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DEVELOPMENT OF CONDITION RATING OF SHOTCRETE LINING OF HYDROELECTRIC POWER STATION BASED ON CONDITION ASSESSMENT OF ITS DISTRESSES

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ABSTRACT

Tunnel underground structure often exposed to an extensive deterioration especially on the tunnel lining. Water leakage is the most common distress occurred in tunnel subsequently causing other distresses to form. After providing services over years, evaluation of shotcrete tunnel lining of underground hydroelectric power station is increasing the degree of importance to ascertain its reliability. This study is conducted to generate condition rating of distress simultaneously identify how combining distresses would affect the condition of shotcrete tunnel lining rather than presenting in a single distress rating. It can be time prohibitive to conduct an assessment to identify the causes that triggered the deterioration of shotcrete using visual inspection and non-destructive test including electrical resistivity and ground penetrating radar. The results from these tests will then be analyzed using statistical analysis to determine every respective condition. There are four distresses were identified as major contribution to the deterioration of shotcrete lining involving water leakage, crack, water saturated zone and rock fractured. Based on the findings, the condition rating that has been developed able to represent more conscious descriptive meaning to each distress. Even tough when it is compared to the single parameter of assessment i.e. the water leakage, there are average different ratings from 4% to 15%.

Keywords: condition assessment, distress rating, shotcrete lining.

INTRODUCTION

The integrity of shotcrete tunnel lining as a part of support structure in an underground tunnel of hydroelectric power station should be ensured. Studies proved that most of the causes inevitably lead to distress encountered in a tunnel particularly induced by water leakage [1], [2], [3]. The study of 226 tunnels in Shenyang by Yuan *et al.* found that the most common types of distress among other distresses have occurred in more railway tunnel are water leaking and crack damage [4]. Water seeping behind the shotcrete lining could be a reason of crack formed. As stated by Richards, water leakage in concrete tunnel lining accelerates the deterioration process by allowing the water to seep through the pathway thereby enabling the contribution of reduction in concrete strength and eventually, concrete material may be decomposed by aggressive water. Therefore, corrosion of reinforcement concrete takes place. Once the concrete have affected by the corrosion process, some other sources of deterioration including cracking and spalling might be formed [1].

Therefore, visual inspection and non-destructive test are performed to evaluate the quality of shotcrete lining to estimate how long the tunnel could provide their services. Visual inspection is a fundamental assessment to be executed to identify the causes of deterioration on concrete structures prior to conducting non-destructive test [5]. Basically, visual inspection requires an observation on affecting surfaces in order to identify and define the distress that would effects the performance of the tunnel [6]. Due to the visual inspection limitations, application of non-destructive test complements the inspection in identifying hidden defects which unrealistically achieved by visualizations [6]. As stated by Richards, Non-destructive test enable to be conducted without causing any damages towards the tunnel lining [1]. A number of expertise involved in the project of strategic highway research program accepted the method of non-destructive test to be conducted to addressed the extent of distress like water leakage, voids, delamination and spalling and etc. [7].

Tsoflias introduced a geophysical method for imaging fractures in the subsurface by using ground penetrating radar (GPR) [8]. The GPR operates by transmitting high-frequency electromagnetic pulse waves to the underground through an antenna once the conductivity and difference dielectric constant is detected [9]. As limitation of non-destructive test to evaluate the condition of rock that have been lined by shotcrete, Ariffin suggested ground penetrating radar and electrical resistivity would be the best method to be employed in identifying the fractured rock or weak zone. Electrical resistivity mainly adopted to identify various material properties throughout the tunnel. The resistivity survey will classify the area into several conditions. For example, value of resistivity less than 100 Ωm is considered as a weak zone and containing water while more than1000 Ωm is considered as high resistivity value which classified as dry zone and less fractured [10].

This study employed the method of visual inspection and non-destructive test by using GPR and electrical resistivity in three section of tunnel Main Access Tunnel (MAT), Cable and Ventilation Tunnel (CVT) and cavern to provide distress rating.

CONDITION ASSESSMENT

Water leakage

The visual inspection is adopted in this study to identify structural distress on the exposed shotcrete lining surface of MAT, CVT and cavern. The nature of water leakage distress is categorized based on guidelines specified by Federal Highway Administration (FHWA) and Construction Industry Research and Information Association (CIRIA) requirements. FHWA is the United States of America government's agency for highway transportation roles to supervise federal funds used for constructing and maintaining the National Highway System. According to FHWA guidelines, level of leakage is divided into 3 conditions as presented in Table-1.

Meanwhile, CIRIA, a member-based research and information organisation that dedicated to make an improvement in all aspects of the construction industry in United Kingdom classified water leakage into 5 as shown in Table-2.

The observations data were categorised based on Federal Highway Administration (FHWA) and CIRIA guidelines were recorded on the standardize form sheet and were scale up the nature of water seepage from 1 to 5.

Table-1. Condition of leakage based on FHWA.

Level	Condition	Leakage
1	Minor	The concrete surface is wet although there are no drips
2	Moderate	Active flow at a volume less than 30 drips/min
3	Severe	Active flow at volume greater than 30 drips/min

Table-2. Condition of leakage based on CIRIA.

Level	Condition	Leakage
1	Damp patch	Damp patch, discoloration of part of the surface of a lining and moist to touch
2	Seep	Seep-visible movement of a film of water across a surface
3	Standing drop	Standing drop, a drop of water which does not fall within a period of 1 min
4	Drip	Drip-Drop of water which fall at a rate of at least 1/min
5	Continuous leak	Continuous leak, a trickle or jet of water drips become a continuous trickle when they fall at a rate of about 300 min

Crack

The nature of cracks distress is categorized based on the guidelines adopted from American Concrete Institute (ACI) Committee. ACI introduced the definition and details of crack as a "complete or incomplete separation, of either concrete or masonry, into two or more parts produced by breaking or fracturing" and its categorization is based on the length and type of the cracks (ACI, 2008).

The assessment of cracks on shotcrete lining basically were evaluated based on its moisture, length, orientation and deposits condition. For every condition of crack presents their rating of severity accordingly. The higher condition rating reflects the greater severity of cracks as presented in Table-3. Table-4 shows the weightage provided for each cracks condition.

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Table-3. Crack condition rating.

Condition	Rating	Remarks
Orientation	1	Vertical - refers to cracks running perpendicular to the tunnel length
	2	Horizontal - refers to cracks running parallel to tunnel length
	3	Diagonal - refers to cracks running between horizontally and vertically.
Length	1	Cracks of length from < 16 cm
	2	Cracks of length from 16 - 32 cm
	3	Cracks of length from 33 - 48 cm
	4	Cracks of length from 49 - 64 cm
	5	Cracks of length > 64 cm
Moisture	1	Moisture is absent; the crack is dry
	2	Moisture present
Deposit presence	1	No deposit observed
	2	Deposits are present

Table-4. Condition weightage for crack.

Condition	Weightage (%)
Moisture	20
Length	30
Orientation	30
Deposits	20
Total	100

In categorization, the overall condition of cracks, it was divided into 5 scale regard to their severity as shown in Table-5 below.

Table-5. Severity of cracks.

Scale	Severity
1	Very good
2	Good
3	Moderate
4	Poor
5	Very poor

The flowchart for determining crack rating is presented as in Figure-1

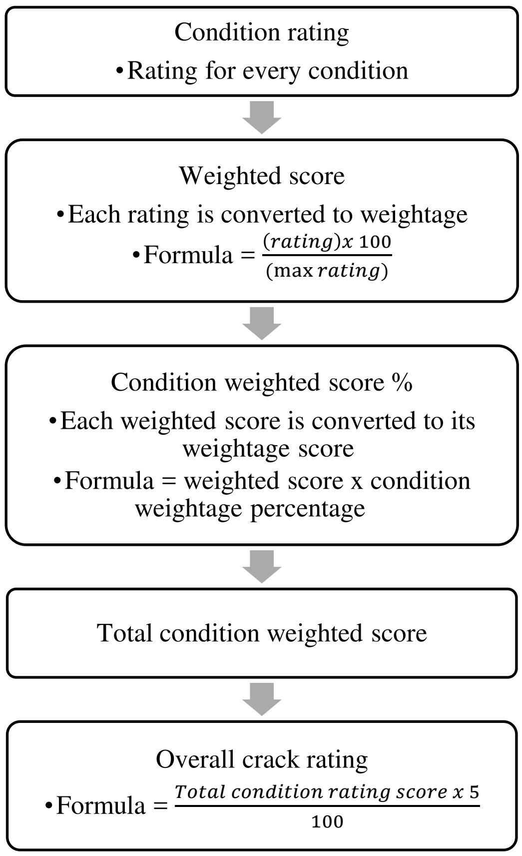

Figure-1. Flowchart of crack rating (Azman, 2015).

Water saturated zone

Electrical resistivity is a geophysical investigation technique based on detecting differences in electrical conductivity or resistance in the ground. Surface electrical resistivity surveying is based on the principle that the distribution of electrical potential in the ground around a current-carrying electrode depends on the electrical resistivity and distribution of the surrounding soils and rocks. The purpose of using electrical resistivity survey in this study is to detect the existence of fractures or weak zones which may affect the stability of the rock.

There are various electrode configurations which can be used in resistivity surveying. The configuration methods that were used in this survey were Dipole-dipole and Schlumberger. Dipole-dipole was set as main configuration while Schlumberger was mostly used as a control. In order to ensure that the flow of current is in good condition, clay or clayey sand was used to patch the visible hole.

Rock fractured condition

In this study, GPR was used to determine possible existence of cavities or weak zones along the wall and the crown of the MAT, CVT and cavern. RAMAC/GPR made by MALA Geo Science, Sweden with 250MHz antenna was used for the survey. The estimated penetration depth was 9 metres. The GPR survey was performed on three scanning lines at the tunnel of the MAT, CVT and cavern. The inspection on the tunnel was performed by placing the antenna on an electric buggy and the antenna was positioned to face the left wall, the crown and the right wall of the tunnel.

Result and analysis

Most water leakages occurred were discovered at chainage 0+000 to 0+025 with total of 26 leakages presents with 2.5 average rating value. Moreover, the longest crack also was identified at chainage 0+001.5 with 1091 mm length diagonally. Based on the resistivity survey, there are water saturated zone was developed behind the shotcrete lining on the right wall, left wall and crown of chainage 0+000 to 0+200. However, almost whole area on the right wall was saturated by water as shown in Figure-2 to Figure-4. Thereby, water pressure behind the shotcrete may triggered the formation of cracks which was confirmed by visual inspection earlier at chainage 0+001.5. This situation is due to lack of weeping hole that required to drain the water to seeping out. Similarly, as presented in Figure-5, results from GPR indicates the condition of rock on the left wall of MAT is highly fractured and highly saturated. This explains that area contains relatively high of wetness with high density of fractures.

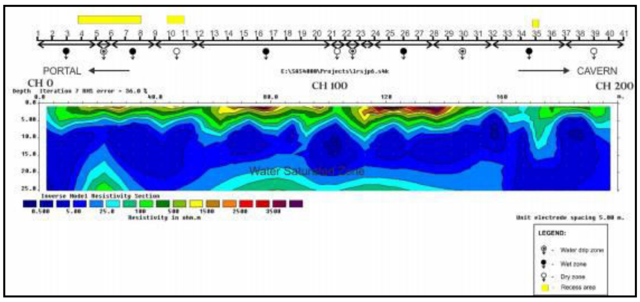

Figure-2. Resistivity result on the right wall of MAT.

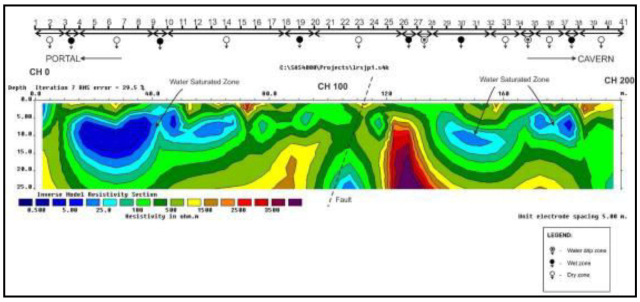

Figure-3. Resistivity result on the left wall of MAT.

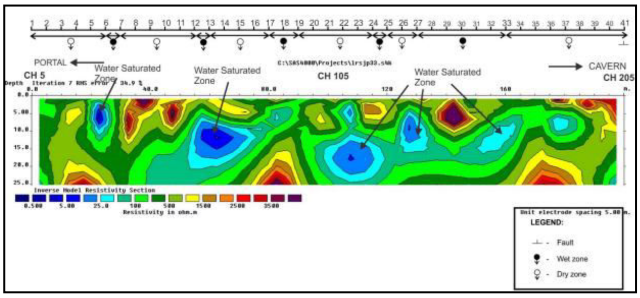

Figure-4. Resistivity result on the crown of MAT.

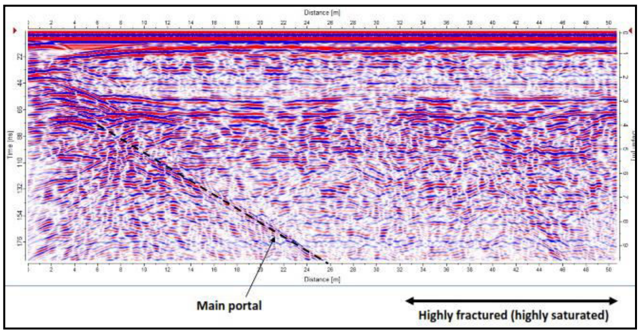

Figure-5. Ground penetrating radar on the left wall of MAT.

The descriptive statistics are delineated based on 396 records of water leakage on shotcrete lining between chainage 0+000 to 1+050. Basically, the section interval recorded was 25 m whereby mean value of the water leaking was recorded at 2.41 for CIRIA and 1.85 for FHWA. Moreover, in attempt to classify the overall condition of the tunnel, it must be preceded with the classification of individual water leakage. From the analysis, most of the individual water leakage are

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discovered at condition 2 which is represents moderate codition.

Condition rating

Condition rating system in this study is developed to detail the distress criteria consists of rating 1 to 5, where rating 1 represents a minor condition and rating 5 represents a severe condition. The detail of condition rating assessment is provided in Table-6.

After each individual distress is rated, the overall distress rating is determined by summing up all distresses at a particular chainage. The classification for overall distress rating are shown in Table-7.

Table-6. Assessment of distress rating.

Type of distress	Rating				
	1	2	3	4	5
Water leakage	Damp patch	Seep	Standing drop	Drip	Continuous leak
Crack	Very good	Good	Moderate	Poor	Very poor
Water saturated zone	>100 Ωm	70-100 Ωm	31-70 Ωm	11-30 Ωm	<10 Ωm
Rock fractured	Massive	Low fractured	Moderately fractured	Highly fractured	Intensely fractured

Table-7. Classification of overall distress rating.

Range	0-4	5-8	9-12	13-16	17-20
Rating	1	2	3	4	5
	Very good	Good	Moderate	Poor	Very poor

The result presents the condition rating of distresses comprised of 4 major distresses which are water leakage, crack, water saturated zone and rock fractured. Based on the result, the highest rating of distress in MAT and CVT were 16 and 14 indicating poor condition. Meanwhile, chainage 0+000 to 0+075, chainage 0+100 to 0+150 and chainage 0+575 to 0+600 in CVT were observed as poor condition. Besides that, the highest rating of distress in cavern was 12 which is in moderate condition level that were located at west wall. The rest of chainage were observed in moderate, good and very good condition. Example of distress rating in CVT is provided in Table-8.

Table-8. Condition rating in CVT.

Chainage	Water leakage	Crack	Water saturated zone	Rock fractured	point	condition
0+000 to 0+025	2	4	5	3	14	Poor
0+025 to 0+050	2	3	5	3	13	Poor
0+050 to 0+075	2	4	5	3	14	Poor
0+075 to 0+100	2	3	5	3	12	Moderate
0+100 to 0+125	2	4	5	3	14	Poor
0+125 to 0+150	3	5	3	3	14	Poor
0+150 to 0+175	2		2	3	7	Good

The results of condition assessment demonstrate good correlation between the visual inspection and non-destructive test, where the water leakage classification reflects by the condition of water saturated zone. These results agree with the classification of water leakage that has been published by FHWA and CIRIA. By using distress rating system in hydroelectric power station, it is able to provide information that allow the estimation of risk and safety measures necessarily to be taken. The condition of tunnel was categorized into 5 levels: very good, good, moderate, low and very low. There were 131 distresses location discovered, representing different level of condition. Out of 131 assessed areas, 68 of tunnel area were in good condition, 46 were identified in moderate condition and 5 were in very good condition.

The analysis of condition rating that combining major distresses revealed that there are range of difference between the condition rating given by water leakage rating alone. The difference was relatively high, which ranged from 4% -15%. Figure-6 present the comparison of condition rating from both rating system.

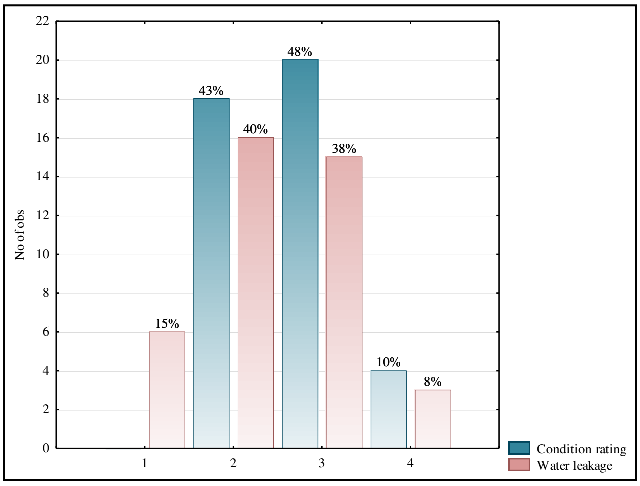

Figure-6. Difference of condition rating system.

CONCLUSIONS

In this study, a condition rating system of distresses comprised of three large main section in MAT, CVT and cavern in hydroelectric power station was developed. The distress rating system was developed to find out the level of condition for a tunnel in detail.

From this study, the comparison of condition level between single distress rating of water leakage with multi distresses assessment comprised of water leakage, crack, water saturated zone and rock fractured are clearly identified. The analysis of condition rating that combining those major distresses revealed that there is no chainage along the 1050 m of MAT were categorized into a very good condition.

The difference between the developed condition rating with water leakage rating was relatively high, which is from 4% to 15%. The water leakage condition that was observed in a very good condition were spotted at chainage 0+175 to 0+200, chainage 0+200 to 0+225, chainage 0+300 to 0+325, chainage 0+325 to 0+350, chainage 0+400 to 0+425, chainage 0+550 to 0+575 and chainage 0+750 to 0+775. However, after reanalyzing the distresses were conducted, those chainages condition were decreased from a very good condition into good and moderate condition. The condition level with 100% similarity of both components was recorded at a level 5, which is a very poor condition. It is clear that the condition of both components was not given a problematic or severe condition to any chainage along the MAT. The least changes were observed at level 4 with 2% of differences, which is indicating a poor condition and were dominated by 3 section of chainages. Followed by condition level 2 and 3 with 3% and 10% of differences respectively.

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