APPEARANCE DEFECTS ON LINING STRUCTURE OF TUNNEL

Rulu Wang (1), Shuai Fan (2) and Yong Yuan(3)

(1) Shanghai Shentong Metro Co. Ltd.
(2) Department of Geotechnical Engineering, Tongji University, Shanghai 20092, China
(3) Key Laboratory of Geotechnical and Underground Engineering (Tongji University), Ministry of Education, Shanghai 200092, China

Abstract

The safe operation of a subway tunnel is directly influenced by its structural serviceability. To give an accurate evaluation on the structural performance of the operating tunnel, comprehensive inspection on the appearance of structural lining surface had been carried out. Inspection scheme was made in achieving successful documenting defects through site investigation except organization of inspection; the scheme gives the requirements and methods to register type and extent of any defect. For the apparent defects most of the attention during inspection focused on were leakage, cracks, dislocation of joint, as well as missing of part of structural members observed on its surface. All the work is expected to give some useful references for the running tunnels of metro lines in similar conditions and provide fundamental data for further action on maintenance.

1. INTRODUCTION

Inspection is one of the most important activities to the maintenance of a structure [1]. There were literatures mentioned the approaches that could be applied to tunnel inspection [2, 3]. However, for routine inspection in practical investigation, visual inspection on the lining surface of a tunnel with simple tools is of significance for an efficient evaluation.

This paper gives the works on the inspection scheme for Shanghai Metro. Meanwhile visual inspection of structural appearance is stressed on the leakage, cracks, displacement between joint, as well as imperfect on the entirety of a lining segment. As there was of proof that water ingression would be harmful to the durability of an underground structure [4], visual inspection of lining surface stresses on the evidence of leakage and its extent. Practical inspection proved the effectiveness of the inspection scheme for the mass routine inspection of Shanghai Metro, which had been extended to more than 400 km in the end of 2010 since its first subway line opened on April 10, 1995.
2. SPECIFY DEFECTS ON TUNNEL LINING

Defects appeared on the lining surface may be of unpleasant scenario in aesthetics, some of them may lead to the deficiency in structural functionality. Furthermore, threatening on running train would arise if safety of tunnel structure were worse due to progressive development of damage. To avoid these situation defects, including leakage, segment damage and dislocation of joints, should be registered along the longitudinal direction of a tunnel during inspection. To achieve an organized inspection classification of surface defects is necessary.

2.1 Leakage

Water ingress is a detrimental problem in keeping serviceability of a tunnel within its working life. Even though tunnel is designed to be watertight to prevent inflow of water, leakage is the most common hazard to the normal use of a tunnel. The harmful effect of leakage on tunnel structure is making deterioration of structural material. Except for this it also threaten the function of fittings within the tunnel. Most leakage occurs at the tube joints or grouting holes of a segment where water is penetrating through the concrete.

The inspection mainly focuses on the evidences and distribution of leakage after groundwater was leaking from a channel. The types of leakage should be distinguished, and their locations (joints, grouting holes, hand holes, or cracks), range, as well as features (specific quantitative indicators) should also be defined accordingly. The drip frequency, when water drop encountered, should be determined by stopwatch.

2.2 Cracking and Spalling

These defects appear on the lining surface may not only imply decrease of structure strength, some of them may become the channel of water ingress. Cracking of concrete is a common phenomenon in the tunnel lining, and sever cracks may cause a threat to the serviceability of tunnel structure. A crack is a linear fracture in the concrete caused by tensile forces exceeding the tensile strength of the concrete. Cracks can occur during curing (non-structural shrinkage cracks) or thereafter from external load (structural cracks). Spalling is a roughly circular or oval depression in the concrete. It is caused by the separation and removal of a portion of the surface concrete revealing a fracture roughly parallel or slightly inclined, to the surface. Usually a portion of the depression rim is perpendicular to the surface. Spalling of concrete cover would expose reinforcing bars which indicates the speed-up of deterioration in lining segment.

Surface damage appeared on segmental lining, including cracks and spalling, are mainly inspected through visual inspection, specifically the information of damage such as type, location, and extent of it. When the cracks developed to a certain extent that comes to a three dimensional closed system with the joints between tube segments, there would be a rare phenomenon that partial concrete of a segment broke apart in disintegration. If this is observed, dimension (area and depth) of broken defect should be measured and recorded precisely, the whole image data as well.

2.3 Dislocation of Joints

Dislocation of joints, including longitudinal and transversal dislocation, reflects the joint deformation of the tunnel, may be harmful to the functionality of the sealing rod and connection bolt.
The location and size of the dislocation should be measured during detection. According to the deformation analysis of tunnel longitudinal performance, it was found that if the size of dislocation were more than 4–8mm of the function of water tightness would be affected. To improve the efficiency for massive inspection, the stagger between segmental joints will not be required to be recorded if its size is less than 4mm.

3. SCHEME OF APPEARANCE INSPECTION

3.1 Inspection Process

Basically, the site inspection of appearance defects is not only a routine maintaining check for the function of tunnel system, it is in fact a professional exploration to find out the deficient or potential degradation of tunnel structure, starting from evidence on lining surface. Therefore, to ensure the validity of site investigation and facilitate the statistics and analysis of data collection, the accuracy of the inspection should be guaranteed, and the inspection process should be normalized and standardized. The process is illustrated in Figure.1.

The types of appearance defects could be initially identified by visual inspection should be listed in advance before inspection. There are other imperfections on the surface of concrete lining, such as honeycombing, chalking, peeling, or popouts. For the lining structure of underground tube here only define three types of them (ref.3.2), that is, leakage, cracks, and dislocation between joint of lining segments. Defects other than these are difficult to define could be detected by special method.

Persons involves inspection are grouped into teams. For an inspection group 3 to 4 person is preferred. One of them takes the duty to search for defect and to conduct measuring, a person should recorded the phenomenon on recoding sheet and take photo of it, the other help to lighting and assist measuring.

3.2 Measuring during Inspection

(1) Leakage

Observed leakage can be divided into subgroup in the light of their extents.

- Wet staining: The water evaporation is faster than the infiltration capacity, there is humid feeling when one touch the surface, but no feeling of water infiltration. This phenomenon may disappear under the conventional ventilation in the tunnel. If the staining cannot be touched, above the waist of tunnel lining, judgments are only relied on visual experience of inspector.
- **Seepage:** This defect will not disappear even in the condition of enhanced artificial ventilation. If one touches the lining surface, he can feel the water obviously. When paste a sheet of paper on it, the paper would change its color after soakage. For the area above one’s waist, and the leakage could be inspected through illuminate by the reflection of light.

- **Dripping:** It is easy to distinguish dripping from other leakage. As the drip rate is uniform, it is also easy to be missed when inspector passes it. So in the inspection one should pay attention to the roadbed whether there is water staining or ponds.

- **Mud gushing:** It is easier to judge this. Where the mud intruded the water inflow could obviously observed. There also is phenomenon of entrainment such as fresh sediment which results in turbid exudates.

### Table 1: Signs of leakage

<table>
<thead>
<tr>
<th>Leakage</th>
<th>Sign</th>
<th>Recording Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Staining</td>
<td>![Image]</td>
<td>Curved boundary is based on the actual distribution of the wet track</td>
</tr>
<tr>
<td>Seepage</td>
<td>![Image]</td>
<td>Curved boundary is based on the actual distribution of the seepage.</td>
</tr>
</tbody>
</table>
| Dripping      | ![Image] | (1) When less than 1 drop / min, it should be marked <1 in the ellipse;  
(2) When more than 60 drops / min, the drip line of flow has been formed, it should be marked ∞ in the ellipse. |
| Mud Gushing   | ![Image] | Curved boundary is based on the actual distribution of the drain sediment. |

### Table 2: Signs of segment damage

<table>
<thead>
<tr>
<th>Segment Damage</th>
<th>Sign</th>
<th>Recording Requirements</th>
</tr>
</thead>
</table>
| Crack          | ![Image] | (1) Curve or line, based on the actual crack shape.  
When the crack width can be measured, it should be noted.  
(2) When the crack is more serious, it should be specifically noted, and keeps detailed image data. |
| Brocken Corner | ![Image] | Fill in the actual range of the broken corner. When the depth can be measured, it should be noted. |

(2) Damage on Segment Surface
As the segment damage is more intuitive, we primarily inspect the crack and broken corner through visual inspection. The crack always presents as fissures darker than segments, and so does the broken corner because of the deficiency of concrete on the surface of the segments.
（3）Dislocation of Joints

The dislocation of joints including stagger and opening can be estimated initially by visual inspection, and ensured by touch at the susceptible point. Also, illuminating by searchlight attached to the pieces is available. Dislocation exists if there is obvious light and shade contrast when the light beam reaches it. The quantity of dislocation can be measured by steel ruler.

Table 3: Signs of dislocation of joints

<table>
<thead>
<tr>
<th>Dislocation of Joints</th>
<th>Sign</th>
<th>Recording Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stagger</td>
<td></td>
<td>The line is perpendicular to the dislocation joint, and the number means the dislocation amount.</td>
</tr>
<tr>
<td>Opening</td>
<td></td>
<td>The two oblique lines show the opening joint.</td>
</tr>
</tbody>
</table>

4. DOCUMENT INSPECTION

4.1 Recording Forms

To properly gather and record structural inspection data for historical purposes, it is necessary to develop forms that are clearly understood and easily entered into a database. These forms can be on pre-printed sheets and then scanned into the database or transferred manually. The forms to be used fall into two main categories: documentation forms and defect location forms. Below are general instructions for proper completion of the subsequent example.

- Tunnel Name: enter the name typically assigned to the tunnel.
- Line Number: enter the number of line the tunnel belongs to.
- Begin Station: enter the beginning station of the tunnel segment for which this form is being completed.
- Liner Type: enter the appropriate type of the tunnel.
- Date of Inspection: enter the month, day, and year the inspection is performed.
- Inspector(s): enter the inspector(s) name.
- Sketches: provide detailed sketches of defects found in areas of the tunnel.
- Photos: provide relevant information for any photos that are taken within that tunnel segment.
Figure 2: An example of recording form

4.2 Examples of statistics

Through the statistics and study of longitudinal distribution law of leakage in transit tunnel, leakage is more serious near the bypass in the middle and the work well at both ends. There is an example given below, as shown in Figure 5 and Figure 6, we count the number of leakage per 10m along the tunnel.
Figure 4: Longitudinal distribution of leakage of down line

5. CLOSING REMARKS

Serviceability of metro lines becomes a major concern since there are huge amounts of people travel relies on them. Basically there are many indices of imperfections or defects that would be associated with the judgment of serviceability. This paper focused mostly on the part of appearance defects which could be easily observed and measured during site inspection. The defects specified here on tunnel lining mainly include leakage, cracks, spalling, and dislocation of joints.

Organization is important for a successful site investigation not only for the efficiency but the consistence between different groups. Usually, an individual involved with site trip is of subjective image when registering a defect. Therefore, training and validation a trial is necessary before practical action even though the person had been taught with the special knowledge.

Detailed consideration on the ways of documenting is important for the on-site register of a defect, but also convenient for statistics and analysis of any defect that would reveal the cause related to it. However, one should be bearded in mind that a defect may be caused from different actions.

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