RISK ANALYSIS OF HYDROELECTRIC POWER STATION CONSIDERING IDENTIFIED RISK FACTORSBASED ON CONDITION DISTRESS RATING

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ABSTRACT

Hydroelectric power station and its infrastructures are very strategic asset to the Nationin providing power to the people and industry. This study is aimed to analyse risks associated with structural stability of shotcrete lining of tunnel and cavern of a hydroelectric power station while considering its risk factors. Prior to conducting risk analysis, level of distress rating for every chainage were determined. These risks were analysed with other significant risk factors by quantifying its impact and probability to generate condition risk for the tunnels and cavern.From this study, by implementing risk analysis in determining condition of shotcrete lining of the tunnel and cavern, the severity of any specific area is defined more precise. The results discovered that the risk values were identified ranging from 0.05 to 10.08. The highest risk value of 10.08 was discovered at the west wall of the cavern which isregards to the fact that cavern possess higher assets value need to be preserved.It is concluded that the results from the risk analysis providedmore accurate estimation on preventive maintenance and remedial action depending on the operational purposes of the tunnel compared to the individual condition rating without the implementation of risk analysis.

Keywords: risk analysis, risk factors, underground structure.

1. INTRODUCTION

Risk is perceived as an effect of uncertainty with respect to its objectives [1]. A risk management process in general is a process whereby the actions are taken concerning on the identification, assessment and reaction [2]. Risk analysis is a part of the risk management with only considering the steps of identification, assessment and evaluation [1]. Risk may arise in various circumstances. Due to this situation, the necessity of risk approached to play a role become important to appropriately address the risk corresponding to its condition [1]. The most important phase in adopting the method of risk management process must be begin with risk identification, as in this phase may reveal the risk sources and its types[3].In attempt to meet the project objectives, aspect of risk may become considerably concern whereby it is essential to take into consideration the management of risk specifically towards the project time, quality, safety, cost and environment [4],[5].

An adoption of risk analysis could be used as a tool in evaluating tunnel safety. Research on power tunnel structures by Xie and Yang explained four approaches in identifying risk factors that should be considered[6]:

a) An extensive review of past experienced.
b) Taking into consideration generic guidelines and specifications.
c) Inspection including site visit.
d) Consultation and discussion from experts.

The method of risk assessment might be presented in qualitative or quantitative analysis depending on the types of data obtained. Quantitative and qualitative analysis would provide different ways in interpreting the data.Whereby, quantitative methods would concern on the frequency and number while qualitative methods commonly focusing on the meaning and experienced [1]. The qualitative analysis process adopts the evaluation steps by considering the risk impact and probability of occurrence based on the identification of risk. Qualitative analysis address the impact and probability of the listing risk that have been identified during the risk identification phases thereby identifying the most critical risk which should be prioritized and to be analysed further [4].

Xie and Yang concluded that the risk assessment can be regarded as a thorough analysis by comparing and rank different level of risks that probably occur and their consequences through risk definition, identification, estimation, and evaluation. The study has also classified risk probability of occurrence and impact into 5 ranks that were excerpted from the Guideline of Safety and Risk Assessment for the Design of Highway Bridge and Tunnel Works, Ministry of Transport of the People's Republic of China[6]. The qualitative analysis process adopts the evaluation steps by considering the risk impact and probability of occurrence based on the identification of risk. Qualitative analysis address the impact and probability of the listing risk that have been identified during the risk identification phases thereby identifying the most critical risk which should be prioritized and to be analysed further [4].

2. METHODOLOGY

The risk analysis process for this study was formulated as shown in Figure-1. It was started by determining the distress rating along the tunnels and cavern. The distress rating explanation can be found in [7], [8]. The risk analysis followed the process by identifying vulnerability of assets inside the tunnels and cavern. The next step was risk identification and risk assessment to determine the probability of occurrence of the distresses

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and it impact. The process was finalised by evaluating the risk and generate the level of risk condition.

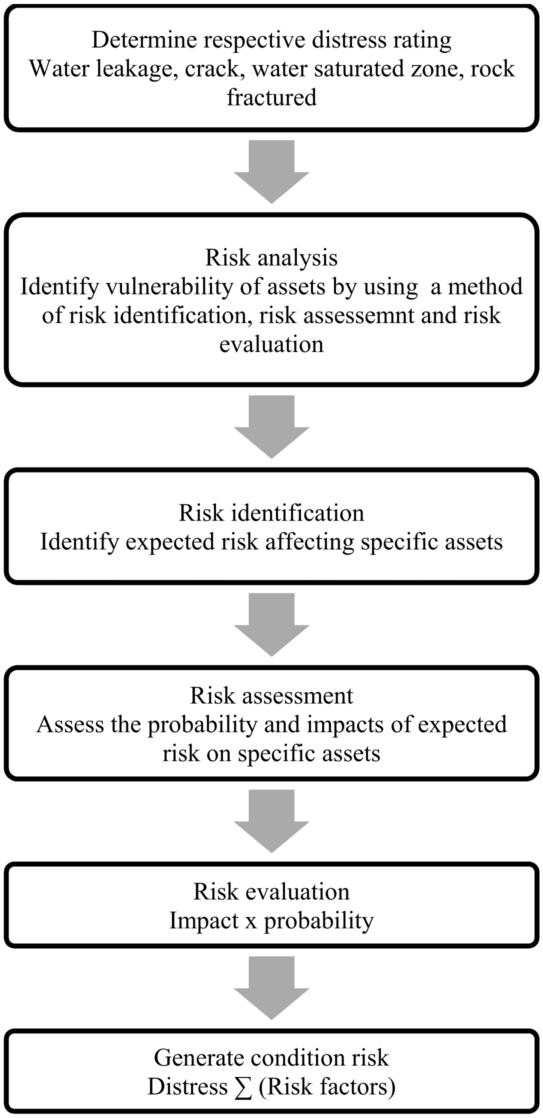

Figure-1. Flow diagram of risk analysis.

Determine respective distress rating

The result from condition assessment have determined 4 distress conditions that play big role in setting the risk on the tunnel services. The most common distress observed was water leaking [8]. Those distress conditions comprised of 4 significant components which were water leakage, crack, water saturated zone and rock fractured[7]. Based on the finding, the highest rating of distress in main access tunnel (MAT) and cable and ventilation tunnel (CVT) were indicating poor condition of the tunnels. However, poor condition areas in the MAT were observed at chainage 0+000 to 0+025, chainage 0+475 to 0+500, chainage 0+825 to 0+850 and 0+850 to 0+875 only, that were ranging from rating value of 13 to 16[7].

Meanwhile, chainage 0+000 to 0+075, chainage 0+100 to 0+150 and chainage 0+575 to 0+600 in the CVT were observed as poor condition. Besides that, the highest rating of distress in cavern was in moderate condition which were located at the west wall. Roughly, the poor condition level of distress is most likely occurred due to the existence of 4 components of the distress in the same location. The rest of distresses were observed in moderate, good, and very good condition[7].

Risk analysis

Risk analysis was employed to address diversities of risks which possibly can affect tunnel services either towards the safety, cost, operation, and any other important measures. In this study, the method for the classification of risk impact, risk probability and risk evaluation are drawn based on Project Management Institute [9].From the overall point of view, it is realized that the implication indicators of the risk are most probably the location of distress and interest of the tunnel.

Risk identification

Risk analysis was conducted in a hydroelectric power station to determine the expected risk which potentially arise and affect the tunnel objectives such as operation, cost, safety, interest etc. A risk analysis process was begun with risk identification. In this phase, several expected risks were identified based on the problem that have been issued before which could increase the rating of distress for a particular area involving water leakage, crack, water saturated zone and rock fractured.

In this case, risk sources were managed in two important considerations. One is the location of distress on the tunnel's shotcrete lining which are side wall and crown and another consideration is their interest, in which the level of identified risk is categorized into three section: MAT, CVT and cavern. This consideration is due to the matter of prioritization. One risk may not be affecting to one condition but might be affecting to another. To provide better understanding, every distress was coded and combined with number starting from 1 to 5 indicating its distress rating. Example of risk identification for location of distress is shown in Table-1. Another risk identification distinguishing tunnel and cavern were coded as A1 until L5.

Table-1. Risk identification for location of distress (Crown and side wall).

No.	Risk identification		Code
1	**Water leakage**	Damp patch in side wall	Ws1
		Seep in side wall	Ws2
		Standing drop in side wall	Ws3
		Drip in side wall	Ws4
		Continuous leak in side wall	Ws5
		Damp patch in crown	Wc1
		Seep in crown	Wc2
		Standing drop in crown	Wc3
		Drip in crown	Wc4
		Continuous leak in crown	Wc5

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Table-1. Risk identification for location of distress (Crown and side wall), *continued*.

No.	Risk identification		Code
2	Crack	Crack rating 1 in side wall	Cs1
		Crack rating 2 in side wall	Cs2
		Crack rating 3 in side wall	Cs3
		Crack rating 4 in side wall	Cs4
		Crack rating 5 in side wall	Cs5
		Crack rating 1 in crown	Cc1
		Crack rating 2 in crown	Cc2
		Crack rating 3 in crown	Cc3
		Crack rating 4 in crown	Cc4
		Crack rating 5 in crown	Cc5
3	Water saturated zone	>100 Ωm in side wall	Ss1
		70-100 Ωm in side wall	Ss2
		31-70 Ωm in side wall	Ss3
		11-30 Ωm in side wall	Ss4
		<10 Ωm in side wall	Ss5
		>100 Ωm in crown	Sc1
		70-100 Ωm in crown	Sc2
		31-70 Ωm in crown	Sc3
		11-30 Ωm in crown	Sc4
		<10 Ωm in crown	Sc5
4	Rock fractured	Massive at side wall	Rs1
		Low fractured in side wall	Rs2
		Moderately fractured side wall	Rs3
		Highly fractured in side wall	Rs4
		Intensely fractured in side wall	Rs5
		Massive in crown	Rc1
		Low fractured in crown	Rc2
		Moderately fractured in crown	Rc3
		Highly fractured in crown	Rc4
		Intensely fractured in crown	Rc5

Risk assessment

Once risks were identified, these verity of impact and probability of occurrence were assessed. The severity of impact is determined by considering the tunnel assets valuation since the different types of risks give rise to different kind of impact. The severity scale that recommended in PMBOK was used for assessing the level of severity of impacts [10]. Therefore, the five-severity scale begin with 0.05, 0.1, 0.2, 0.4 and 0.8 wereused to assess the severity of impacts primarily on the operation, safety, and cost. The higher rating of distress, the higher impact was assigned. Table-2 presents the severity of impact related to the specific code of identification risks.

Table-2. Severity of impact.

Identifica-tion risk code	Very low	Low	Moder ate	High	Very high
	0.05	**0.1**	**0.2**	**0.4**	**0.8**
Ws1	0.05				
Ws2		0.1			
Ws3			0.2		
Ws4				0.4	
Ws5					0.8
Wc1	0.05				
Wc2		0.1			
Wc3			0.2		
Wc4				0.4	

Table-2. Severity of impact, *continued*.

Identifica-tion risk code	Very low	Low	Moder ate	High	Very high
	0.05	**0.1**	**0.2**	**0.4**	**0.8**
Wc5					0.8
Cs1	0.05				
Cs2		0.1			
Cs3			0.2		
Cs4				0.4	
Cs5					0.8
Cc1	0.05				
Cc2		0.1			
Cc3			0.2		
Cc4				0.4	
Cc5					0.8
Ss1	0.05				
Ss2		0.1			
Ss3			0.2		
Ss4				0.4	
Ss5					0.8
Sc1	0.05				
Sc2		0.1			
Sc3			0.2		
Sc4				0.4	
Sc5					0.8
Rs1	0.05				
Rs2		0.1			
Rs3			0.2		
Rs4				0.4	
Rs5					0.8
Rc1	0.05				
Rc2		0.1			
Rc3			0.2		
Rc4				0.4	
Rc5					0.8

The rate of occurrence is determined based on past incidents that were recorded. The probability of occurrence was assigned based on the available information. It is scaled from 0.1 up to 0.9 as in Table-3. The scale was assigned depending on how frequent the unwanted risk has occurred.

Table-3. Probability of occurrence.

Identifica-tion risk code	Very low	Low	Mode rate	High	Very high
	0.1	**0.3**	**0.5**	**0.7**	**0.9**
Ws1			0.5		
Ws2					0.9
Ws3	0.1				
Ws4		0.3			
Ws5	0.1				
Wc1		0.3			
Wc2			0.5		
Wc3	0.1				
Wc4			0.5		
Wc5	0.1				
Cs1	0.1				
Cs2	0.1				
Cs3		0.3			
Cs4		0.3			
Cs5	0.1				
Cc1	0.1				

Table-3. Probability of occurrence, *continued*.

Identification risk code	Very low	Low	Moderate	High	Very high
	0.1	**0.3**	**0.5**	**0.7**	**0.9**
Cc2	0.1				
Cc3	0.1				
Ws1			0.5		
Ws2					0.9
Ws3	0.1				
Ws4		0.3			
Ws5	0.1				
Wc1		0.3			
Wc2			0.5		
Wc3	0.1				
Wc4			0.5		
Wc5	0.1				
Cs1	0.1				
Cs2	0.1				
Cs3		0.3			
Cs4		0.3			
Cs5	0.1				
Cc1	0.1				
Cc2	0.1				
Cc3	0.1				
Cc4	0.1				
Cc5	0.1				
Ss1					0.9
Ss2				0.7	
Ss3			0.5		
Ss4				0.7	
Ss5		0.3			
Sc1			0.5		
Sc2			0.5		
Sc3			0.5		
Sc4	0.1				
Sc5	0.1				
Rs1	0.1				
Rs2			0.5		
Rs3				0.7	
Rs4			0.5		
Rs5	0.1				
Rc1	0.1				
Rc2	0.1				
Rc3				0.7	
Rc4	0.1				
Rc5	0.1				

Risk evaluation

The evaluation of risk was categorized into three level: high, moderate, and low. It is presented in Table-4 and the risk value regards to the identified risk is presented in Table-5.

Table-4. Risk matrix.

0.8	**0.08**	**0.24**	**0.4**	**0.56**	**0.72**
0.4	0.04	0.12	0.2	0.28	0.36
0.2	0.02	0.06	0.1	0.14	0.18
0.1	0.01	0.03	0.05	0.07	0.09
0.05	0.005	0.015	0.025	0.035	0.045
Impact ↑ Probability→	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**

Table-5. Risk value.

Identification risk code	Impact	Probability	Value
Ws1	0.05	0.5	0.025
Ws2	0.1	0.9	0.09
Ws3	0.2	0.1	0.02
Ws4	0.4	0.3	0.12
Ws5	0.8	0.1	0.08
Wc1	0.05	0.3	0.015
Wc2	0.1	0.5	0.05
Wc3	0.2	0.1	0.02
Wc4	0.4	0.5	0.2
Wc5	0.8	0.1	0.08
Cs1	0.05	0.1	0.005
Cs2	0.1	0.1	0.01
Cs3	0.2	0.3	0.06
Cs4	0.4	0.3	0.24
Cs5	0.8	0.1	0.08
Cc1	0.05	0.1	0.005
Cc2	0.1	0.1	0.01
Cc3	0.2	0.1	0.02
Cc4	0.4	0.1	0.04
Cc5	0.8	0.1	0.08
Ss1	0.05	0.9	0.045
Ss2	0.1	0.7	0.07
Ss3	0.2	0.5	0.1
Ss4	0.4	0.7	0.28
Ss5	0.8	0.3	0.24
Sc1	0.05	0.5	0.025
Sc2	0.1	0.5	0.05
Sc3	0.2	0.5	0.1
Sc4	0.4	0.1	0.04
Sc5	0.8	0.1	0.08
Rs1	0.05	0.1	0.005
Rs2	0.1	0.5	0.05
Rs3	0.2	0.7	0.14
Rs4	0.4	0.5	0.2
Rs5	0.8	0.1	0.08
Rc1	0.05	0.1	0.005
Rc2	0.1	0.1	0.01
Rc3	0.2	0.7	0.14
Rc4	0.4	0.1	0.04
Rc5	0.8	0.1	0.08

Condition risk

To generate the condition risk in MAT, CVT and cavern, a more detailed risk analysis was determined considering the rating of distress that have been analysed at the first stage. The condition risk was generated based on the following basis:

Condition Risk = Distress x ∑ (Weighted Risk Factors)

From summary of the distress rating that were obtained from condition assessment as in [7], it was noted that the ranging of distress rating in the MAT, CVT and cavern were ranged within 5-13, 5-14 and 4-12 respectively. The distress rating of 14 is the highest value that was occurred in the CVT, and distress rating of 4 is the lowest value that was occurred in the cavern. In this paper, the rating system was used to determine condition risk.

3. RESULTS AND DISCUSSIONS

The overall risk analysis in comparison to the respective distress rating, impact, and probability for the MAT, CVT and cavern are presented in this section. The study of risk concludes that risk in the CVT is the lowest compare to the MAT and cavern. The highest condition risk of 4.06 was calculated at chainage 0+000 to 0+025, chainage 0+025 to 0+050, chainage 0+050 to 0+075 and chainage 0+100 to 0+125 but still in very low risk category. From the analysis, among the 4 components that considered in increasing the value of distress rating, water saturated zone within range of resistivity value of 11-30 Ωm tends to contribute to the high level of risk as represents by Ss4+H4 code. The risk of CVT can be perceived as very low as expected due to the very low of impact towards the tunnel in terms of operation, safety, and cost. CVT risk would be the lowest risk is primarily due to the less of services provided. It should be noted that when the tunnel was function less and not become a priority, the impact will be rated lower than others.

The risk at the MAT is dominated by Ss4+G4 that represent water saturated zone within range of resistivity value of 11-30 Ωmon side wall which occurred at chainage 0+025 to 0+050 and chainage 0+825 to 0+850. However, risk value for this condition is classified as a low risk within range of 6 to 11. It needs to be emphasized that the results of distress rating at this chainage is relatively high which is 16, and it is classified as poor condition. In some way, analyses of risk prove that those chainages were in low risk. A possible reason for the unexpected low risk is due to the MAT service purposes. The MAT risk is low because of that tunnel is not functioning for any important operation but the consequences were investigated may turned out in increasing the risk of safety as it is functioning as access way for people to commute to the powerhouse cavern.

There are 4 components that would influence the increasing of distress rating: water leakage, crack, water saturated zone and rock fractured. The existence of these4 components will directly tend to increase the risk towards a particular condition. However, this is only true if it may give a high impact to the tunnel activities. For instance, if it is the case that the distress rating was 16, the severity of impact is as high as it could affect the overall operation and the risk value might be higher. Furthermore, the probability of occurrence is also low where it obviously made the degree of risk lower.

The analysis in powerhouse cavern presents the highest risk and it was occurred at west wall of cavern where the risk is triggered by component of crack rating 4 on the side wall with 10.08 of condition risk (i.e. coded by Cs4+F4). According to the classification of condition risk, the risk value of 10.08 is classified as low risk in which the risk is in ranged from 6-11. The impact of risk is higher because of cavern is placed and equipped with sensitive heavy machineries, turbines and other important operation equipment which could cause an operation to be disrupted if any failure happened. For this purpose, the risk in cavern was set slightly higher than for the MAT and CVT. This is mainly caused by the fact that the impact in cavern is higher if compared to MAT and CVT. The summary of the risk analysis is shown in Table-6, Table-7, Table-8 and in Table-9:

Table-6. Summary analysis forthe MAT.

Descriptive Statistics (MAT)					
	Valid N	**Mean**	**Min**	**Max**	**Std.Dev.**
MAT	400	1.24	0.05	6.08	1.06

Table-7. Summary analysis for the CVT.

Descriptive Statistics (CVT)					
	Valid N	**Mean**	**Min**	**Max**	**Std.Dev.**
CVT	400	1.02	0.05	4.06	0.83

Table-8. Summary analysis for the cavern.

Descriptive Statistics (Cavern)					
	Valid N	**Mean**	**Min**	**Max**	**Std.Dev.**
Cavern	360	1.70	0.05	10.08	1.61

Table-9. Range of condition risk in MAT,CVT and cavern.

Location	**MAT**	**CVT**	**Cavern**
Condition	Very low-low	Very low	Very low-low

Cavern area represent higher risk value and seemingly under operations, in which, the exposure to the possibility of operations failure is excessive when compared to MAT and CVT tunnel. Allocating 10.08 of risk value on the west wall requires thorough assessment and detail analysis on the relationship of the distresses between risk factors and appropriate control measure desired by the tunnel owner. For detail analysis, risk value of 10.08 is affected by the following aspect:

Table-10. Detail of condition risk in cavern.

Risk code	**Risk identification**	**Impact**	**Probability**	**Risk value**
Cs4	Crack rating 4 in side wall	0.4	0.3	0.12
F4	Crack rating 4 in cavern	0.8	0.9	0.72

Based on the assessment, there were no presence of water leakage observed on the west wall of cavern. However, cracks, water saturated zone and rock fractured were observed with 5, 4 and 3 of distress rating values respectively.

4. CONCLUSIONS

This paper presents the condition risk encountered by hydroelectric power station. A total of 100 risk factors over 2 km long of tunnel and at powerhouse cavern were identified and classified based on an interview, literature review and on site investigation. One of the reason the location of distress should take into consideration is due to the impact of the distress that influenced by the location of distress. For instance, if the location of distress is at crown, it would impact not only to the tunnel structure stability but to the tunnel operation and human safety. Meanwhile, the location of distress at the sidewall more prone to the tunnel structure stability as the water could seep through the wall and not directly fall on the pathway and any sensitive equipment.

In regards to tunnel safety, risk analysis is added in this study to investigate the consequence and probability of distress towards the tunnel and cavern. Based on the result presented, exploration of the identified risks of the hydroelectric power station have discovering that the value of risk was ranging from 0.05 to 10.08. The risk value of10.08 was discovered at the west wall of cavern was reflecting the fact that cavern possess higher assets value need to be maintained. It is noticeably that the need to control and manage the risk is depending on the operational purposes of the tunnel. The lowest risk value was observed at several areas in the MAT, CVT and cavern but most of the cases were observed in the CVT. This situation is defined by the service purposes of the CVT which is functioned for ventilation of the cavern.

By implementing risk analysis in assessing the distress condition of tunnel and cavern, It has increased the feasibility in estimating of present condition and risk level of the tunnel and cavern. It helps the tunnel owner to decide the appropriate preventive maintenance and remedial action.

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