Evaluation of Condition Assessment of Tunnel Lining using Inspection Manual of CIRIA and FHWA

Fathoni Usman¹, Nursimaa Banuar¹, Mohd Nadzari Ismail² and Nor Azura Othman²

¹Civil Engineering Department, Universiti Tenaga Nasional, Malaysia
²TNB Research Sdn. Bhd, Malaysia

E-mail: fathoni@uniten.edu.my

Abstract. Maintenance need to be provided as the tunnel has serves such a long time and it is to ensure no severe failure in the tunnel will occur that would lead to the unwanted causalities. This paper presents visual condition assessment of tunnels of hydroelectric power station to determine deterioration level of shotcrete lining based on FHWA, and CIRIA report C671.

From the assessment, it is found that 40% of leakage condition is in rating 2 for MAT and 63% also leakage in rating 2 for CVT. The most severe area is along Chainage 0+300 for MAT and Chainage 0+400 for CVT. Shotcrete lining is also found able to function properly to provide drainage diverting the leaking.

1. Introduction

There are three large main sections in the tunnel of a hydroelectric power station which are Main Access Tunnel (MAT), Cable and Ventilation Tunnel (CVT), and Cavern where the turbine and machine hall are located. The matter of water in this assessment is considerably concern since it may result in further instability of the tunnel lining and induce to rock fall if it is not taken seriously. As shotcrete act to protect and cover weak formation of rock face, inspections on shotcrete lining have to be conducted in order to maintain the shotcrete lining condition to remain in a good condition.

The common defect in tunnel is leakage. Leakage is characterized by water seeping through the lining and is further classified based on observed inflow. According to Federal Highway Administration (FHWA), level of leakage is divided into 3 which is minor (i.e. the concrete surface is wet although there are no drips), moderate (i.e. active flow at a volume of less than 30 drips/min), and severe (i.e. active flow at volume greater than 30 drips/min). FHWA has proposed a threshold value of leaking where the leaking still in a range of tolerance. The limit of allowance actually has developed since 1960’s by tunnel’s owner. A maximum value of 0.8 liters/minute per 75 linear meters is one of the allowable limits [1]. This limit is for reference purposes only, with the main emphasis for determining repair required on the location of the leak and the condition of the tunnel components that are affected. Meanwhile, CIRIA, a research and information organization dedicated to improvement in all aspects of the construction industry categorized the leakage into 5 conditions from the damp patch on the leaking surface to continuous leak when they fall at a rate of about 300 drops/minute [2].

This assessment focus on MAT and CVT where the MAT function as access way to the cavern while CVT act to dilute and remove contaminants, control temperature, smoke control and improve visibility in the tunnel. The CVT also provide fresh air to prevent dangerous or harmful accumulation...
of dust, mists and vapors or gases. The objective of this study is to determine condition of the shotcrete lining along the MAT and the CVT subjected to deterioration using the both inspection manual of FHWA and CIRIA.

2. Methodology

Visual inspection on the surface of shotcrete lining along MAT of 1050 m and CVT of 750 m length is conducted to record and determine its condition. Figure 1 shows the process in a form of flow chart diagram. It starts with preparation of standard form and tools to be used in the inspection processes. The details recorded on every defect observed including type of defects, deposited color, number of drippings due to leakage, dimension of deteriorated areas and location of defects as in Figure 2. Also, some samples are collected (i.e. water drippings, deposited materials, and soot). Figure 3 shows the area of observation along cross section the tunnel.

After the completion of visual inspection on both MAT and CVT, analysis on the data obtained during the visual inspection take place. Descriptive statistical analysis is used. The level of deterioration shall be determined. Thus, the areas of severe defects manage to be discovered.
3. Analysis and discussion

The obtained data consist of defects location, description of defects, images, level of leakage based on FHWA and CIRIA respectively, and deposited color. Majority the type of defects observed along the MAT and CVT are leakage and corroded anchor bolts are also observed. The summary of the tabulated data to be analyzed is as shown in Table 1. Graphs of frequency of leaking observed are used to determine the common type of leakage and the most severe area along the MAT and CVT.

Table 1. Example of tabulated data from the visual assessment.

| Ref.no | Running dimension | Leakage (FHWA) | Leakage (CIRIA) |
|--------|-------------------|----------------|-----------------|
| LW-45  | 0 + 247.26        | 1              | 1               |
| LW-46  | 0 + 246.92        | 2              | 2               |
| LW-47  | 0 + 248.69        | 2              | 2               |
| LW-48  | 0 + 253.04        | 1              | 5               |
| LC-34  | 0 + 258.92        | 2              | 2               |
| CC-3   | 0 + 259.16        | 2              | 1               |
| RW-29  | 0 + 275.396       | 1              | 1               |

Figure 4 represents the condition of water leaking on the rock surface before the application of shotcrete lining. The data shows that the most severe area has occurred along the chainage 0+600 to 0+700 which are most likely at rate 4 to 5 based on CIRIA guidelines. It is clearly can be seen that the leaking along the chainage 0+600 to 0+700 have reduced to rate 2 to rate 3 after application of shotcrete lining as shown in Figure 5.

![Figure 4](image-url)

**Figure 4.** Water leaking condition along the MAT before shotcrete lining was applied
From the box plot analysis of MAT based on the CIRIA and also FHWA leakage scale, the result obtained indicates that chainage 0+300 to chainage 0+400 and chainage 0+900 to chainage 0+1000 were in severe condition as shown in Figure 5. Both chainages represent condition of continuous leak of water drips and they fall at dripping rate of about 300 drops/min which is at scale 5. Meanwhile, less affected area have observed along the chainage 0+500 to chainage 0+600 where most of the defects have been categorized into condition 1 which is representing a damp patch-discoloration of part of the surface of a lining and moist to touch.

Majority the leakages observed along the CVT are in moderate rate which can be said that there are only minor numbers of leakages classified as severe which are needed to be taken into further investigation. Based on box plot analysis as in Figure 6 and histogram in Figure 8 along the CVT, it shows that majority of leakage observed are classified in level 2 (i.e. seeping visible movement of film of water at the surface). It is discovered that leakages are mostly occurred from chainage 0+000 to chainage 0+100 with number of 78 moderate leakages observed. The largest number of severe leakage are discovered occurred at chainage 0+200 to 0+300 and at chainage 0+400 to chainage 0+500 hence the area need to be considered for further action in order to avoid failure.

It is observed that after almost 20 years of application of shotcrete lining, the function of the lining for the purpose of supporting the tunnel and also for diverting ground water leaking through the discontinuity of rock has degraded. Normally the process of degradation of the shotcrete lining is started when the ground water percolate or seep through the weak formation of structure of rock and the tunnel lining. It is also caused by calcination process where it clogged the weeping holes on the lining. Proper maintenance works need to be conducted to avoid possible failures such as falls of rock through or with the shotcrete and inability of shotcrete to support its own weight.

![Figure 5. Box-plot of water leakage on the MAT.](image)

![Figure 6. Box-plot of water leakage on the CVT.](image)

![Figure 7. Box-plot of water leakage on the MAT.](image)

![Figure 8. Box-plot of water leakage on the CVT.](image)
Figure 9 shows condition of water leaking at chainage 0+350 to chainage 0+375 of left wall of the MAT. It shows many leaking on the shotcrete lining are found in different rating condition. There are also sign of dried deposited materials indicating there was water leaking from that point but due to calcination the path of the water has clogged. Analysis of the deposit material using SEM EDX found that the mineral content on the deposited material at this location is Carbon (77.06%), Calcium (6.92%) and Ferrum (16.02%). It is also reflected from the color of the deposited material, it varies from white, reddish to black. The red circles are the weeping holes provided on the shotcrete lining to drain the water.

![Water leaking at chainage 0+350 to 0+375 left wall of the MAT](image)

**Figure 9.** Water leaking at chainage 0+350 to 0+375 left wall of the MAT

### 4. Conclusion

Most of distress observed is ground water leaking as its condition often appears in wetness and moisture. Result of statistical analysis confirmed that there are severe leakages observed along the right and left wall of the MAT with the presence of deposited mineral thereby could contribute to shotcrete deterioration. Most of the deposited mineral appears in white, green, black, brown and reddish in color and all those colors might indicate high mineral content and chemical reaction occurred behind the underground structure. Meanwhile, based on analysis for the CVT, the area having the highest water leaking rating is from chainage 0+400 to chainage 0+500 as a consequence more prone to shotcrete failure. Thereby require maintenance works needed to avoid any disruption in future.

### References

[1] Federal Highway Administration 2005, Highway and Rail Transit Tunnel Inspection Manual, US Department of Transportation, 2005 Edition. US.

[2] L. McKibbins, R. Elmer, K. Roberts 2009, Tunnel: Inspection, Assessment and Maintenance, CIRIA C671, Classic House, London