Simulation of Breach Outflow for Earthfill Dam

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Abstract. Dams have been built for many reasons such as irrigation, hydropower, flood mitigation, and water supply to support development for the benefit of human. However, the huge amount of water stored behind the dam can seriously pose adverse impacts to the downstream community should it be released due to unwanted dam break event. To minimise the potential loss of lives and property damages, a workable Emergency Response Plan is required to be developed. As part of a responsible dam owner and operator, TNB initiated a study on dam breach modelling for Cameron Highlands Hydroelectric Scheme to simulate the potential dam breach for Jor Dam. Prediction of dam breach parameters using the empirical equations of Froehlich and Macdonal-Langridge-Monopolis formed the basis of the modelling, coupled with MIKE 11 software to obtain the breach outflow due to Probable Maximum Flood (PMF). This paper will therefore discuss the model setup, simulation procedure and comparison of the prediction with existing equations.

1. Introduction
Dams are purposely built for irrigation, power generation, flood mitigation, water supply and recreation. However, substantially huge amount of water body stored behind the standing dam structure could seriously pose severe risks to many. Great level of energy stored in the impounded reservoir will cause unbearable impacts should it be released suddenly to the downstream area. It is therefore important to conduct a dam break study to determine the outflow resulted from such unwanted dam break event to prepare for the necessary Emergency Action Plan (EAP) and to quantify the social, economic, and environmental impacts downstream of the dam. The art of dam break modelling lies primarily in the prediction of the outflow hydrograph as a result of dam failure. This can be done via physical model and laboratory experiment and numerical modelling technique. Physical model is not always financially viable hence the numerical modelling is often taken as a better alternative. Numerical modelling techniques estimate the outflow hydrograph via two main methods; physically based methods and predictor equations.

Physically based methods predict the breach outflow using an erosion model based on hydraulics principles, sediment transport and soil mechanics. This is found to be the most difficult prediction method since many of the dam failure cases contain high degree of uncertainty. Research and data
available from sediment transport under rapidly varying flow are limited, which results in the use of approximation of the standard predictor equations. This method relies heavily on compilation of case study based on actual failure scenarios hence more straightforward calculation. Various predictor equations are developed from the compiled cases to assist in calculation of some important parameters. Amongst the many software used for prediction of dam break outflow hydrograph includes DAMBRK, FLDWAV, BREACH, and MIKE. Tingsanchali (Tingsanchali, 1998) reported that based on Meyer-Peter & Mueller formula, BREACH model computed the peak outflow hydrograph as a result of dam breach is 2.8 times the observed peak. MIKE 11 model computed the breach outflow with a peak equal to 0.167 times of the observed peak and a time to peak equal to 1.167 times of the observed value. This study had therefore used the MIKE modelling package to simulate the dam break event and to determine the outflow hydrograph to be routed to the downstream area. This paper will therefore discuss on the prediction of dam breach parameters, setting up the model using MIKE 11 software and simulation of dam break event under PMF Failure scenario for Jor Dam.

2. Study Area
Jor Dam is part of the existing Cameron Highlands Hydroelectric Scheme, comprises of seven power stations and 3 major dams, namely Sultan Abu Bakar dam at Ringlet, Sultan Yussuf Dam at Jor and Mahang Dam at Kuala Woh. The scheme was constructed in late 1950s and began its operation since 1963. The total installed capacity of the scheme is 262MW, aiming for peaking load. Jor Reservoir was created by damming the Jor River through construction of Jor Dam. Jor Dam is 44.8m high situated at 17th miles, Tapah-Cameron Highlands Road in Perak. Jor dam were constructed in the years of 1965-1967. Major inflows feeding into Jor reservoir are Sg Jor, tailrace of Sultan Yusuff Power Station, Sg Sekam and Sg Batang Padang. The dam is earthfill material with central clay core with total volume of 680, 000 m$^3$ of earthfill. The 15 km long Menglang tunnel conveys the water from Jor reservoir to the underground Sultan Idris II (Woh) power station, some 420 m below its head pond. Any excess of water from the reservoir will be channelled downstream via siphon bell-mouthed spillway and 8.84m diameter of concrete-lined tunnel. Main purpose of the reservoir is for power generation, which is operated by TNB. Land use in 2008 indicates 99% of the Batang Padang districts are village, cultivated plantation on farmlands and forest.

| Table 1. Details of Jor Dam. |
|-----------------------------|
| **Dam Type** | **Earthfill** |
| Crest Level (m) | EL 496.83 |
| Dam Height (m) | 44.8 |
| Crest Length of Dam (m) | 210 m |
| Gross Storage (million m$^3$) | 3.85 |
| Surface area at FSL (km$^2$) | 0.32 km$^2$ at EL 493.45m |
| Catchment (km$^2$) | 393.9 |

3. Methodology
The process of obtaining outflow hydrograph using MIKE 11 software requires the prediction of dam breach parameters and setting up model that represents the actual layout on the ground. Those two processes are detailed out in the latter.

3.1 Prediction of breach parameters
Breaching mechanism of a dam is described by dam breach parameters and represented by breach width, $b$, breach height, $h$, side slope, $s$ and time of failure, $t_f$. Dam breach can be specified by trapezoidal, rectangular, or triangular shape. Linear breaching and erosion-based breaching are both relevant but the latter contains high degree of uncertainty. The trapezoidal formation with linear formation mechanism is adopted for the purpose of dam break modeling, based on the assumption that
the dams breach linearly with the time. Froehlich and MacDonald and Langridge-Monopolis (MDLM) are the most suitable predictor equations (Wahl, 1998). The process of determining the breach parameters is in the form of loop. It starts off with the assumption that a dam will breach under an overtopping condition due to Probable Maximum Flow (PMF), whereby the water level was set at the maximum crest level of the dam. Simulation predicted that Jor Dam will not fail under overtopping condition, as the maximum water level achieved was EL 496.82 m, less than the dam crest level. The average breach width was calculated using Froehlich is 44.8 m, but the adopted breach width was taken as 210 m to fit the dam geometry. The side slope, s for was taken as 1V:1H for an earthfill dam (Froehlich, 1995b). Failure time, $t_f$ for Jor dam was calculated as 2.376 hrs (MDLM) and 0.244 hours (Froehlich).

3.2 Model Setup
A set of four sub-files was created to complete the dam break model set up, added with two time series file namely dam breach parameters and PMF inflow. The four sub-files required were network, cross section, boundary conditions and hydrodynamic conditions. Network file describe the river channel with the associated dam structure to replicate the actual scenario, named as Sg Batang Padang. Dam structures were described the based on dam height, crest length, and crest height whilst Spillway structure was described using the spillway coefficient, height, width and level. Points were inserted along the channels and defined as chainage, by assigning specific cross section which was described in the cross section file. Storage curve was used to define the reservoir whilst the specific geometry of the spillway described the cross sections of spillway chainages. Three boundary conditions were specified; PMF Inflow time series for Jor Dam inserted at chainage 0 of Sg Batang Padang and defined as ‘Inflow’ boundary type, ‘Dambreak’ time series which will compute the progress of breach with regards to width, height and side slope and ‘Q-h’ or stage – level curve, inserted at the final chainage Sg Batang Padang. For hydrodynamic file, initial water level need was defined at Full Supply Level (FSL) to allow a smooth hydrodynamic computation. The river beds were assumed to be of packed clay with the recommended Manning’s (M) equals to 30 (MASMA, 2000).

4. Results and Discussion
The outflow hydrograph reached the peak value of 13,006 m$^3$/s. The outflow hydrograph showing peak discharge at the dam is illustrated in Figure 1.

![Figure 1. Outflow hydrograph of Jor Dam under PMF failure](image)

Although Macdonald-Langdrige-Monopolis and Froehlich predictor equations are best applicable to earthfill dams, the peak outflow simulated for Jor dam was much higher. However, comparison was also made with other predictor equations, of which deviation from the simulated value ranges from 16% to 69%.

5. Conclusion
Dam could fail due to various causes such as piping, overtopping, foundation and many others. In the case of dam break modelling, it is important to predict the breach parameters accurately. The peak outflow discharge due to failure of Jor dam was 13,006 m$^3$/s based on time of failure of 0.244 hours, breach width 210m and breach height of 43m. The outflow hydrograph will be coupled with topographical information and flood plain roughness to obtain flood inundation map, which can be modelled using MIKE 21 or MIKE Flood. However, further validation using experimental setup is needed to verify the peak outflow and the breach parameters.

| References                          | Peak Flow Equations | Calculated Peak Flow (m$^3$/s) | Deviation from Simulated Peak Flow (%) |
|-------------------------------------|---------------------|---------------------------------|---------------------------------------|
| Bureau of Reclamation (1988)        | $Q_p=19.1(h_w)^{1.85}$ | 19545.12                        | 50                                    |
| MacDonald and Langridge-Monopolis (1984) | $Q_p=3.85(V_w h_w)^{0.411}$ | 8542.37                         | -34                                   |
| Froehlich (1995a)                   | $Q_p=0.607(V_w^{0.295} h_w^{1.24})$ | 5277.72                         | -59                                   |
| Kirkpatrick (1977)                  | $Q_p=1.268(h_w + 0.3)^{2.5}$ | 15078.38                        | 16                                    |
| SCS (1981)                          | $Q_p=16.6(h_w)^{1.85}$ | 16986.86                        | 31                                    |
| Singh and Snorronson (1984)         | $Q_p=0.54(S.h_d)^{0.5}$ | 6580.47                         | -49                                   |
| Costa (1985)                        | $Q_p=2.634(S.h_d)^{0.44}$ | 10379.48                        | -20                                   |

Acknowledgement
The author would like to express gratitude and sincere thanks to Tenaga Nasional Berhad for funding of this research project, as well as UNITEN as the collaborator.

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