Estimation of breach outflow hydrograph using selected regression breach equations

M F Shahrim and F C Ros

Disaster Preparedness & Prevention Centre, Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia Kuala Lumpur, Malaysia

Abstract. Embankment dam is commonly built in Malaysia as it provides essential benefits to the local population, such as agricultural activity and flood control measures. However, the release of high potential energy by the impoundment imposes risk of catastrophic event during the dam failure. Therefore, estimation of flood arrival time under dam break event can be beneficial as primary information using numerical model to simulate the breaching process of the embankment dam. The purpose of this study is to establish dam breach profile of Temenggor Dam in predicting breach outflow hydrograph. A few selected regression equations for breach parameters will be tested namely Froehlich, Macdonald and Langridge-Monopolis and Von Thun and Gillete. One-dimensional dam break modelling were performed based on the calculated breach parameters for overtopping and piping failure. Hydrologic Engineering Center's River Analysis System (HEC-RAS) software is used for the dam break analysis. Results obtained from the study indicated that overtopping failure yields the highest peak breach flow of 202,099 m^3/s, compared to piping failure's highest peak discharge of 201,126 m^3/s.

1. Introduction

Dams are commonly known as megastructure which can provide essential needs for multiple purposes such as flood control, electricity generation, irrigation, water supply and recreation. Its impoundment system stores massive potential energy in providing benefits for human, but it would also impose risk of sudden containment breach leading to loss of life and property at downstream. Malaysia has several big size dams which all of them are identified as high risk in terms of impact to society and economic effect [2]. Although Malaysia has not experienced any event of dam failure, the incident of dam failure disasters around the globe would instigate the necessity of forecasting, prevention, and mitigation plan for the event of failure at all constructed dams.

In December 2014, Malaysia has experienced the worst flood disasters at few northern states in Peninsular including Perak. Temenggor Dam, situated along the Sungai Perak, is experienced risk of overtopping as a result of continuous rainfall and its storage had to be discharged in stages to avoid further catastrophic damages [4]. Ishak highlighted that the existing villages is situated along the downstream of Perak river and there is a probable loss of human lives and damages should the unexpected event of dam break occurs.

To study the dam break event of Temenggor Dam, a breach progression must be fully understood in order to assess the risk level towards the affected community and properties. Wurbs (1987) highlighted that breach simulation could provide information with certain degree of uncertainty of all aspects in flood modelling. However, despite of this limitation, a set of breach parameters must be quantified in order to generate reasonable outflow hydrograph to understand rate of the released water, peak discharge time and time arrival at downstream [3]. Estimation of these parameter can be used as references for the installation of preventive measures like warning systems [5].

The outflow hydrograph depends on the breach geometry and formation time, hence overtopping and piping failure will be considered as it is the most probable cases for embankment dam in its failure event [7]. The overtopping failure is based on Probable Maximum Flood (PMF) condition, which is the largest possible flood at that location at maximum rate of precipitation, while the piping failure is modelled during Clear Day Failure (CDF) condition, which is normal reservoir level at absence of precipitation. The aim of this paper is to perform dam break analysis of Temenggor Dam by producing breach outflow hydrograph under PMF and CDF conditions using HEC-RAS hydrodynamic model.

2. Study Area

The Temenggor Dam is a rock-filled embankment dam situated at the Perak state impounding reservoir of 127 million cubic meter at its Full Supply Level (FSL) of elevation (EL) 248.5 meter. Commissioned in 1978, the dam is owned by Tenaga Nasional Berhad (TNB) and has a crest length of 537 m. Temenggor Dam is one of the cascading hydroelectric dams along Perak river where it is the upper most dam followed by Bersia Dam approximately 20 km downstream from Temenggor Dam.

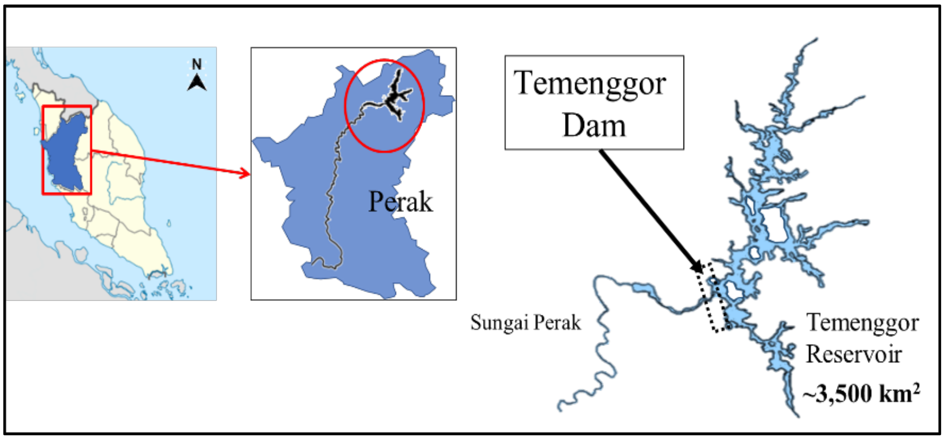

Figure 1. Temenggor Dam location.

3. Methodology

The process of acquiring outflow hydrograph using HEC-RAS software requires the estimation of dam breach parameters using regression equations and setting up model that represents the actual layout on the ground.

3.1. Estimating breach parameters

The estimation of the breach location, type, dimension, and development time are crucial in making reliable prediction of the peak discharge, outflow hydrographs and downstream inundation. Several researchers have developed a set of regression equations using past historical data to determine the breach parameters such as breach width, breach formation time and side slope. Many dam break studies adopt regression equations by Froehlich, MacDonald and Langridge-Monopolis (MLM) and Von Thun and Gillete (VTG). Peak discharge is also determined using regression equations of these methods which will be used for comparison purpose with that obtained from calculated peak discharge from simulation model. Table 1 shows regression equations used in dam break analysis.

Table 1. List of regression equations for breach parameters.

Breach Parameter	Froehlich (1995a)	Froehlich (2008)	MacDonald and Langridge-Monopolis (1984)	Von Thun and Gillete (1990)
Average Breach Width, B_{ave} (m)	$B_{ave} = 0.1803\ K_0 V_w^{0.32} h_b^{0.19}$ K_0=1.4 for overtopping K_0=1.0 for piping	$B_{ave} = 0.27\ K_0 V_w^{0.32} h_b^{0.04}$ K_0=1.3 for overtopping K_0=1.0 for piping	-	$B_{ave} = 2.5 h_w + C_b$ C_b = coefficient based on reservoir size
Bottom Breach Width, W_b (m)	-	-	$W_b = \frac{V_{er} - h_b^2(CZ_b + \frac{h_b Z_b Z_3}{3})}{h_b(C + \frac{h_b Z_3}{2})}$ C=crest width of the top of dam Z_b=0.5, Z_3=avg. slope	-
Breach Formation Time, t_f (hr)	$t_f = 0.00254\ V_w^{0.53} h_b^{-0.90}$	$t_f = 6.32 \sqrt{\frac{V_w}{g h_b^2}}$	$t_f = 0.0179\ V_{eroded}{}^{0.364}$	$t_f = 0.02 h_w + 0.25$ (erosion resistant) $t_f = 0.015 h_w$ (easily erodible)
Peak Flow, Q_p (m^3/s)	$Q_p = 0.607\ V_w^{0.295} h_w^{1.24}$	-	$Q_p = 1.154\ (V_w h_w)^{0.412}$	-
Slide Slope, m	1.4 for overtopping 0.9 for other failures	1.0H for overtopping 0.7H for other failures	0.5	0.5

Table 2 shows the general input to calculate breach parameters based on most occurred scenarios in dam break failure, which is piping and overtopping.

Table 2. General input for breach parameters.

<table>
<tr><th>Input</th><th>Piping Failure</th><th>Overtopping Failure</th></tr>
<tr><td>Volume of water during failure, V_w (m^3)</td><td>6.05×10^9</td><td>7.36×10^9</td></tr>
<tr><td>Volume material eroded, V_{er} (m^3)</td><td colspan="2">55.3×10^6</td></tr>
<tr><td>Height of breach, h_b (m)</td><td colspan="2">117.8</td></tr>
<tr><td>Height of water, h_w (m)</td><td>117.8</td><td>127</td></tr>
<tr><td>Height of dam, h_d (m)</td><td colspan="2">127</td></tr>
</table>

3.2. Model setup

Hydrologic Engineering Center's River Analysis System (HEC-RAS) model is used to digitize river network from Temenggor Dam to Bersia Dam which captures stream line, river cross section and reservoir volume.

A section of Perak river from Temenggor Dam to Bersia Dam are created from Digital Elevation Model (DEM) data which has the network of 18,466 meter length. The river cross section from survey data in several locations were aligned within the river network and interpolation is carried out between the cross sections as shown in Figure 2.

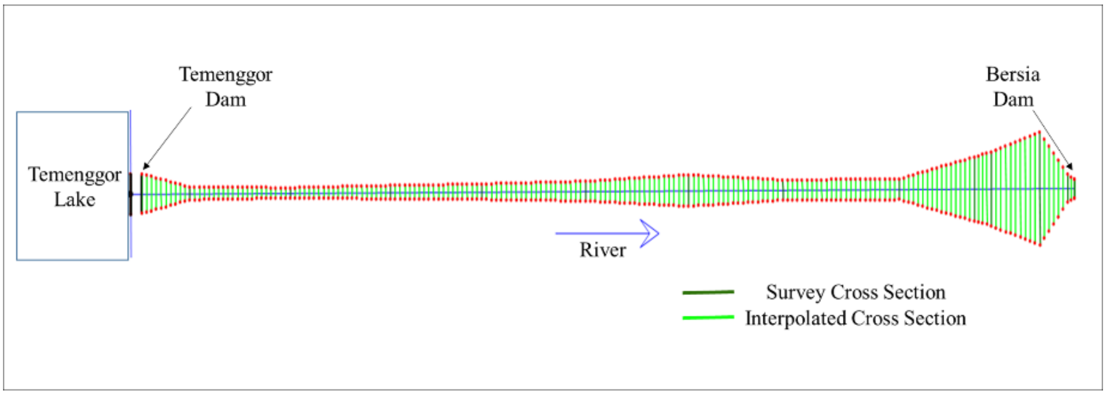

Figure 2. Basic geometry model of Temenggor Dam and river network.

Manning's roughness coefficients, which represent the resistance to flow and flood plain, are used to calculate the discharge within the channel. For Perak river, the friction resistance is low and the Manning's coefficient are fixed at 0.035 for bed channel and 0.16 for river banks.

Probable Maximum Flood (PMF) data for Temenggor reservoir is utilized in the model as shown in Figure 3. PMF is mainly used to simulate the dam break for overtopping failure type while piping failure is assumed to occur during the normal operation level of reservoir, known as Clear Day Failure (CDF).

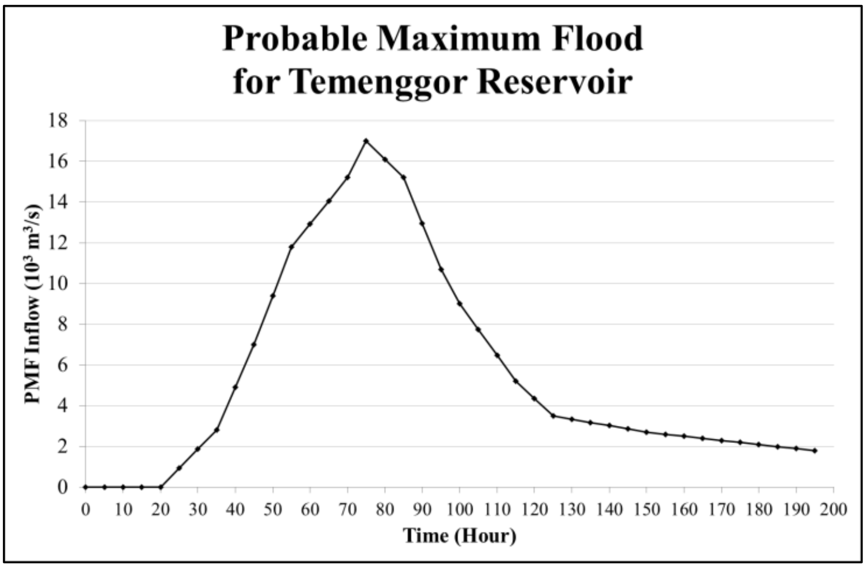

Figure 3. Probable Maximum Flood Time Series.

The breach progression graph at Temenggor Dam is assumed to be linear until it reached the dam invert level at EL 130 m. Simulation is subsequently carried out using HEC-RAS after all parameters has been established for both piping and overtopping failure cases.

4. Results and Discussion

The breach parameters were determined using regression equations yield as shown in Table 3. It is observed that for both overtopping and piping failure, Temenggor Dam has potential to experience total collapse as some of the calculated breach width exceeding the dam's crest width of 537 m. Hence, for MLM and Froehlich (1995), it is assumed that the maximum shape of breach would have the same shape as the first upstream cross section of the river. Table 4 summarizes the final breach bottom width of each method which is used as input for HEC-RAS simulation.

Table 3. Calculated breach parameters for Temenggor Dam.

Breach Parameter	Piping Failure (CDF)				Overtopping Failure (PMF)			
	Froehlich (1995)	Froehlich (2008)	MLM	VTG	Froehlich (1995)	Froehlich (2008)	MLM	VTG
Bottom Breach Width, W_b (m)	497	353	1446	286	733	485	1844	311
Breach Formation Time, t_f (hr)	4.96	3.43	10.81	2.61	5.51	3.79	11.78	2.81
Peak Flow, Q_p (m^3)	1.73 x 10^5	-	2.86 x 10^5	-	2.02 x 10^5	-	3.21 x 10^5	-
Slide Slope, m	0.9	0.7	0.5	0.5	1.4	1.0	0.5	0.5

Table 4. Simulation input of breach bottom width for Temenggor Dam.

Breach Parameter	Piping Failure (CDF)				Overtopping Failure (PMF)			
	Froehlich (1995)	Froehlich (2008)	MLM	VTG	Froehlich (1995)	Froehlich (2008)	MLM	VTG
Bottom Breach Width, W_b (m)	497	353	537	286	537	485	537	311

For Temenggor Dam CDF case, the reservoir level is assumed to be at the FSL which is EL 248.4 m during the initiation of the dam break event. The simulation yields peak discharge between 169,547 m^3/s and 201,126 m^3/s with VTG prediction at the highest flow. The arrival time to overtop Bersia Dam after the Temenggor Dam breach is found to be between 1.1 and 2.3 hour as shown in Figure 4.

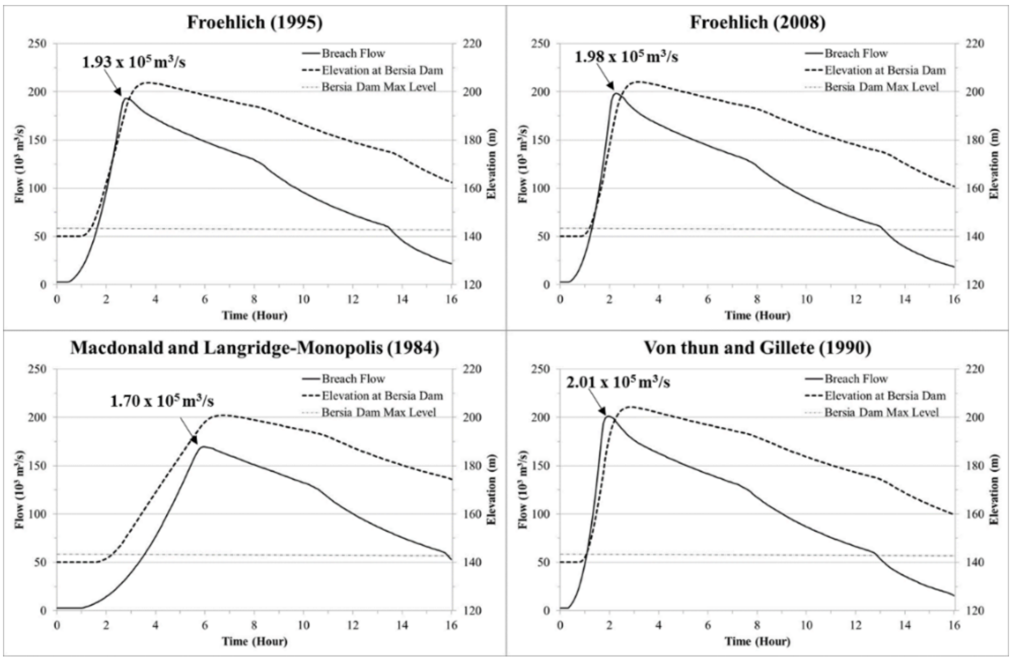

Figure 4. Breach hydrograph and downstream elevation for Temenggor Dam CDF case.

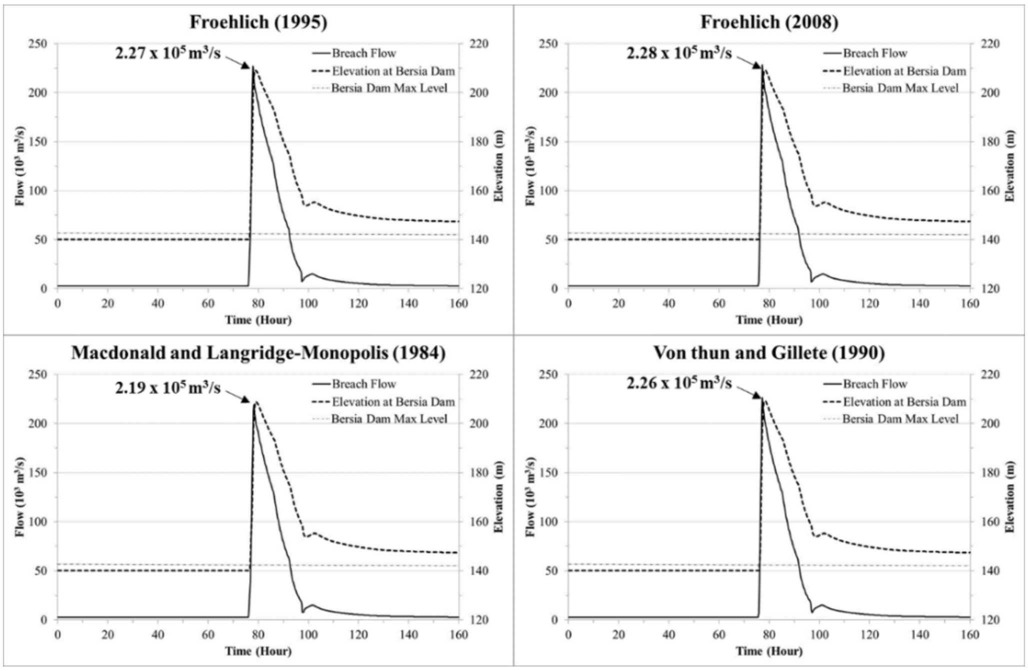

Figure 5. Breach hydrograph and downstream elevation for Temenggor Dam PMF case.

The maximum breach flow obtained from simulation is found to be close against the calculated peak discharge by Froehlich between -1.8% to +16.5% difference, whereas peak discharge calculated using MLM equation shows greater number compared to simulation results of -28.8% to -40.8% difference.

5. Conclusion

It is desirable to acquire an accurate prediction of the breaching process due to complexity of dam failure mechanics. The regression equations by Froehlich, MLM and VTG to determine dam breach parameters is found to be reliable and able to provide first level estimation in understanding the mechanism of dam break. The peak discharge calculated using Froehlich equation were found to be fairly close to the simulation results while MLM equation overestimates its peak discharge. Failure of Temenggor Dam will result to instantaneous failure to Bersia dam at downstream less than 1 hour of time arrival at earliest due to the high hydraulic impact of the flood wave. Temenggor Dam break analysis is able to provide a first stage assessment on the breach progression and estimated failure time should the dam break occurs. The hydrographs produced in this study are able to provide subsequent input in producing flood inundation map at downstream area using terrain data from Digital Elevation Model (DEM). Affected places of interest such as settlements, evacuation areas and other water impoundment system can be identified in addition to becoming reference for emergency response plan development for the unexpected dam break event. This study will also enhance the community resilience towards disaster, stressing the ability to reduce the possible impacts of a disaster as well as to effectively respond a recovery following a disaster.

References

[1] Che Ros F 2009 *Hydrodynamic Modelling of Embankment Dam Breaches: Case Study of Kenyir Dam* (Universiti Tenaga Nasional, Malaysia: ME Thesis)
[2] DID 2017 *Senarai Empangan di Malaysia* (Malaysia: Department of Irrigation and Drainage Malaysia)
[3] Froehlich D C 1995 Embankment Dam Breach Parameters Revisited *Water Resources Engineering Proceeding* pp 887 - 891

[4] Ishak N H and Hashim A M 2018 Dam pre-release as an important operation strategy in reducing flood impact in Malaysia *E3S Web of Conferences* **34**
[5] Lamichhane N and Sharma S 2017 *Hydrology* **4**(2) 24
[6] MacDonald T C and Langridge-Monopolis J 1984 *ASCE Journal of Hydraulic Engineering* Vol **110** No 5 pp 567 - 586
[7] Saad Sh Sammen T A Mohamed A H Ghazali L M Sidek A El-Shafie 2017 *Natural Hazards* **87** (1) 545-566
[8] Von Thun J L and Gillette D R 1990 *Guidance on breach parameters* (Denver: US Bureau of Reclamation)
[9] Wurbs R A 1987 *Journal of Hydraulic Engineering* Vol **113** Issue 1