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Hazard Identification Risk Assessment and Risk Control (HIRARC) for Mengkuang Dam Construction

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Abstract The construction industry is a main contributor to Malaysia's economy and yet some construction projects are considered being extremely unsafe, unhealthy, and exposing to a lot of hazards and risks to worksites. Hazard Identification, Risk Assessment and Risk Control (HIRARC) is a process commonly used to determine and evaluate both existing and potential hazards on a worksite and an effective control action plan used to reduce the identified hazards. HIRARC risk management is a fundamental to the business operation, planning and management. This study investigates the implementation of the HIRARC Risk Management Plan and Risk Registered Matrix for the construction project of the Mengkuang Dam in Malaysia, which involved the scopes of raising and extension of the existing dam. Construction of the dam upgrading and expansion was subjected to severe risks factors such as potential impact to the existing dam, project schedule delay, exceeding the project budget and contractual dispute. The Risk Register Matrix based on HIRARC was initiated for this project and was also implemented during the construction of the dam. The risk management plan framework and process involved in the risk identification, risk assessment, risk control, and mitigating measures are discussed for further assessments of risk control and action plans. The findings have shown that the construction project risk in term of the relative risks can be reduced by implementing an effective control action plan to mitigate the risks significantly. The HIRARC risk management that applied in this study can also be adopted in other dam construction projects to provide an effective safety management system and reduce the project relative hazard risks.

Keywords Risk Management, Risk Assessment, Risk Control, Construction Safety

1. Introduction

The construction industry is a main contributor to Malaysia's economy, and yet construction projects are considered as being extremely unsafe, unhealthy, risky and hazardous to workers. The statistical data published by Malaysia Department of Occupational Safety and Health (DOSH) [5] under Ministry of Human Resources cited that a total of 4,863 occupational safety accidents and 144 deaths were reported in the year 2019. This 2019 statistic shows that the fatality rate for the construction sector of 11.28 for every 100,000 workers is the highest among all the sectors in Malaysia. For construction sector, the occupational safety accidents reported in 2019 are at rate of 3.18 for every 1,000 workers [5]. The Occupational Safety and Health Act (OSHA) 1994 [8], was enforced by DOSH to address the alarming accident rates in the construction sector. The Safety and Health Officer Regulations under the OSHA has made it compulsory for any company for any building operation or work of engineering construction with projects above RM20 million to appoint a Safety and Health Officer (SHO).

Hazard Identification, Risk Assessment and Risk Control (HIRARC), an effective safety management system has been implemented to control risks and minimize hazards at the construction sites. HIRARC risk management is a fundamental to the business operation, planning and management. The study by Asmalia [2] cited that hazard identification and risk assessment are processes used to determine and evaluate both existing and potential hazards on a worksite and the control action plan used to control or eliminate the hazards identified.

The government of Malaysia has been facilitating the implementation of HIRARC in the construction sector by publishing the guidelines and construction industry standard as a guide for the implementation of HIRARC. These guidelines and regulations include "Guidelines for Hazard Identification, Risk Assessment and Risk Control (HIRARC)" published by DOSH in 2008 and the "Construction Industry Standard CIS 25: 2018 - Construction Activities Risk Assessment (CARA) using Hazard Identification, Risk Analysis and Risk Control (HIRARC)" published by Construction Industry Development Board (CIDB) published in 2019. These published standards aim to provide a systematic and objective method to determine hazard and assess their associated risks for construction work activities.

2. Hazard Identification, Risk Assessment and Risk Control (HIRARC)

CIDB construction industry standard CIS 25:2018 [4] defined "Construction Risk Management as the procedure associated with identifying a hazard assessing the risk, putting in place control measures and reviewing the outcomes for the construction industry". CIDB Construction Activities Risk Assessment (CARA) has identified HIRARC as a systematic and objective risk management approach for hazard determination and assessment of the associated risks for construction work activities.

HIRARC is a systematic approach of Risk Management which includes the process of hazard identification, risk assessment and risk control. The hazard identification is important to determine the potential hazards that may cause harms to the workers and publics. The risk assessment process evaluates the chances of the hazards occurring and the severity possibility associated with it. The risk control process allows the planning and monitoring of the control action plan to be in place to constantly prevent and minimize the risks.

2.1. Hazard Identification

Hazard is defined as any events, causes or situations that may cause potential impact in terms of injuries or health illness, environmental damage or any combination of these [4],[7]. Hazard control aims to implement control to reduce the risk associated with a hazard. Hazard identification aims to determine any potential incidents and mechanism that can cause the hazard to happen [4] [7]. Hazard identification includes the identification of any conditions, practices, situations or human behavior that may cause hazardous event such as disease, harm to people, injury or death, environmental impact and damages to the property and equipment.

2.2. Risk Assessment

Risk is a combination of the likelihood and severity of a specified hazardous occurrence with a specific circumstance that may have caused the event to occur [4]. Risk assessment evaluates the potential risks to safety and health that may occur due to hazardous conditions at the site. Risk assessment includes the process of estimating and evaluating the risks levels associated with the identified hazards. The risk assessment results will be ranked and used as the consideration for the decision making and determining the control action plan to be adopted for the project.

2.3. Risk Control

The risk assessment and analysis results will be used to determine the control action plan that can be adopted at the construction project. The risk control will prioritize the risk elimination and control of the hazards occurrence at source of the risk by using engineering principle and control measures. However, not all risks can be eliminated or prevented. For risks that cannot be prevented, the risk control action plan shall focus on reducing the hazards or risks by the design of safe work systems or reducing the probability of the risk occurrence through regular monitoring and preventive actions.

3. Case Study – Risk Management for Mengkuang Dam Expansion Project

This paper studies the risk management process for Mengkuang Dam Expansion projects using the HIRARC method. The construction of the Mengkuang Dam upgrading and enlargement project is selected for this case study as this dam construction was subjected to several risks factors such as potential impact to the existing dam, project schedule delay, exceeding the project budget and contractual dispute. The biggest challenge of this project is that the supply of raw water supply from Mengkuang Dam has to be maintained during the dam construction stage. This means that the impounded raw water in the existing dam must always be maintained to be utilised when required. Effective Risk Management Plan is required in managing the challenges of construction a new dam beside the existing dam and other major issues to minimize the impact of delay, re-works and cost overrun to the project.

A risk management workshop for the Mengkuang Dam expansion project was conducted by Malaysia Ministry of Energy, Green Technology and Water (KeTTHA) in May 2012 to deliberate on the risk factors and risk management plan to be implemented during the dam construction stage. The Mengkuang Dam Expansion Project adopted the Hazard Identification, Risk Assessment and Risk Control (HIRARC) for the Risk Management Plan during the project construction stage. The Risk Management Plan including the Risk Register Matrix and Risk Analysis for Embankment Construction was implemented during the construction of this Project.

3.1. Background of Mengkuang Dam Expansion Project

The Mengkuang Dam is located near Bukit Mertajam in Pulau Pinang, Malaysia. This dam is an important water source for Sg Dua Water Treatment Plant which provides the water supply for 80% of the consumer in Pulau Pinang. The plant source the raw water supply from Sungai Muda through Sungai Dua Canal [9],[11],[12],[13].

Due to the increase of water demand in Pulau Pinang, the existing Dam completed in 1983 with the capacity to store 22 million cubic meters is not sufficient to meet the raw water supply demand of the Water Treatment Plant in Sungai Dua. The Mengkuang Dam was constructed to convey raw water whenever there is a shortfall of water supply from Sg Muda catchment. This was cited from the work published by Hasnul in 2016 [9], that river capacity is not sufficient to meet the total water demand for residential, commercial, industrial and agricultural irrigation supply, during the drought season. The "Mengkuang Dam Expansion Project – Construction of the Dam and Associated Works Stage 1 Project" aims to increase current dam capacity of 22 million cubic meters to the new storage capacity of 73.5 million cubic meters. This will increase the supply to Sungai Muda Water Treatment Plant from the current 300 million liter per day to 1000 million liter per day.

The published work by Khor et al (2016) reported that the "Mengkuang Dam Expansion Project – Construction of the Dam and Associated Works Stage 1 Project" contract value is RM 607 million. This large scale project is implemented with the collaboration between the Government of Malaysia and the Government of The Republic of China. Khor [13] reported that China International Water and Electric (M) Sdn. Bhd, (CWEM) was awarded for the Phase I of the project construction works with site procession date on 1st August 2011. The Mengkuang Dam expansion and associated works project were completed in July 2015. The newly completed Mengkuang Dam has increased the existing dam capacity of 22 cubic meter to the maximum raw water storage capacity of 73.5 million cubic meters [11],[12],[13]

Figure 1. Overall view of the Mengkuang Dam during construction (CFWong, 2012)

The dam upgrading and extension works involved increasing the height of the existing dam and the new construction beside the current dam. Figure 1 shows the overall view of the Mengkuang Dam during Construction. The biggest challenge during the project construction work is that the existing dam operation cannot be interrupted throughout the construction process. The supply of raw water from the existing dam has to be consistently maintained during operation as any interruption will disrupt the water supply to the consumer. During the construction, the safety risks of piping failure due to the foundation excavation were identified as one of the serious potential risk.

The construction of this dam enlargement project was subjected to several risks factors such as potential impact to the existing dam, project schedule delay, exceeding the project budget and contractual dispute. Effective Risk Management Plan is required in managing the challenges of construction a new dam beside an existing dam and other major issues to minimize the impact of delay, re-works and cost overrun to the project.

4. Methodology – HIRARC

The Mengkuang Dam Expansion Project adopted the Hazard Identification, Risk Assessment and Risk Control (HIRARC) Risk Management Plan during the project construction stage which is the reference to Department of Occupation Safety and Health (DOSH), Malaysia – "Guideline for Hazard Identification, Risk Assessment and Risk Control (HIRARC)", 2008. The Risk Management Plan for this project including the Risk Register Matrix and Risk Analysis for Embankment Construction was implemented during the construction of this Project.

A risk management workshop for the Mengkuang Dam Expansion project was conducted by Kementerian Tenaga, Teknologi Hijau dan Air (KeTTHA) on 21 May 2012 among the project owner, consultant and contractors to deliberate on the risk factors and risk management plan to be implemented during the dam construction stage. During the risk management workshop, HIRARC methodology is identified as the Risk Management approach to be adopted during the construction stage of the Mengkuang Dam project. The construction risks during the embankment construction were identified. The potential causes and consequences were also deliberated and identified. Based on the Risk Register Matrix formulated, the risk is analysed using HIRARC method to identify preliminary risk assessment; control and action plan to mitigate the risks identified and the risk with control evaluation.

For Mengkuang Dam Project, HIRARC Risk Management is implemented for the process of hazard identification, risk assessment and risk control. The hazard identification for the embankment construction identified all the hazard and risks factors that may cause harms to the works and publics during the construction. During the hazard identification process, potential causes and consequences of the risks were identified. The Risk Register Matrix during construction is prepared to assess the potential of the hazards and risks occurring and the possible severity associated with it. HIRARC Risk Assessment analyses the risks identified for the preliminary risks assessment as a basis to formulate the control measures to be implemented during the embankment construction process. The risk control process enables the planning and monitoring of the control action plan to ensure that the construction risks are adequately prevented at all times. However, not all risks can be eliminated or prevented. For risks that cannot be eliminated, the risk control action plan focused on reducing the hazards or risks by the design of safe work control measures and reducing the probability of the risk occurrence through proper monitoring and preventive measures.

The HIRARC process includes classification of work activities; identification hazards and risks associated with these work activities and implements risk assessment through hazard analysis and risk estimations through the evaluation of the likelihood of occurrence, and the severity of hazard. Based on the assessment, the decision can be made whether risk is tolerable and the control measures to be implemented.

4.1. Register Matrix during Construction

Risk is the combination of the likelihood and severity of a specified hazardous event with a specific circumstance that may have caused the hazardous to occur. The risk can be calculated using the following equation:-

Risk (R) = Likelihood (L) x Severity (S)

The parameter of equation defined as Risk (R) is the "combination of likelihood and severity", Likelihood (L) is "an event likely to occur within the specific period or in specified circumstances" and Severity (S) is "outcome from an event such as severity of injury or health of people, or damage to property, or insult to environment, or any combination of those caused by the event" [7].

During the construction, a quantitative risk assessment was implemented to identify the cause of the risk, the consequences and the control action plan to be implemented versus the do-nothing option. HIRARC risk register matrix is to quantitatively evaluate the risk reduction of the Risk Assessment with the control action taken against the preliminary do-nothing risk assessment.

A construction risk register matrix was implemented during the construction of the dam. The risk management plan framework and matrix include

(1) risk probability, definition and rating
(2) risk severity, definition and rating
(3) risk Likelihood vs. risk Severity
(4) risk profile identification

The Likelihood for this project is defined as in Table 1 in the project Risk Management Plan.

Table 1. Risk Likelihood, Definition and Rating

Likelihood	Definition	Rating
Most likely	Happened frequently	5
Possible	Likely to happen	4
Conceivable	Might happen. Occurred before but very rare	3
Remote	Unlikely to happen. Occurred before but extremely rare	2
Inconceivable	Has never happened before	1

Severity impact can be categorized into five categories. The severity impact is defined and with rating score for the construction projects in Table 2

Table 2. Risk Severity, Definition and Rating

Severity Impact	**Definition**	**Rating**
Catastrophic	Project to be suspended / involve fatality / structural damage to the construction	5
Very serious	Major impact. "Stop Work Order" to be instructed.	4
Serious	Re-work / demolition of existing work	3
Minor	Minor impact. Repair work required	2
Negligible	No significant impact. No major repair work is necessary	1

Risk can be presented in various methods to report the results of analysis for the decision making on risk control. For this project, the risk assessment adopted a qualitative method of probability and severity evaluation, in order to present the result in an effective risk matrix and distribution of the risks during the construction of the dam.

Table 3. Risk Likelihood vs. Risk Severity

	Severity				
Likelihood	1	2	3	4	5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

Table 4. Risk Profile identification based on the Risk Registered Matrix

19 - 25 = High	H
13 - 18 = Medium	M
6 - 12 = Low	L
1 - 5 = Very Low	VL

The Risk Likelihood, definition and rating are defined in Table 1 and the Risk Severity, definition and rating are defined in Table 2. The Risk Profile is defined as High Risk; Medium Risk; Low Risk and Very Low Risk (Table 4) based on the analysis of the Risk Likelihood vs Risk Severity (Table 3). The Relative Risk can be calculated from the Likelihood (L) and Severity (S) using the following formula:

Relative Risk (R) = Likelihood (L) x Severity (S)

5. Risk Assessment for Embankment Construction

The risk analysis for the Embankment Construction for Mengkuang Dam Expansion Project is based on Hazard Identification, Risk Assessment and Risk Control (HIRARC)

5.1. Setting Out Risks

The setting out error risk may cause delay which needs time to rectify and if construction, redesign, modification and reconstruction are required.

5.2. Risk of Cofferdam Overtopped

During construction, the cofferdam may have a risk of overtopped due to inadequate height, inadequate flood attenuation measures, flood severity beyond design level (exceptional rainfall). This may cause delay and fill embankment quality to be compromised.

Table 5. Setting Out Risks*

(*Actual HIRARC Assessment implemented for the Mengkuang Dam Project)

No	Risk	Causes of Risk	Consequences	Controls / Action Plans	Preliminary Risk Assessment	Risk with Control Evaluation
1	Setting Out Setting Out Error	1. Utilizing wrong TBM 2. Disturbed TBM 3. Surveyor error 4. Utilizing un-calibrated equipment	1. Delay - need time to rectify. If constructed, re-design, modification and reconstruction is required 2. Cost overrun	1. Confirmation check by Consultant's surveyor 2. Re-survey to confirm suspect disturbed TBM 3. Provide protection to TBM 4. Clear labeling to TBM 5. Ensuring all surveying work has closing error check 6. TBM shall be established on strong and stable monument	Probability: 3 Severity: 3 Risk: 9	Probability : 2 Severity : 3 Risk: 6

Table 6. Cofferdam Overtopped Risk*

(*Actual HIRARC Assessment implemented for the Mengkuang Dam Project)

No	Risk	Causes of Risk	Consequences	Controls / Action Plans	Preliminary Risk Assessment	Risk with Control Evaluation
2	<u>**Cofferdam**</u> Cofferdam overtopped	1. Inadequate height 2. Inadequate flood attenuation measures 3. Flood severity beyond design level (exceptional heavy rainfall)	1. Delay 2. Fill embankment quality compromised	1. Design comply to relevant codes 2. Regular monitoring and maintenance of the temporary diversion channel	Probability: 3 Severity: 2 Risk: 6	Probability : 2 Severity : 2 Risk: 4

5.3. Risk of Excessive Groundwater

During the embankment construction, there are risks of encountering excessive ground water which may cause delay and compromise the quality of the fill embankment

5.4. Risk during Foundation Excavation

During foundation excavation, there is a possibility of slope instability due to ground water seepage, surface erosion, and gradient too steep. It is important that adequate slope gradient is provided with proper slope protection and to control any excession ground water seepage.

5.5. Risk of Insufficient Clay Core Material

Clay core Material is an essential component of the embankment dam. With planning and over-estimation of the availability of the material will cost delay and cost overrun.

Table 7. Risk of Excessive Ground Water*

(*Actual HIRARC Assessment implemented for the Mengkuang Dam Project)

No	Risk	Causes of Risk	Consequences	Controls / Action Plans	Preliminary Risk Assessment	Risk with Control Evaluation
3	**Control of Water** Encounter excessive ground water	1. High water table 2. Highly permeable soil layer	1. Delay 2. Fill embankment quality compromised	1. Construction of proper ground water cut-off works 2. Provide ground water dewatering system	Probability: 3 Severity: 3 Risk: 9	Probability : 2 Severity : 2 Risk: 4

Table 8. Risk during Foundation Excavation *

(*Actual HIRARC Assessment implemented for the Mengkuang Dam Project)

No	Risk	Causes of Risk	Consequences	Controls / Action Plans	Preliminary Risk Assessment	Risk with Control Evaluation
4	**Foundation Excavation** Excavation slope instability	1. Ground water seepage 2. Surface erosion 3. Poor materials 4. Gradient too steep	1. Loss of life and properties 2. Delay 3. Cost overrun	1. Provide adequate slope gradient 2. Provide slope protection 3. Control excessive ground water seepage	Probability: 3 Severity: 3 Risk: 9	Probability : 2 Severity : 3 Risk: 6

Table 9. Risk of Insufficient Clay Core Material*

(*Actual HIRARC Assessment implemented for the Mengkuang Dam Project)

No	Risk	Causes of Risk	Consequences	Controls / Action Plans	Preliminary Risk Assessment	Risk with Control Evaluation
5	**Clay Core Material** Insufficient borrow materials – clay core, shoulder materials	1. Over-estimate the availability of fill materials 2. Poor planning, management and handling	1. Delay 2. Cost overrun	1. Carry out confirmation trial pits to ascertain availability of fill materials 2. Impose proper logistic planning, and handling of fill materials	Probability: 3 Severity: 3 Risk: 9	Probability : 2 Severity : 3 Risk: 6

Table 10. Risk of Excessive pore pressures built up under and within embankment fill*

(*Actual HIRARC Assessment implemented for the Mengkuang Dam Project)

No	Risk	Causes of Risk	Consequences	Controls / Action Plans	Preliminary Risk Assessment	Risk with Control Evaluation
6	Excessive pore pressures built-up under and within embankment fill	1. Embankment filling too fast 2. Impoundment of reservoir too fast 3. Inadequate design of drainage layer	1. Risk of embankment failure 2. Delay 3. Cost overrun 4. Loss of properties and life	1. Routine pore pressure monitoring to ensure it does not breach the threshold limit 2. Consultation with Consultant when anomalous readings are observed or thresholds limit breached	Probability: 3 Severity: 5 Risk: 15	Probability : 2 Severity : 5 Risk: 10

Table 11. Risk of Anomalous vertical & horizontal displacement / deformation to embankment fill*

(*Actual HIRARC Assessment implemented for the Mengkuang Dam Project)

No	Risk	Causes of Risk	Consequences	Controls / Action Plans	Preliminary Risk Assessment	Risk with Control Evaluation
7	Anomalous vertical & horizontal displacement / deformation to embankment fill	1. Unsuitable fill material and poor compaction 2. Foundation failure 3. Seismic activity	1. Risk of embankment failure 2. Delay 3. Cost overrun 4. Loss of properties and life	1. Use only approved fill materials 2. Conduct field density test to ensure compaction comply with specifications 3. Routine vertical & horizontal displacement / deformation monitoring to make sure that it is within the threshold limit 4. Consultation with Consultant when anomalous readings are observed or thresholds limit are exceeded. 5. Conduct regular vibration monitoring to make sure that blasting works are within the permissible limit	Probability: 3 Severity: 5 Risk: 15	Probability : 2 Severity : 5 Risk: 10

5.6. Risk of Excessive Pore Pressures Built Up under and within Embankment Fill

During the embankment construction, there is a risk of excessive pore pressures built up under and within embankment fill. This risk of excessive pore pressures has a potential impact to embankment failure, schedule delay, budget overrun, properties damages and even death if the embankment failed.

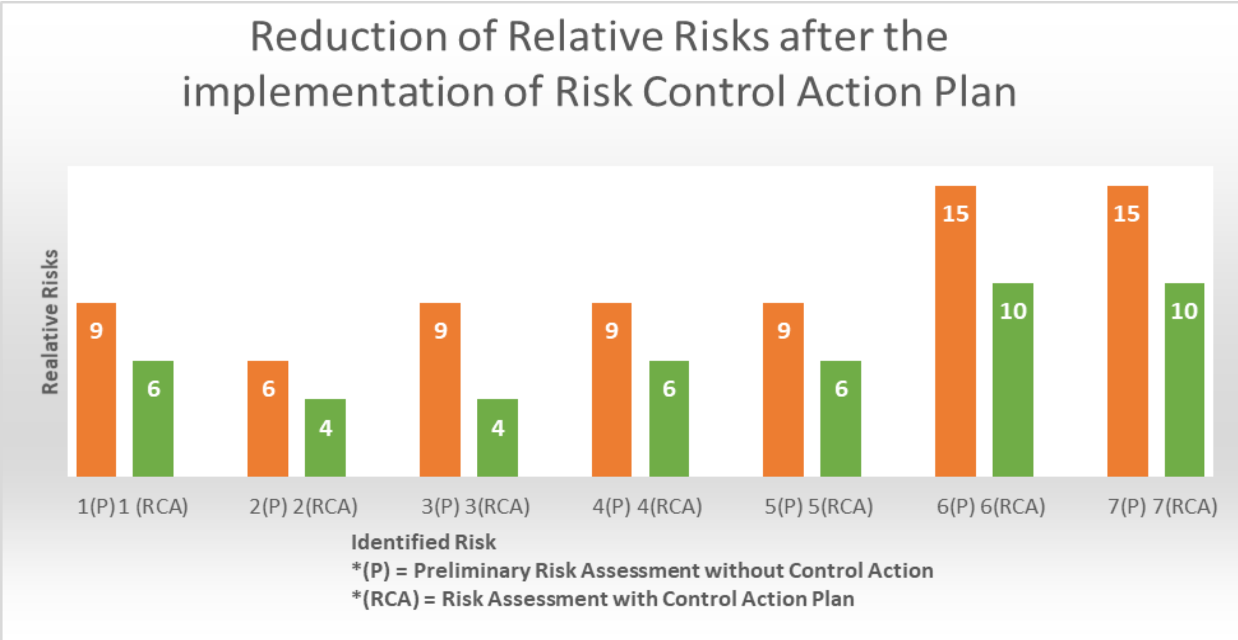
5.7. Risk of Anomalous Vertical & Horizontal Displacement / Deformation to Embankment Fill

During the construction of the embankment, there is a possibility for risk of anomalous vertical & horizontal displacement / deformation to embankment fill. It is paramount important to put in proper controls and action plan to prevent these risks as the consequences can be severe.

6. Risk Analysis for Embankment Construction

The above HIRARC Risk Matrix is used during the construction stage to quantitatively evaluate the risk reduction of the Risk Assessment with the control action taken against the preliminary do-nothing risk assessment. The risk assessment was implemented to determine the cause of the risk, determine the consequences and plan the control action plan to be implemented versus the do-nothing option.

Based on HIRARC risk register matrix above, the relative risks are shown to have reduction after the implementation of the risk control action against preliminary do-nothing approach. This is shown in Figure 2 which summaries the reduction of relative risks after the implementation of Risk Control Action Plan.



Legends

1	Setting Out Risks
2	Risk of Cofferdam Overtopped
3	Risk of Excessive Groundwater
4	Risk during Foundation Excavation
5	Risk of Insufficient Clay Core Material
6	Risk of Excessive pore pressures built up under and within embankment fill
7	Risk of Anomalous Vertical and Horizontal displacement / deformation to embankment fill
*(P) = Preliminary Risk Assessment without Control Action *(RCA) = Risk Assessment with Control Action Plan	

Figure 2. Reduction of Relative Risks after the implementation of Risk Control Action Plan

7. Conclusions

Construction projects are always exposed to hazards and risks. For a crucial project such as the Mengkuang Dam expansion project and associated works, it is important to have an effective Risk Management Plan. Construction of this type of upgrading project was subjected to severe risks such as the safety of existing dam, project schedule delay, budget overrun, and contractual dispute. Hazard Identification, Risk Assessment and Risk Control (HIRARC) is an effective risk analysis process in the Risk Management Plan that was adopted during the construction stage of Mengkuang Dam upgrading project in Malaysia. The HIRARC assessment of Risk Management Plan has helped to identify the causes and consequences that arise for the project. Risk control action plan has also been formulated for mitigation purposes. Based on the HIRARC risk assessment on the probability and severity of the risk, the relative risks are reduced with the implementation of this control action plan. The case study of the Mengkuang Dam Risk Management HIRARC Assessment shows that the construction project risk in term of the relative risks can be reduced by implementing effective control action plans to mitigate the risks. Although the project risks cannot be fully mitigated, a proper control action plan can minimise the likelihood and/ or the severity of the risks associated with the construction scope of works and eventually reduce the relative risks. The HIRARC risk management can also be adopted in other dams or construction projects for a better hazard and risk management. All construction projects shall identify the hazard and conduct risk assessment prior to the construction stage. An effective risk control and action plan can be monitored and implemented with HIRARC to reduce the project relative risk.

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Tenaga, Teknologi Hijau dan Air (KeTTHA) on 21 May 2012. During the risk management workshop, HIRARC methodology is identified as the Risk Management approach to be adopted for the Mengkuang Dam Expansion project.

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