surging. By the end of 2016, the mileage of highway tunnels in China has reached 14039.9 km, increasing 9.7% from a year earlier. 49.3% of the tunnels are long tunnels and 23.8% are extra-long tunnels. Restricted by tunnel construction technology and technical problems in early stages, numerous tunnels have diseases. Statistics suggest that 30% of Chinese highway tunnels and 28.4% of railway tunnels suffer severe leakage disease. Meanwhile, 30% of metro tunnels in Beijing, Shanghai and Guangzhou have leakage disease. Even in Japan that enjoys more developed underground engineering techniques, more than 30% of its tunnels have leakage disease [1-3].

As a line goes that nine out of ten tunnels suffer water leakage, leakage disease is one of the most common diseases in tunnel operation. It would impact lining structure, machine equipment, highway pavement and operating environment. What’s worse, it may undermine structure bearing capability, disturb driving order and endanger traffic safety [4-6].

There are various types of tunnel leakage. Different classifications of them in engineering are as follows [7-9]:
(1) Classified by leakage forms: point leakage, joint leakage and surface leakage;
(2) Classified by leakage location and flow: leakage, drip, linear leakage and jet flow from tunnel vault as well as leakage and flow from side wall;
(3) Classified by recharge source: underground water recharge and surface water recharge.

In view of leakage disease in highway tunnels, a number of qualitative studies at home or abroad have been applied to specifications of operation and maintenance for tunnels. In Japan, Handbook of Maintenance Management for Road Tunnel classifies water leakage into four classifications in terms of positions of leakage (vault or wall), states of leakage water (jet flow, current, drip or wetting). In the USA, Highway Rail Transit Tunnel Inspection Manual introduces some indexes and takes surface wetting and 30 drips per minute as criteria to classify leakage into three categories: mild, medium and severe. In China, Technical Specification of Maintenance for Highway Tunnel classifies leakage disease into four classifications in terms of structure positions, leakage degrees, impacts on driving, etc. In light of all the existing specifications, qualitative analysis is the main method of research on highway tunnel leakage disease while quantitative study is insufficient. Structural division is the main evaluation index yet operation state is ignored. The results of water leakage classifications cannot reflect leakage’s influences on traffic operation and cannot guide tunnel leakage treatments. Therefore, those classifications have limitations as traffic volume skyrockets [10-13].

Combining with characteristics of water leakage disease in tunnels, this paper summarizes the impacts of leakage on driving safety. In light of shortcomings of the existing guides, leakage classification systems and index value takings. The research results would provide important ideas for future research of tunnel lining leakage.

2. The Influence of Water Leakage on Driving Safety

2.1. Impacting reaction ability of drivers.

Drivers’ reaction time, response action and vehicle serviceability determine driving safety in tunnel leakage condition. Generally speaking, when driving in tunnels with leakage disease, drivers would be distracted by water leakage. As a result, reaction time would increase. When vehicles are passing leakage region, definition of windshield would decrease because of leakage water. Driving vision would be impacted, which would cause response action deviation in state of emergency. Besides, affected by leakage water, friction coefficient of road would decline so that emergency braking distance may increase. Leakage would increase reaction time, decrease action accuracy and deteriorate vehicle performance. It would increase the possibility of traffic accidents.

2.2. Affecting driving emotions.

Emotion, people’s reaction to internal or external emergencies, has three states: weak and long-lasting state of mind, strong and short state of passion as well as intense state of stress. When drivers see leakage in tunnels, they would be nervous due to self-protection. Negative emotions such as repression, boredom and anger would be intense as time goes by. After emergencies, stress emotions would narrow drivers’ attention range and trigger heavy stress. Drivers would fail even forget to handle the emergencies. Affected by those emotions, they would respond slowly and take actions wrongly, which results in traffic accidents.

2.3. Affecting line of sight.

Few drainage systems in highway tunnels take structural water leakage into consideration. The lack of drainage channel, the deficiency in drainage capacity and the accumulation of water leakage result in local ponding. Tunnel lights and vehicle lights cause glare, which decreases visibility. Drivers are restricted to notice the change of vehicles and driving environment, especially when the water leakage is severe. Besides, the bad ventilation condition in linear structural tunnel restricts the dissipation of vehicle heat. As a result, water leakage on road surface tends to evaporate. The vapor attached to vehicle windows narrows down drivers’ visual range to the region that wipers can reach. Influenced by the narrowing visual range and splash of water on rear-view mirrors and windshields, the visual range is decreased.
2.4. Affecting driving environment.
Water leakage causes water film on road surface. The water film between tire and road would be constantly squeezed and discharged from both sides when vehicles are running. However, polished tires or tires with shallow tire tread patterns cannot squeeze out water timely. When the relatively motionless water film is squeezed, instantaneous hydrodynamic pressure would appear and undertake part of weight of vehicles. At this time, the adhesion coefficient of road decreases, and tire hydroplaning happens. As a result, vehicles cannot control direction and accidents may happen.

3. The Influences of Water Leakage on Tunnel Operation

3.1. Braking
As Figure 1 shows, when vehicles are running on wet pavement, the adhesion coefficient of automobile tire and road surface decreases and braking distance increases. Partial leakage makes some parts of road wet while some parts dry, which causes different adhesion coefficient of tire and road. As shown in Figure 2, when automobiles are driving in high speed, the uneven load on automobiles changes driving direction and increases the side slip angle. As a result, automobiles are unstable.

![Fig. 1 Diagram of vehicles braking on uniform pavement](image1)

Because of leakage water, the braking distance increased

![Fig. 2 Diagram of vehicles braking on uneven pavement](image2)

Due to the leakage of water, the vehicle slips and deflects

3.2. Overtaking
Steering wheels are used to change directions of vehicles. When vehicles suddenly change lanes or overtake, yaw rate appears. When vehicles suddenly change lanes or overtake, yaw rate changes and yaw moment and side slip angle increase. The process of changing lanes in tunnels is shown in Figure 3. The driver turns the steering wheel to overtake or change lanes. In that process, the steering wheel suddenly turns to left. After the car crossing the center line, the driver returns the steering wheel. At that time, the yaw response of rear wheels lags and the road holding of tire reaches saturation. The direction cannot be changed immediately. The yaw moment resulted from the lateral force of front wheels and rear wheels makes the car rotate and additional side slip angle appear. As shown in Figure 4, the running track veers off the target track.
4. The Shortcoming of Existing Classification Criteria

According to researches, Handbook of Maintenance Management for Road Tunnel (Japan), Highway Rail Transit Tunnel Inspection Manual (USA) and Technical Specification of Maintenance for Highway Tunnel (USA) are the main handbooks of classifications of leakage. Table 1 contrasts different classifications, numbers of grades and items affecting the classification. The existing classifications focus on the states, forms and positions of leakage. The evaluation indexes are not complete and they have few ties with strategies. Here are more specific analyses:

4.1. The classification criteria are not complete.

Figuring out the causes or inducements of leakage disease and its effects are the foundation of making strategies to address it. In the existing classifications, leakage is classified by qualitative criteria such as states, forms and positions of water leakage. Insufficient analyses on the causes of leakage disease and its negative influences on tunnel operation impede the application of classifications to disease treatment.

4.2. Quantitative criteria are insufficient.

In most classifications of leakage, major criteria are qualitative. Only Highway Rail Transit Tunnel Inspection Manual (USA) has a quantitative criterion. Few quantitative criteria makes tunnel project meaningless. In all the manuals of tunnel operation at home and abroad, the indexes of tunnel operation are not listed in the classification criteria of leakage. The results of classifications have few relations with therapies of tunnel disease.

4.3. Analysis on function environment is insufficient.

Water leakage has negative influence on tunnel structure, mechanical and electrical equipment, driving and pedestrian safety as well as pavement structure. The degree of disease has close relations with construction quality, structural type, mechanical and electrical type, driving status, pavement structure and rules of transport management. The existing classification criteria of water leakage are so single that they cannot reveal the function environment and results of leakage.

4.4. Disease treatments are not considered.

The classification criteria of leakage disease are degrees of water leakage but not operation status such as driving speed, types of vehicles, positions of leakage, driving behaviors, etc. The results of
classifications cannot reveal the relationship between the degrees of water leakage and tunnel operation. Therefore, the results cannot guide operation and management of tunnels.

Table 1. Leakage water classification statistic table

| Name                                                                 | Classification criteria          | Numbers of levels | Items affecting classification |
|-----------------------------------------------------------------------|----------------------------------|-------------------|-------------------------------|
| Maintenance Management for Road Tunnel (Japan)                        | Qualitative degrees, Positions   | 4                 | none                          |
| Highway Rail Transit Tunnel Inspection Manual (USA)                   | Quantitative index               | 3                 | none                          |
| Technical Specification of Maintenance for Highway Tunnel             | Qualitative degrees, Positions, Forms | 5                 | 2                             |
| Technical Manual of Railway Engineering Affairs                       | Qualitative states               | 5                 | 4                             |
| Evaluation Standard of Deterioration of Highway, Bridge and Tunnel    | Qualitative states               | 5                 | 4                             |

Note: the qualitative states include jet flow, current, drip and wetting. The quantitative index is 30 drips per minute. The positions include vault, side wall and road surface. The forms include outflow of sandy soil, ponding and freezing. The influences on driving include no influence, probable influence, influence and severe influence.

5. Conclusion

Tunnel lining leakage disease is one of the most common diseases during operation. If lack of awareness and timely prevention, it would impact lining structure, machine equipment, highway pavement and operating environment. The article analyses the leakage operation influence from the aspect of driving safety and tunnel operation. Point out the shortcomings of existing leakage classification methods. The research results list as follows:

1. Analyse the influence of water leakage on driving safety, including impaction reaction ability of drivers, affecting driving emotions, affecting line of sight and affecting driving environment.

2. Analyse the influences of water leakage on tunnel operation, including braking and overtaking.

3. Summarize the shortcoming of the existing water leakage classification criteria, for example, the classification criteria are not complete, quantitative criteria are insufficient and analysis on function environment is insufficient. Disease treatments are not considered.

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