Numerical modelling dam break analysis for water supply project

M S Lariyah¹, M Vikneswaran¹, B Hidayah¹, Z C Muda¹, S Thiruchelvam¹, A K Abd Isham², H Rohani²
¹ Centre for Sustainable Technology and Environment (CSTEN), College of Engineering, Universiti Tenaga Nasional
² HLA Associates Sdn. Bhd.

E-mail: lariyah@uniten.edu.my

Abstract. Dam provides many benefits to the society, but it can also cause extensive damage to downstream area when it fails. Dam failure can cause extensive damage to properties and loss of human life due to short warning time available. In general, dam spillway was designed to drain the maximum discharge from the dam during the Probable Maximum Flood (PMF). The spillway is functioned to prevent the dam from failure due to overtopping, which can lead to the dam failure. Dam failure will result in large volume of water travelling at very high velocity to the downstream area of the dam. It can cause extensive property damage, destruction of important facilities, and significant loss of human life along the way. Due to the potential of high hazard it poses to the downstream area, a dam break analysis is considered very essential. This paper focuses into the dam failure analysis for Kahang Dam by prediction of breach flow hydrographs and generation of inundation map at downstream area. From the PMF scenario simulation, the maximum inflow is 525.12 m³/s and peak discharge from the dam during dam failure is 6188m³/s. The results are able to provide information for preparation of Emergency Response Plan (PMF), in which appropriate steps can be taken by relevant authorities to avoid significant loss of human lives.

1. Introduction

Nowadays, dams are constructed for multiple functions such as supplying drinking water for citizens, process water for industrial and commercial usage, and cooling water for the thermal power stations. Other than their many beneficial uses and value, dams also present risks to property and life due to their potential to fail and cause catastrophic flooding. Dam owners and regulators need carefully analyse and inspect dams to identify potential failure modes and protect against them to mitigate these risks. Since no program for preventing dam failure can ever be certain, and because the potential for loadings exceeding design limits can never be eliminated, another essential part of risk mitigation is simulating potential failures and planning. This prioritization process facilitates an effective use of financial and human resources to improve public safety and reduce dam failure risk. The analyse area includes two significant urban settlements, namely Kluang township incorporating the old town council area and adjacent villages, as well the Bandar Tenggara township to the east. The remainder area is primarily rural with economic activity concentrated in agriculture which represents the primary economic base for Kluang district.

The proposed Kahang Dam is located across Sg. Kahang, a tributary of Sg. Sembrong. The axis of the dam would be located approximately 1km upstream, of the point where a paved road from the Kluang-Mersing main road to Felda Kahang Timur crosses Sg. Kahang. Kahang Dam is an earthfill
embankment dam and the dam core filled with impermeable material, clay. A reinforced concrete outlet structure with control gate will be built across the dam to control releases into the Sg. Kahang downstream.

2. Literature Review

Based on some literature review [1] prediction of the reservoir outflow hydrograph and the routing of that hydrograph through the downstream valley are the two primary tasks in the analysis of a potential dam failure. When populations located close to a dam at risk area, it is important to predict the breach outflow hydrograph and its timing relative to events in the dam failure. A dam break study should cover dam inspection, selection of failure storm, prediction of breach outflow hydrograph and data collection (Coleman, 2002). The breach outflow hydrograph will be utilized to predict the arrival time and flood depth at the reservoir downstream area. Dam breach parameter can be predicted by using empirical and physically based methods. The effective critical breach parameters equations were identified from a numerous researchers [2], [3] and [4]. Equation 1 to Equation 3 shows the common dam breach parameter equation respectively.

\[
B_{avg} = 2.5h_w + C_b \quad ; \quad t_f = 0.015h_w \quad \text{highly erodible} \quad (1)
\]

\[
B_{avg} = 0.1803K_o V_w^{0.32} h_b^{0.19} \quad ; \quad t_f = 0.00254(V_w)^{0.53} h_b^{0.9} \quad (2)
\]

\[
V_{er} = 0.0261(V_w h_w)^{0.769} \quad ; \quad t_f = 0.0179V_{er}^{0.364} \quad (3)
\]

Where, \(B_{avg}\) is breach width, \(t_f\) is failure time, \(C_b\) is reservoir coefficient and \(K_o\) is failure coefficient.

3. Methodology

This dam break analysis involves the field data collection and computer simulation to evaluate the dam failure and the impact of dam break to downstream area. It is particularly more important in this analysis because there are numbers of villages at the downstream area. The field work involves field data collection that is necessary for the estimation of probable maximum precipitation (PMP) and for the estimation of probable maximum flood (PMF). The obtained PMF values will be routed through the reservoir, and checked whether the existing spillway capacity for each reservoirs is adequate for the PMF. If the existing spillway is under designed, the dam will be simulated for its failure. Even if the spillway capacity is adequate for the PMF, it will be assumed that the dam will fail due to poor maintenance, and the impact of its failure to the downstream area be estimated. This paper discussed the first phase of dam break analysis which is prediction of breach outflow hydrograph for all dam failure modes.

The breach parameters include breach width, depth, initiation time and rate of development. These dam break analysis will be carried out using MIKE 11 Dam Break (DB) module, which could generate the outflow hydrograph from a breached dam. MIKE 11 can be linked to hydrologic models, can model reservoirs, perform sophisticated structures, model mechanism of dam failure and can be linked to telemetry and forecasting systems. The flow shall be routed downstream using MIKE 21 in order to determine the maximum water level, discharge along the flood path and the flood wave travel time at different locations of the river downstream of the dam [6], [7].

4. Results and Discussion

For PMF overtopping failure, spillway of the dam was designed to cater PMF (non-overtopping dam). Figure 2 shows the PMF inflow hydrograph for Kahang dam. From MIKE 11 simulation, the reservoir water level under PMF condition was EL 49 m. It is assumed that the initial water level in the Kahang reservoir was at EL 48.5 m start to initiate breach at 52.5 m. The derived failure time of 0.176 hours was estimated using Froelich Equation [3], and the breach was developed until it reached the dam.
invert level of 37 m with the breach side slopes of 1V:2H and bottom breach width equalled to 107.065 m. Von Thun and Gillette equations was adopted for estimation of breach geometry [4]. The dam peak discharge was simulated to be at 6188 m$^3$/s and illustrated in Figure 3.

The integrated dam break study – even when carried out with the latest mathematical models and improved data – falls largely in the realm of predictions based on the set of assumptions made for the study [5]. Therefore, sensitivity analysis was performed in order to estimate the influence of variations made in the model by varying the breach width, breach depth, failure time and breach side slope to determine the sensitivity of the peak breach discharge to these variables [6], [7]. Based on simulated peak discharge, the breach sensitivity analysis for Kahang Dam is summarized in Table 1.

**Table 1. Breach Sensitivity Analysis.**

| Breach Parameters | Failure time, $t_f$ (hour) | Side Slope (H:V) | Breach Width (m) | Breach Depth (m) | $Q_{peak}$ (m$^3$/s) |
|-------------------|---------------------------|------------------|-----------------|-----------------|----------------------|
|                   | 0.176                     | 1:2              | 105.489         | 15.5            | 6110.063             |
|                   | 1.996                     | 1:2              | 105.489         | 15.5            | 4846.889             |
|                   | 0.176                     | 1:1              | 105.489         | 15.5            | 5756.076             |
|                   | 0.176                     | 1:3              | 105.489         | 15.5            | 6462.333             |
|                   | 0.176                     | 1:2              | 35.13           | 15.5            | 2688.520             |
|                   | 0.176                     | 1:2              | 200             | 15.5            | 10211.435            |
|                   | 0.176                     | 1:2              | 105.489         | 8               | 1246.185             |
|                   | 0.176                     | 1:2              | 105.489         | 12              | 3501.201             |

The four parameters affected the breach hydrograph’s peak. For the same breach side slope, breach depth and breach width, the difference in peak discharge was only 21 % for failure time of 1.996 hours. For the same failure time and breach width, the gentler side slope yielded a slightly higher peak discharge compared to the steeper side slope. The peak value of the breach hydrograph differed by 12% when the breach side slope changed from 1H: 1V to 1H: 3V. For breach width, the difference in breach bottom width had a greater influence on the peak discharge which was in the range of 56 – 67 % for breach bottom width of 35.13 m and 200 m. The higher breach depth also resulted higher peak discharge as compared to shallow breach depth. The difference in peak discharge was 64% when the
breach depth changed from 8 m to 12 m. The above results are possible since the Kahang Dam height is 17.5 m with a relatively 460 m crest length, hence the breach area varied drastically with the breach depth and breach bottom width. Since Kahang Dam has a large reservoir area, the failure time was not so critical in influencing the peak outflow discharge. Therefore, the changes of side slope do not given significant different in peak discharge due to short crest length. Thus, breach width was recognized as the most sensitive breach parameters followed by breach depth.

5. Conclusions

The consequences of dam failure will depend on the type of failure scenarios which are Clear Day Failure (CDF) and Probable Maximum Flood Failure (PMF). In the event of dam failure, there might be structural damage, loss of life, disruption of services and interruption of normal social and economic activities. These losses largely depend on the flood velocity, inundation depth and duration. Depending on these flood parameters, consequences can be classified as minor, moderate and major. To help define these situations the Kahang rivers should be gauged, and caution, warning and danger levels should be determined and shown at the public places of interest.

The generated flood inundation map from MIKE 21 modeling will be used to develop Emergency Action Plan (ERP) for the unexpected dam break event to coordinate the responsibility authorities such as dam owners, police and fire services in the people evacuation plans, other flood warning systems, post-flood actions and hazard classification of affected areas. This dam break study is also important to estimate the property damages and loss of human resulting from a dam breach. This study will enhance the community resilience towards dam failure and stressing the ability to reduce the possible impacts of a disaster as well as to effectively respond a recovery following a disaster.

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