Stability Analysis and Cost Benefit Analysis of the Extension Retaining Wall for Kenyir Dam Spillway

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Abstract. Retaining wall is a structure that are designed and constructed to withstand lateral pressure acting on it. It also plays a huge role to channel the water to the safe area that can minimize the impact of vortex phenomena. This paper is comparing the stability analysis and cost benefit analysis between two types of retaining wall that proposed to be an extension wall to the existing spillway's retaining wall at Kenyir Dam:- i) gabion wall and ii) reinforced concrete retaining wall (RC wall) . The optimized dimension and layout for both type of retaining wall is presented in this paper considering the stability analysis requirements. Other than that, cost benefit analysis is conducted in order to compare the most effective cost between these two type of walls. It is found that the price for gabion wall is lower than RC wall considering the replacement of the gabion wall after 10 years.

Keywords: Gabion, Reinforced Concrete Retaining Wall, Retaining Wall, Cost Benefit Analysis.

1 Introduction

Dam are man-made hydraulic structures that usually contribute to economic and domestic benefits such as electricity and water storage[1]. Dam can be beneficial in generating the renewable electricity that can be supply to the user. This type of dam is called hydroelectric dam[2]. Sultan Mahmud Power Station or known as Kenyir Dam is one of the largest hydroelectric dam in Peninsular Malaysia[3]. Located in Terengganu, this Power Station produces 100 megawatts by allowing the water flow through the penstock into four turbines. During monsoon season, the water level of the dam rises causing the water to flow over the spillway y with a maximum capacity of 7,000 cubic meters per second [4]. However, when spilling event occurs at Kenyir Dam Station, one of the things that concern the most is the direction of water release from spillway and pressure tunnel.

Because of the conversion of whole potential energy into kinetic energy, water flowing over a spillway has a very high kinetic energy. The equations used by the past researcher to develop the fluid flow was turbulence kinetic energy, k [5]

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_j)}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\varepsilon - Y_m + S_k$$

Figure 1 show the plan view of the Kenyir Dam Station. The arrow indicates the direction of the water release from both spillway and pressure tunnel. It shows the contrast in the angle of water release from these two sources which can cause vortex. A vortex, also known as a drain's whirlpool, forms because of the downdraft that the drain creates in the body of water. The downward flow of the water begins to rotate, and as the rotation speeds up, a vortex forms [6]. These phenomena are very critical and able to cause a serious effect relate to the safety of the dam. Along this line, the retaining wall is needed to be installed to prevent the backflow of water towards the power station and will cause vortex at the downstream.

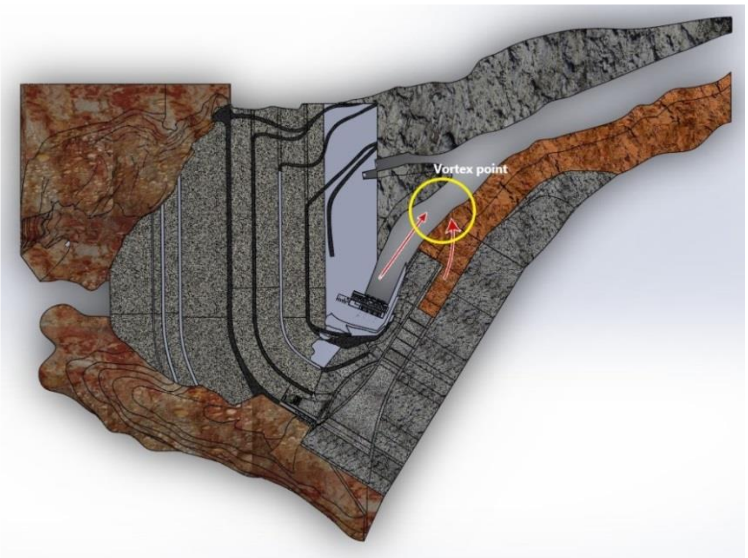

Fig. 1. The plan view of Kenyir Dam Station

Retaining wall is a structure that are designed and constructed to withstand lateral pressure acting on it. The lateral pressure could be also due to earth filling, liquid pressure, sand, and other granular materials behind the retaining wall structure[7]. In this case, retaining wall is needed to withstand the pressure from water flowing through the spillway. Other than that, the retaining wall also plays a huge role to channel the water to the safe area that can minimize the impact of vortex phenomena. However, before designing the retaining wall, it is important to execute the stability analysis which consists of these three elements:

i. *Sliding* – The backfill exerts a lateral pressure against the wall. This sliding force is resisted by the friction between the soil and the footing, and by the passive pressure at the front of the wall. When more sliding resistance is required, a shear key may be provided. The factor of safety against sliding equals the resisting force divided by the driving force, and the minimum value should be 1.50.

ii. *Overturning* – The overturning moment from the applied forces must be resisted by an opposite moment produced by the vertical forces, including the wall selfweight and the weight of the backfill over the heel. The factor of safety against overturning is defined as the resisting moment divided by the overturning moment, and the minimum value should be 1.50.

iii. *Settlement* – The allowable soil bearing pressure should be provided by the soils report, which already includes a safety factor of about 3.0. The resultant of the bearing pressure should fall within the kern to avoid negative soil pressures at the heel.

2 Methodology

This study focus on the stability analysis and cost benefit analysis for both type of retaining wall:- i)gabion wall and ii) reinforced concrete retaining wall.

2.1 Stability Analysis

The lateral force due to water flow constitutes the main force acting on the retaining wall, which might cause the wall to overturn, slide and settle. Thus, it is very important to analyze the stability of the wall as it is very crucial to the safety of the wall. The design of gabion begins with the selection of trail dimensions for a typical vertical cross section through the wall. Figure 2 show four main steps that must be followed in conducting the stability analysis.

Fig. 2. The procedure of stability analysis.

In this study, the overturning moment is calculated from the water force acting laterally towards the wall, M_o, while the resisting moment is calculated as

$$M_r = W_w X_w + W_h X_h + W_t X_t$$

where W_w, W_h, W_t, are weight of wall, head and toe of the retaining wall while X_w, X_h, X_t are distance from the center of wall, head and toe to the rotation point at toe. The factor of safety against overturning is calculated as

$$Fs = \frac{M_r}{M_o}$$

For sliding analysis, the driving force for sliding is calculated from the water force acting on the wall, while the friction resisting force at the base of footing is calculated as

$$F_R = W \times \mu$$

Where W is the weight of the wall and m is friction coefficient between concrete and the soil. The wall is said to be stable in sliding when the friction resisting force is more than the acting force on the wall. Meanwhile, for the stability against settlement, bearing pressure is calculated by the center of the total weight from the edge of the toe.

$$e = B/2 - [(M_R - M_O) / W_g]$$

Where Wg is total weight of retaining wall including stem, footing, earth and surcharge and B is the width of the retaining wall. The maximum pressure under the base is calculated by

$$P = (Wg/B)(1 + 6e/B)$$

The maximum pressure under the base is being compared to the rock bearing pressure which was 3300 kN/m^2 for granite. The detailing design for RC wall was following the conventional procedure of reinforced concrete design.

2.2 Cost Benefit Analysis

Cost benefit analysis (CBA) is method to be used to decide the estimation value of the project, comparison costs and benefits of the project. The comparison of the total cost for both type of retaining wall is calculated by using equation Present Values Cost (PV Cost). Present value is the current value of an expected future stream of cash flow.

$$\text{PV(cost)} = X + \Sigma C_{ji}(1+r)^{-i} + C_a\left(\frac{1-(1+r)^{-n}}{r}\right) - Z(1+r)^{-n}$$

Where ;

X = initial cost	Cij = future cost	r = interest rate
Ca = annual cost	Z = benefit	P = present value
C = cost	n = no of years	F = future value
A = annuity		

In this analysis, the comparison of two types of retaining wall was considering only 1m length of the wall for research.

3 Result and Discussion

In order to overcome the problem discussed the introductory part, retaining wall is proposed to channel the water flowing through the spillway with the suitable distance and angle of curvature. Figure 3 show the proposed location of the retaining wall at the downstream area. In this section, the stability analysis and cost benefit analysis for both gabion and reinforced concrete wall is presented.

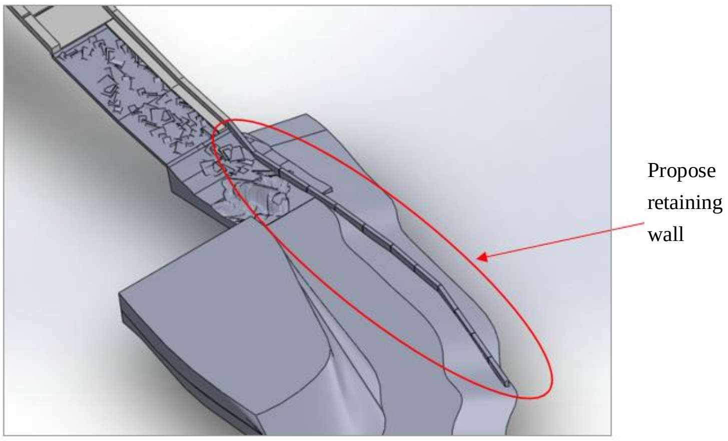

Fig. 3. Proposed location of retaining wall

3.1 Stability Analysis

Figure 4 show the optimize layout and dimension of the gabion and reinforced concrete wall that fulfill the stability requirements. A gabion wall shown in Figure 3(a) is a retaining wall made of stacked stone-filled gabions tied together with wire. It is usually battered (angled back towards the slope), or stepped back with the slope, rather than stacked vertically. Gabion Walls are generally analyzed as gravity retaining walls, that is, walls which use their own weight to resist the lateral earth pressures. Meanwhile, cantilever retaining wall which is constructed of reinforced concrete consists of a relatively thin stem and a base slab as shown in Figure 3(b). The detailing design of the reinforced concrete was following the conventional design according to Eurocode 2.

Table 1 show the summary of the comparison of the action force, moment and pressure towards the retaining wall and resisting force, moment and pressure by the retaining wall. To make sure the stability analysis is in optimize condition, the action parameters in those three elements should be less that the resisting strength parameter considering the safety factor of 1.5 or 2.0. Referring to the summary of stability requirement in the Table 1, it shown that the stability against sliding contribute to the selection of the design of the wall. This is due to the water pressure acting laterally towards the retaining wall.

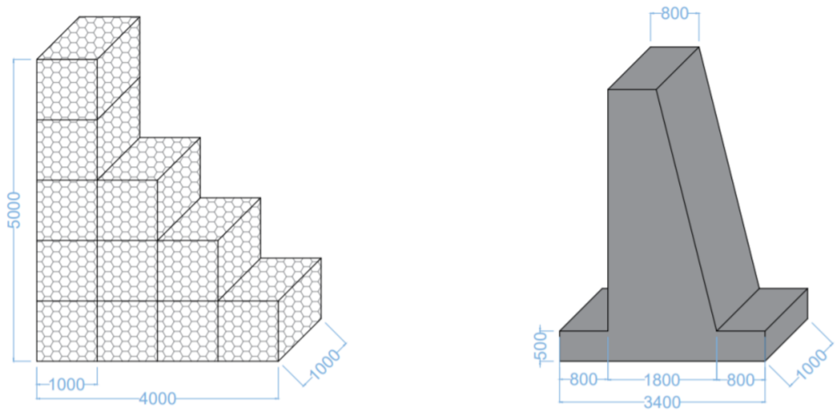

Fig. 4. The optimize layout and dimension of retaining wall

Table 1. Stability analysis of the gabion and reinforced concrete wall

STABILITY REQUIREMENT	GABION ACTION	GABION RESISTING	RC WALL ACTION	RC WALL RESISTING
Overtuning (kNm)	70.24	563	46.8	323
Sliding (kN)	35	78	28	51
Settlement (kN/m^2)	40.44	3300	59.4	3300

3.2 Cost Benefit Analysis

A cost benefit analysis is carried out as an appropriate analytical tool considering various benefits, safety investment, direct and indirect costs of accidents. With an indication of the magnitude of net benefits associated with a particular project or policy, CBA has traditionally focused on efficiency and providing the policy makers [8]. In this section, the initial construction cost and the maintenance cost is discussed.

a) Construction Cost

Table 2 shows the price rate for building material, labour wage and machinery hire rate as well as the equipment purchase for 1m length of the wall. It is collected from The National Construction Cost Centre under Construction Industry Development Board (CIDB)[9] and JKR Rates Online (RATOL)[10]. It shows that there is a huge different between the total construction cost for gabion wall and RC wall. The total price of gabion was RM8,883.61 including the material, machinery and labour which were RM1,116.81, RM6,802 and RM964.80 respectively. RC wall on the other hand having a total cost of RM19,603.45 including the material, machinery and labour which were RM1,483.80, RM11,316.65and RM6,803.00 respectively.

Table 2. Estimation Construction Costs (per meter length)

Cost (per meter length)	Gabion Wall	RC Wall
Material	RM 1,116.81	RM 1,483.80
Machinery	RM 6,802.00	RM 11,316.65
Labour	RM 964.80	RM 6,803.00
Total	**RM 8,883.61**	**RM 19,603.45**

b) Lifetime and maintenance

The life expectancy of gabions depends on the lifespan of the wire, not on the contents of the basket. The structure will fail when the wire fails. Galvanized steel wire is most common, but PVC-coated and stainless steel wire are also used. PVC-coated galvanized gabions have been estimated to survive for 60 years[11]. Some gabion manufacturers guarantee a structural consistency of 50 years[12]. However, other than the main factor of gabion failure which was the wire basket condition, there are some failures that may reduce the lifespan of gabion of disturb its role as a retaining wall such as buldging, corrosion, erosion of filled stone, backfill crack, and foundation erosion[13]. In such a way, the worst case scenario was the failure of the wire of the basket, which may need a replacement of the gabion basket in some period of time, depending on the condition of the wall.

In this section, the price of gabion to be replaced after 10 years is discussed. It then being compared to the RC wall which was designed to have 50 years lifespan with the cost of maintenance is said to be negligible because of the strength of RC concrete that can withstand a 10 years lifespan. The price forecast for gabion wall need to be calculate after 10 years are shown in Figure 3. The rate of interest is increase by 2% annually from the current year[9]. Table 4 shows the comparison of the initial construction cost and present value costs. Based on Table 4, it shown that gabion wall gave the lower cost than the RC wall. The calculated replacement price of gabion wall was RM9,043.36 which gave RM16,302.17 as a total value of PV(cost) .

Table 3. Forecasting for construction cost for a period of 10 years

Year	Construction Cost	Year	Construction Cost
2019	RM8,883.46	**2024**	RM8,972.29
2020	RM8,901.23	**2025**	RM8,990.06
2021	RM8,918.99	**2026**	RM9,007.83
2022	RM8,936.76	**2027**	RM9,025.60
2023	RM8,954.53	**2028**	RM9,043.36

Table 4. Initial Construction and Present Value Costs (per meter length)

	Gabion Wall	RC Wall
Initial construction costs (year 0)	RM8,883.46	RM19,289.80
Maintenance / replacement after 10 years	RM9,043.36	-
PV (Cost)	RM16,302.17	RM19,289.80

4 Conclusion

As a conclusion, the stability analysis and cost benefit analysis of two type of retaining wall have been successfully determined. The CBA shows that there is a different in total cost of construction between these two types of wall. The initial construction cost for gabion and RC wall was RM8,883.46 and RM19,289.80 respectively. Meanwhile, PV cost for gabion and RC wall after 10 years marks the price of RM16,302.18 and RM19,289.80 respectively. However, depending on the corrosive contaminant condition of the gabion wall, there will be a possibility that the wall does not need any maintenance or replacement for that particular 10 years. Thus, it can be concluded that, with or without maintenance or replacement cost, the gabion wall still contribute to the lower cost compare to RC wall.

5 Acknowledgment

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References

1. M. R. M. Radzi, M. N. Nashrudin, M. H. Zawawi, A. Abas, A. Azman, and A. Hassani : Effect of free surface water level of Kenyir Dam on spillway structure using fluid-structure interaction (FSI) analysis, Applied Physics of Condensed Matter 2131, 020043 (2019)
2. Azizi Arbain, Ahmad Zhafran Ahmad Mazlan, Mohd Hafiz Zawaw, Mohd Rashid Mohd Radzi : Vibration Analysis of Kenyir Dam Power Station Structure Using a Real Scale 3d Model. Civil And Environmental Engineering Reports 30(3), 48–59, (2019).
3. B. K. Tan : Geotechnical Aspects Of The Kenyir Dam Project, Trengganu, Peninsular Malaysia, 133–137 (2000)
4. Kenyir Lake Homepage, https://kenyirlake.com/kenyir_dam.htm, last accessed 2019/09/11
5. M. H. Zawawi, M. G. Swee, N. S. Zainal, N. M. Zahari, M. A. Kamarudin, and M. Z. Ramli : Computational Fluid Dynamic Analysis for Independent Floating Water Treatment Device. AIP Conference Proceedings 1885, 020122 (2017);
6. How Tornadoes Work, https://science.howstuffworks.com/nature/climate-weather/storms/tornado1.htm, last accessed 2019/09/11
7. Retaining Wall Types, Materials, Economy, and Applications, https:// theconstructor.org/geotechnical/retaining-wall-types-use/24566/ last accessed 2019/09/11
8. Elias Ikpe1, Felix Hammond and David Proverbs, A Cost-Benefit Analysis (CBA) of Construction Health and Safety Management : A Theoretical Discussion. 1035–1043, (2008)
9. CIDB Homepage, "myN3C National Construction Cost Centre," Construction Industry Development Board (CIDB), 2019, http://myn3c.cidb.gov.my, last access 2019/10/01
10. K. K. J. K. Raya, "JKR Rates Online (RATOL)," 2009, http://ratol.jkr.gov.my/, last access 2019/10/01
11. C. History, River Bank Protection. In : Durable Gabion Retaining Structure Product : Gabions, Falls Road, Baltimore, Md, Usa (1974)
12. C.E. Shepherd Company Homepage, https://ceshepherd.com/modular-gabion-systems/, last access 2019/10/04
13. Ganesh C. Chikute and Ishwar P. Sonar : Failures of Gabion Walls. International Journal of Innovative Technology and Exploring Engineering (IJITEE) , 8(11), 1384–1390 (2019)