RISK AND VALUE MANAGEMENT FOR A MAJOR WATER SOURCE EXPANSION PROJECT

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Synopsis : This paper describes the risk and value management plan (RVMP) formulated for a major water source expansion project in order to manage the risks of construction and the uncertainties related to the foundation conditions, construction materials, weather conditions, environmental impacts, etc.

The framework and methodology of the RVMP is presented. This case study demonstrates that the RVMP is beneficial in dealing with risks related to construction of a large scale water source expansion project and has resulted in significant saving in the construction cost, reduced the risks of construction and minimized the social and environmental impact during construction of the project.

Introduction

Construction of large scale civil engineering project is always exposed to some construction risks that can lead to delay and cost overrun. Detailed Investigation during feasibility study and design stage carried are not possible to cover all aspect of uncertainties and risks. Water source development projects which involve construction of dams commonly encounter a number of uncertainties e.g. floods during construction, foundation conditions, construction materials, weather conditions, environmental impacts etc. Risk management decision making during construction stage must evaluate the effects of the actions taken. Whatever is done to the dam during construction will have impact on the future performance of the dam.

This paper describes the risk and value management plan (RVMP) formulated for the implementation of the Mengkuang Dam Expansion Project. It involved integration of risk management and value management in an iterative manner to reduce the risk and construction cost and meet the functionality of the project. The framework of the RVMP and the related issues in its implementation are discussed.

Importance of the Water Source Expansion Project

The Expansion of Mengkuang Dam Project with construction contract value RM 607 Million is a large scale water sorce augmentation project. It increases the existing reservoir's active storage from 22 to 73.5 million cubic meter and the raw water supply capacity from 350 to 650 million litre per day. This water source expansion project is vital for the security of raw water supply to the Sg. Dua Water Treatment Plant which provides over 80% of the potable water supply of Penang state. The project is located in Pulau Pinang and approximately 8km from Bukit Mertajam as shown in figure 1.

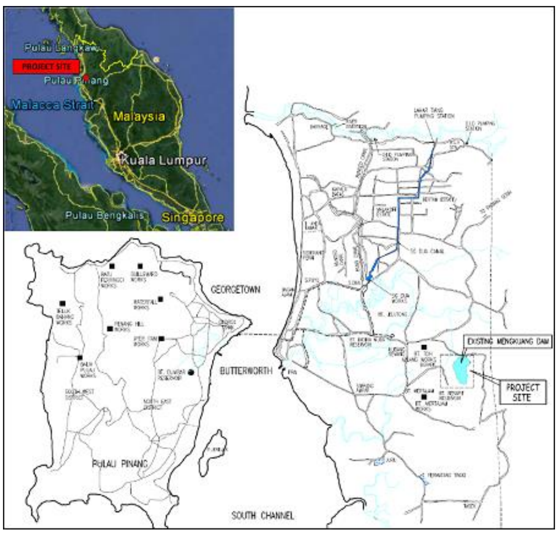

Figure 1 - Location Plan

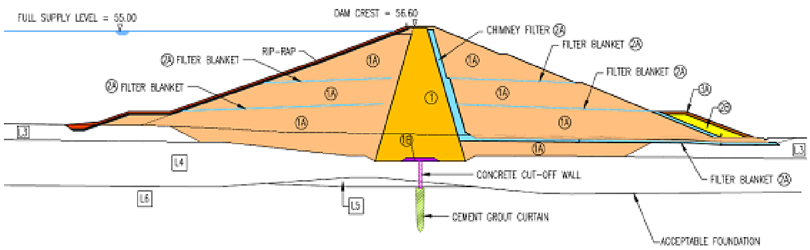

Figure 2 - Typical Design Section of New Dam

The existing Mengkuang Dam is an earthfill dam approximately 1 km long and 31m high .It formed part of the Mengkuang Pumped Storage Scheme completed in 1985. The water source expansion project involved raising the existing dam by 11 m and construction of a new dam 2 km long 45 m high adjacent the existing dam.

The construction contract was implemented in two stages. Stage 1 involves construction of a new dam at the left valley adjacent existing dam. Stage 2 involves raising the existing dam. The new dam is a zoned earthfill dam as shown in Figure 2. Figure 3 shows the new dam completed on 31st July 2015. The draw-off tower located near the left abutment of the new dam is shown in Figure 4.

Figure 3 - Panoramic View of the Mengkuang Dam

Figure 4 – A View of Draw-off Tower

Level 1 – Qualitative Risk Assessment

- Risks identification covering Technical, Environmental, legal, Contractual & Financial
- Likelihood of occurrence
- Consequence & significance
- Risk Rating
- Mitigations actions or monitoring for rating 3 & below
- Move to Level 2 for rating 4 & above

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Level 2 - Semi Quantitative Assessment

- Failure Modes Identification
- Likelihood of occurrence
- Consequence Analysis
- Mitigation Action
- Move to Level 3 for Risks with high consequence

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Level 3 - Quantitative Assessment

- Event Tree & Effect Analysis
- Probability Assessment
- Consequence Analysis
- Tolerability
- Risk Mitigation Options Evaluation
- Recommendation for Action

Figure 5 – A Three Tiered Risk Management Plan

Risk Management at Construction Stage

A three tiered risk management plan was formulated for the project and the process involved is illustrated in figure 5. A risk assessment was conducted to assist the decision-making process of determining what is the acceptable level of risk and which option provides the most suitable risk reduction measure. The process involves several phases, namely : risk identification, risk estimation, risk aversion and risk management.

Level 1 Risk Assessment

In level 1 risk assessment a qualitative method was used for quick evaluation of the risks. A workshop was conducted to deliberate on some 50 risk factors identified. Various risk categories covering technical, environmental, legal, contractual and financial risks were evaluated. In the category of technical risk, risks are organised further according to their particular nature or discipline such as hydrology, hydraulic, geology, geotechnical, structure, mechanical, electrical etc. The process performed in the risk analysis involves the following :

- Separating the project into its component parts and functions.
- Identifying the construction activity or influence that has potential to impact negatively on the design, construction and operation of the project, on third party or the environment.
- Identifying failure mechanisms of each project component part and functional unit.
- Analysing risk of each factor, its probability of occurrence and consequences.

A project risk register describing the risks and source of these risks and the parties responsible for them was drawn up. An assessment of these risks was undertaken by evaluating the potential impact or consequence and their likelihood of occurrence, from which a risk rating was derived.

A project risk management plan detailed the initial risk control action to reduce the rating of each risk such that the residual probability and impact was reduced to an acceptable level. The register was under continual review and revision throughout the construction stage.

An initial risk control plan with mitigation measure was applied for risk with rating medium to high, otherwise, monitoring is sufficient. In cases which the consequence or impacts are high but the probability of occurrence was uncertain, a level 2 risk analysis was undertaken.

Level 2 Risk Assessment

The workshop has identified 13 risks factors for level 2 assessment as shown in Table 1 and their locations are shown in figure 6. A semi-quantitative approach was adopted. Its primary focus was on the dam safety issues. The failure mechanisms of each project component part and functional unit were identified. For each risk factor, its probability of occurrence, consequence, tolerability and mitigation measures require were evaluated.

Some risks constitute a threat throughout more than one stage of the project from design, construction, commission and operation; in such cases their particularities related to each stage were assessed. Some risks impact only at the construction and commissioning stage, while others impact on the safety of the dam for future operation. What had been done at the construction stage will have impact on the future performance of the dam.

In some cases, investigations were needed in order to perform the risk analysis. In cases which require long lead time to resolve the risk issues, early effective solution were needed. This required quick action, sound judgment and correct decision by the parties concerned. The decision on the selection of option for mitigating action can become difficult for cases which probability of failure is low but the consequences is very high involving loss of life, extensive damage to environment and economic losses.

Three risks factors were identified as critical for level 3 detailed analysis as follow :

(1) Risk of failure of existing dam with reservoir water level at EL 43m during construction of new dam. The consequence of failure of the existing dam would be serious. A quantitative risk analysis was conducted as discussed below.

(2) Risk of failure of existing dam during construction of dam raising works. This risk was subsequently reduced to a tolerable level after the decision to lower the reservoir water level was adopted as the mitigation measure to the first issue above.

(3) Risk of piping at left abatement of new dam adjacent Weng Lee Quarry.

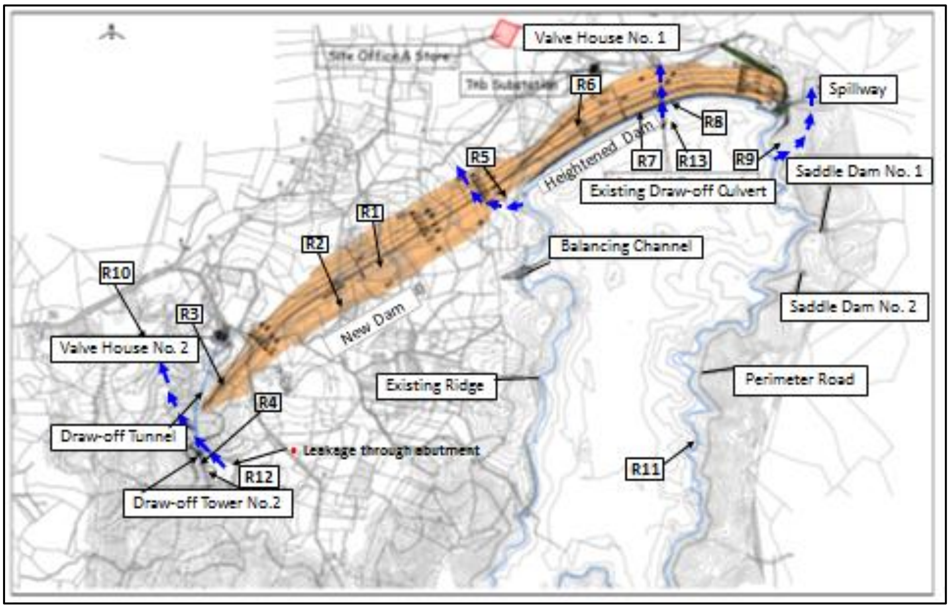

Figure 6 - Location of Identified Risk Factors For Level 2 Risk Assessment

Table 1 –Risk Factors Identified For Level 2 Risk Assessment

R1	Piping at old river course due to arching effect at filled embankment Ch400.	R7	Risk of collapse of existing dam during trenching for construction of plastic concrete cutoff wall.
R2	Excessive settlement resulting in cracks at dam embankment due to thermally altered granite at dam foundation Ch350 to ch950m.	R8	Piping through clay core of dam embankment due to low stress zone along drawoff culvert.
R3	Piping at left abutment lead to blow out at Weng Lee Quarry face due to layer of whitish thermally altered granite.	R9	Slope instability at inlet channel of spillway.
R4	Cut slope instability at drawoff tower No.2.	R10	Rock blasting at Weng Lee Quarry impact on integrity plastic concrete walls, grout curtain of dam.
R5	Ch.1750 Piping through left abutment at existing dam due to layer of porous weathered granite.	R11	Slope instability of hills at reservoir rim during operational stage.
R6	Piping of existing dam during construction of raising existing dam due to excavation at toe of dam.	R12	Tunnel Inlet Portal instability during construction.
		R13	Instability of Access Bridge to Draw-off Tower No 1.

Level 3 Risk Assessment On Failure Of Existing Dam

The existing dam was filled to its full supply level EL 43m at the time of construction of the dam expansion project. During construction of the new dam, excavation for the foundation preparation works was carried out at left abutment of the existing dam. Concentrated leak was observed at an excavated trench about 100 m away from the existing dam. The leaks were discharging from a thin porous layer of highly weathered granite as shown in figure 7. This observation has prompted the need to assess critically the safety of existing dam due to construction of the project.

Figure 7 - Concentrated Leak at left abutment of existing dam

Purpose of Level 3 Risk Assessment

A risk assessment was required to determine whether the do-nothing option is acceptable and if it is not acceptable whether lowering the reservoir water level would reduce the probability of breaching of the dam to acceptable level and how it compares with the option of a structural measure of soil improvement works or option of control of construction activities near existing dam.

Methodology

Risk identification initially involves the determination of the primary sources or initiating events which could lead to the risk of failure of the existing dam. These failure mode initiators include extreme storms, earthquakes, design and construction flaws in conjunction with normal hydraulic loads, and human agency. The second step involves the development of an event tree diagram which details the possible failure modes of the dam in a logical sequence of events .The failure modes in various categories in terms of hydraulic overtopping, internal erosion/ piping, mass movement and slope instability. Conditional probabilities to each branch of the event trees are assigned and the consequences of failure for each failure mode represented by each separate branch in the event tree are estimated. Consequences consist of estimating the likely loss of life and economic damages associated with each of the failure modes.

Risk aversion consists of looking at both structural and non-structural options to reduce the risks of failure to a tolerable level.

Risk Identification

The study was not aimed at assessing the overall probability of failure of the existing dam under all possible causative events. Thus the following types of specific events were not included: Events which cause a slip of the upstream shoulder of dam such as rapid draw down, floods which cause overtopping of dam; and earthquake which cause crack, liquefaction or slip failure of dam.

The risks associated with the above events would be similar for all the options assessed and the risks would be very low so as not to affect the overall risk comparisons.

Insofar as the reservoir water level is concerned, floods need not be considered as a separate causative event as the dam has adequate freeboard, has an ungated spillway and thus the factor of safety would be similar to all options.

Initiating Events

The plausible initiating causative event would be the piping event initiated by excavation at the abutment of existing dam and the downstream toe of the existing dam. From the observation at the excavated trench (about 2m deep), concentrated leak through the existing dam abutment is hydraulically connected to the existing reservoir filled with water. There is a layer of highly weathered granite approximately 1m thick which is relatively porous. A potential failure mode related to internal erosion at the abutment soils was considered likely to occur during foundation excavation at left abutment of existing dam.

Assessing Whether Erosion Will Initiate

The hydraulic shear stresses (HST) in the leakage conduit was computed based on method by Wan and Fell (2004). The reservoir level under consideration, assumed leakage conduit dimensions and location relative to the reservoir surface were taken into consideration so the hydraulic gradient can be determined.

The HST computed is compared with the critical shear stress (CST) which will initiate erosion for the soil in the abutment. CST was estimated based on results by Wan and Fell (2002) who developed method to estimate critical shear stress using laboratory test results of the Hole Erosion Test. Piping analysis using analytical method was faced with uncertainty on factors such as hydraulic gradient, permeability, variability of materials and their properties and erodibility of materials. A probabilistic risk assessment was considered important to assist in the decision making process in addressing the issue on the safety of existing dam due to construction works.

Event Tree Construction and Postulated Breach Mechanism

It is recognized that there are limited exposures with which to observe potential development of the failure mode. Internal erosion failure mechanism might result through progressive sloughing and unravelling of the downstream abutment slope as a result of flows undercutting and eroding of the abutment, until the reservoir is breached at which point rapid erosion of the abutment soils is likely to cause instability to the embankment and eventually cutting a breach to the dam.

If internal erosion and piping failure modes were to initiate, it would be difficult to detect during rainy days and night times when no one is at the site. The failure modes could be well developed and in progress by the time it is detected. Once the abutment is breached to the reservoir, rapid enlargement and complete loss of the reservoir filled with 22 MCM of water could occur. Also even if detection were made, there are uncertainty on the evacuation efficiency. Figure 8 shows the Event Tree constructed based on the postulated failure mechanism.

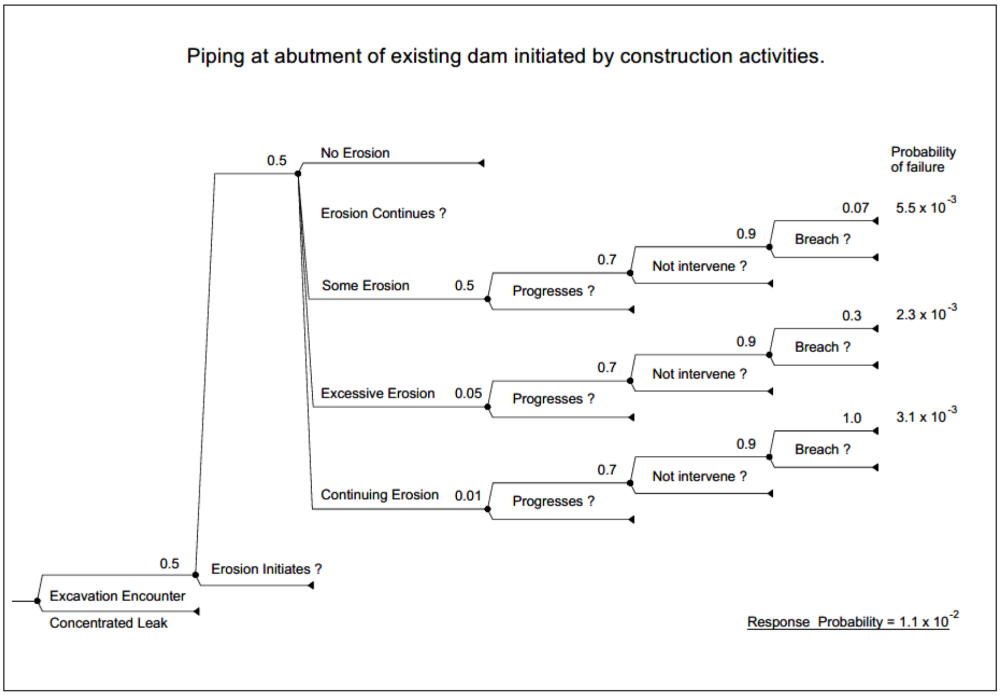

Figure 8 - Event Tree for Piping Failure Mode

Probabilistic Risk Analysis

The assigned conditional probabilities for each event tree were based on method by Fell and etal, 2008 "A Unified Method for Estimating Probabilities of Failure of Embankment Dams by Internal Erosion and Piping ".In the event trees, the aggregate conditional probability of dam failure along the failure path is the product of probability of occurrence of all conditional probabilities along that path. The aggregate conditional probability of failure for a causative event is determined by summing of all the probabilities of the paths that lead to dam failure. The whole question of piping was very complex and judgement couple with analytical method were required as a guide for this type of risk analysis. The aggregate conditional probabilities for each of the causative event can be plotted against the appropriate annual exceedance probability (AEP) value.

Consequences

Consequences were classified under several categories: loss of life, economic loss, environmental and social damages. The inundation maps prepared from the dambreak simulations were used to estimate the population at risks and the properties in the flood plain. There are several communities nearby would be inundated along the river basin according to the dam break study conducted. The consequence due to the dam failure would be catastrophic.

The tolerable risk levels are related to such factors as the geographical situation, the level of economic development, the cultural values and the political sensitivity. The risk management plan followed the guidelines of the Canadian Dam Association on the principle that the risk should be as low as reasonably practicable (ALARP) and the maximum level of societal risk for life safety should be less than 10^{-3} /year for loss of one life that was not explicitly foreseen and identified in advance of the failure; a higher risk is considered unacceptable.

Mitigation Measures – Options Evaluation

Options considered include :-

- Option 1 - Do no-thing approach was considered not acceptable due to large number of population at risk.
- Option 2 -Lowering reservoir water level from elevation 43 m to 34 m were evaluated. This would reduce water storaged from 22MCM to 12 MCM .This option will impact on security of the water supply system of Penang state.
- Option 3 - Construction control by limiting extend of foundation excavation at any one time. The method was considered not reliable due to its high residue risk.
- Option 4 - Structural design to incorporate soil improvement works using jet grout columns so that removal of the soft materials can be omitted. This option entails high cost and time and contractual issues.

Risk Reduction Option

Option 2 – lowering existing reservoir water level was recommended for the lease contractual impact and minimum cost involved. Other merits of option 2 include :

- The ridge contains large amount of suitable clay core materials can be abstracted for construction of the project. The needs to import clay core materials from external source can be avoided.

- A channel can be cut through the ridge so that the two reservoirs can be connected. This would allow omission of drawoff works at right valley reservoir and extensive optimization of design for the raising of existing dam.

However, option 2 involved serious impact on the security of water supply system. The potential risk was not acceptable to Penang government unless an alternative water source as back-up could be provided. Beris dam water source from Kedah state was identified as a suitable back up source. However charges on raw water was imposed by Kedah government. The issue was resolved through a process of negotiation amongst Federal Ministry (KeTTHA), Penang and Kedah State government.

Risk of Piping at Left Abutment of the New Dam

By 2012 the hill adjacent Weng Lee Quarry was extensively excavated by the commercial quarry operation. Geological investigation at quarry face revealed a series of heavy jointed and sheared zone in the rock mass. Thin layers of thermally altered granite were observed at the quarry face. This completely weathered rocks become soft when expose to rains and becomes powdery when dry. There is concern that piping through this weak materials at the left abutment of the new dam which pose uncertainty to the long term safety of the dam. Sub-surface exploratory boreholes and in-situ permeability tests conducted showed high Legion value and leakage potential. The result of risk analysis showed that the risk was unacceptable. The risk mitigation measure consisted of construction of three rows cement grout curtain at the left abutment of the dam with an additional cost RM 6.2 million to the contract.

Value Management

A value management plan (VMP) implemented for the project involves the following process :

- identify opportunities and potential candidates for design optimization.
- evaluation of alternative solutions, anticipated risks and problems encountered during implementation or execution stage both contractual, technical and financial due to design changes.
- meeting Client's needs and requirements without compromising the function and performance.

The objective of the value engineering exercise is to save construction cost, reduce construction risk and better project delivery. The approach adopted involved integration of risk management and value management in an interactive manner and working together in achieving clients' and stakeholders' requirements. The process of deriving the optimum solution is illustrated in Figure 9. The views of stakeholders especially from the authorities, Client project management team were taken into account to validate the recommendations for design optimization in accordance to the requirements of the project.

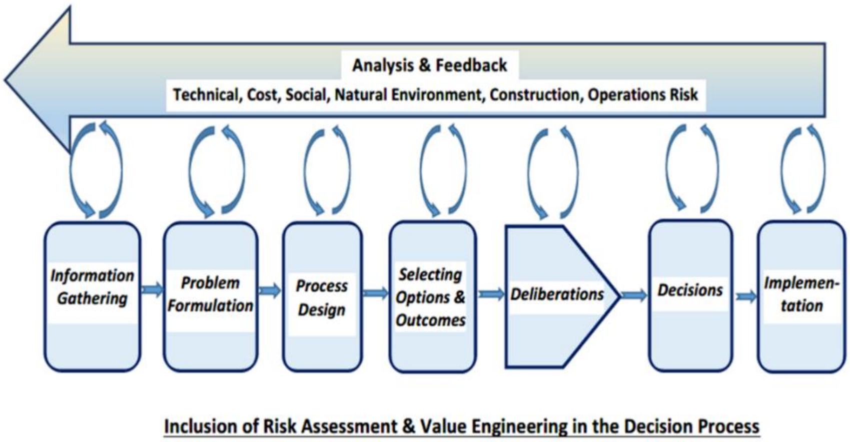

Figure 9 - Integration of risk management and value management in an iterative process of deriving optimum solutions

The VMP had identified 9 key areas for design optimization which has resulted in a saving in construction cost of approximately Rm150 Million as described below.

VE1 - Maximise Abstraction of Borrow Materials At Ridge Adjacent Existing Reservoir.

VE2 - Channel to Connect The Two Reservoirs .

VE3 - Redesign of Dam Raising Works.

VE4 - Omission Of Concrete Retaining Walls At Dam Toe Area

VE5- Change In Valve House Location

VE6- Redesign Of Spillway

VE7- Change Of Filter Materials

VE8- Change In Alignment Of Pipeline

VE9- Redesign Of Reservoir Perimeter Road

Conclusions

1. Construction of large scale water source development project is always exposed to some construction risks and uncertainties that can lead to delay and cost overrun. Risk management can be applied throughout the construction period to achieve the best outcomes for the project.
2. Value management alone cannot achieve good results or produce solution effectively without incorporating risk management. Risk management should come first before value management.
3. Cooperation of key stakeholders is vital to obtain prompt decision making in order to achieve a desirable project delivery.
4. Risk management and value management can be integrated in an iterative process which lead to a well informed decision, better design, reduce construction risk, cost and time saving.
5. Risk assessment can provide basis for decision making in selection of mitigation measures require together with other considerations including engineering judgments, stakeholders expectations, economic and political factor to assist decision-maker select appropriate actions.

Reference

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