American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)
ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

Modeling Approach for Earthen Dam Breach Analysis in North Yamar Dam, Myanmar

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Abstract

In case a Dam breach occurs, it is hazardous for lives, properties and environment in downstream extents. Dam break studies are necessary for forecasting of flood disaster and evaluation of hydrological safety among dams. To investigate possible inundation extents and breach outflow, an experimental study for both overtopping and piping failures was performed in the North Yamar Lower Dam constructed across Yamar creek in Pale township of Sagaing Region. This study is to examine the applicability of hydraulics and hydrologic models, HEC-RAS (USACE Hydrologic Engineering Center's River Analysis system) and HEC-HMS (Hydrologic Engineering Center's Hydrologic Modeling System) upon Dam Break. One-dimensional HEC-RAS model was applied in collaboration with HEC-HMS model to predict the potential flood risk due to different breach modes. The extreme hydrological event such as possible maximum flood event (PMF) was considered for the overtopping breach and sunny day piping event for piping breach. Dam Breach outflow hydrographs were generated by HEC-HMS individually and imported them into HEC-RAS for downstream flood estimation. The unsteady mixed flow simulations were performed by HEC-RAS and ArcGIS (Geographic Information System) was used to produce an inundation map based on simulated water surface elevations and extents. The models were calibrated based on the historical floods happened in North Yamar Dam from 2005 to 2017. By scenario analysis for with and without emergency spillway, overtopping breach influenced on different consequences whereas piping affected not much differences. The probable peak discharge would be over 7,000 m^3/s and 3,800 m^3/s respectively.

Keywords: Dam breaks outflow; HEC-RAS; PMF; HEC-HMS; Scenario analysis.

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1. Introduction

Dams support numerous benefits for society, however, their failure also produce devastating disasters [1]. Dam Breach is an excessive deformation of the embankment which will occur the uncontrolled release of reservoir water to damage the appurtenant structures at the downstream location [2]. Earthen dams are less rigid and more susceptible to failure [3]. The breakage frequencies of earth dams are almost four times greater than concrete dams or masonries [4]. The United State Army corps of Engineering Hydrologic Engineering center (HEC) research document lists 13 dam failure causes as: (1) earth quake (2) land slide (3) extreme storm (4) piping (5) equipment malfunctioning (6) structure Damage (7) foundation failure and Sabotage [4]. Different Case studies show that dams failure due to several reasons ranging from seepage or piping, overtopping foundation defects, sliding, natural disasters and equipment failure [5]. Overtopping is an uncontrolled flow of water over the crest of the dam. The main causes of overtopping are: under estimation of the design flood and inadequate spillway capacity, large and rapid landslides in the reservoir, insufficient free board and malfunctioning of the spillway gates [6]. Piping through the dam body is caused by: faulty construction, insufficient compaction, cracks in the embankment due to foundation settlement, animal borrows pipes and conduits inside the dam body [6]. Several models have been developed by various institutions and research centers for dam break analysis such as NWS-DAMBRK, NWS-FLDWAV, HEC-HMS, and HEC-RAS Model [7]. For this study, a dam break analysis was performed using HEC-HMS, HEC-RAS models on North Yamar Lower Dam, an earth embankment dam. These models were chosen for this study as they are open source applications and their flexibilities to ArcGIS environment. The analysis focused on the effects of dam break due to piping and overtopping during Probable Maximum Flood scenario.

1.1. Statement of Problem

In Myanmar, large numbers of dams have been constructed ranging from small earth dams to mega large dams in the past decades. Despite their benefits, dams have large risk when failed due to excessive inflow or seepage through the body. This demands the need for dam break pre-event analysis to predict the dam breach parameters, outflow magnitude and its downstream nature of propagation, so that preventive measures can be put in place to avert catastrophic damages. This paper presents dam break analysis for North Yamar dam. North Yamar dam is chosen for this analysis as an experimental study area because of its geographic conditions and data availability. North Yamar dam is located within Pale Township of Yinmarbin District in Sagian Division. The dam was built in 1995 and completed in 1999. Dam construction was made across North Yamar creek and there are different economic developments downstream of the dam such as many residential, hydropower plant, irrigation projects, religious houses, farms, industries, bridges and roads which have the potential of being completely inundated or at least in some way adversely affected by the catastrophic flooding that may result from the failure of North Yamar Dam.

1.2. Objectives of the study

The general objective of the study is to analyze the Dam break case study of North Yamar dam using hydrologic and hydraulic models. The specific objectives are;

- To determine parameters of the dam break;
- To determine peak outflow hydrograph when dam break occurs by either overtopping or piping mode of failure;
- To estimate the hydraulic conditions (water level, top width and arrival time of flood wave) at critical downstream locations ;
- To find out flood-prone areas of downstream area due to dam failure.

1.3. Limitation of the study

However, there were some limitations to this study as follows;

- This study did not include the estimation of future climate change scenarios.
- This study did not consider the various return periods of rainfall data in the modeling.
- Other dams that located above or near North Yamar dam were not included in the modeling because of data availability.
- HMS model was calibrated and validated with the observed peak water level data from the year 2005 to 2016 only.
- The other various factors that involve the analysis like land cover changes were not looked into while determining the Manning coefficient 'n'.

2. Materials and Methods

2.1. Study area

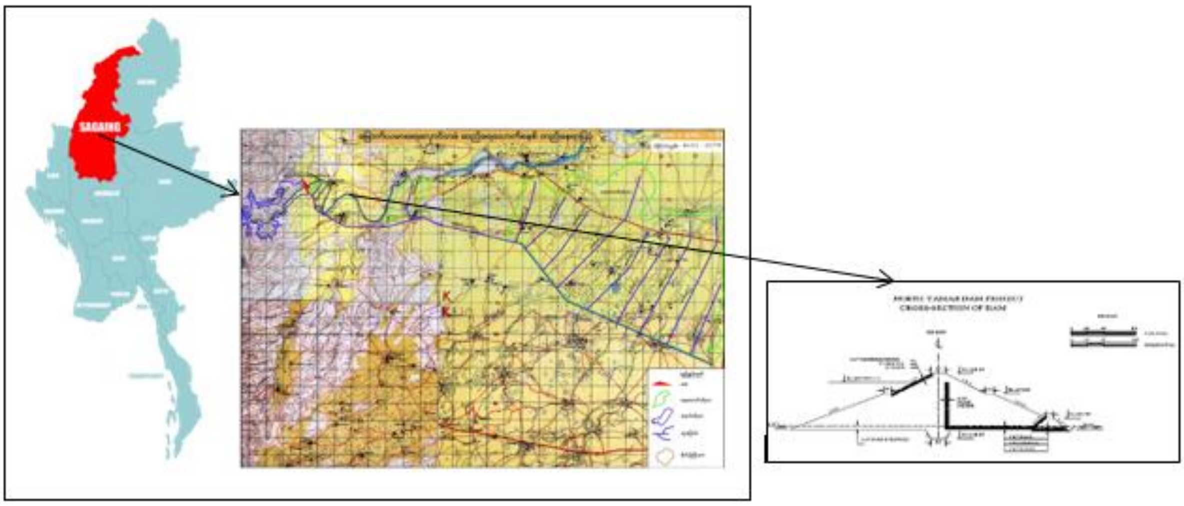

Figure 1: Location of study area

North Yamar dam is administratively located within Pale Township of Yinmarbin District in Sagian Division, Myanmar. The dam was built in 1995 and completed in 1999. Dam construction was made across North Yamar creek that flow from western mountain range to northeastern direction where is merged with Chindwin river. The dam is earthen embankment dam which has a catchment area of 494.64 km^2. The catchment area has average annual rainfall 864 mm/year and average annual inflow is 66,430 Ac-ft according to Irrigation and Water Utilization Department, Myanmar. The dam height is about 20 m and its length is 3170 m which possess 11.4 Million m3 storage capacities. North Yamar has two typed of spillways, main spillway is Ogee shaped and emergency one is broad crested type spillway. Figure 1 describes the location of the study area.

2.2. Methods of Dam Break Analysis

In For this study, HEC-HMS and HEC-RAS software was utilized for dam break analysis. HEC-HMS was used to extract the hydrograph flow from pre-developed hydrologic model for the inflow, probable maximum flood of rainfall and perform the dam breach analysis of North Yamar Dam. HEC-RAS was used to create the flood inundation map of downstream of the reservoir.

2.2.1. PMP calculation

For the hydrological assessment, an analysis is done to check whether the dam has adequate spillway capacity to safely handle the Probable Maximum Flood (PMF) in order to avoid dam crest overtopping. The Probable Maximum Precipitation (PMP) over study area is required to find out PMF against the dam. There are various methods that can be used for estimation of PMP. In this study, the revised Hershfield's Km value method was adopted to make statistical estimation approach according to the previous study in China [8]. The annual maximum rainfalls for the durations of 1 day were abstracted from data archive of each station from nine rainfall stations within the study area as shown in Figure 3. The PMP calculation is shown in Figure 2. Where, *Xpmp* is the PMP for a given station for a specific duration, and *Xn* are the mean and standard deviation for a series of n annual maximum rainfall values of a given duration respectively. *Km* is the frequency factor and is the largest of all the calculated *K* values for all stations in a given area. *Xm, Xn-1* and *Sn*-1 are the highest, mean and standard deviation respectively excluding the *Xn* and *Sn* value from the series. To find out the short duration PMP, time rainfall distribution method and Alternative block method was adopted to build up a design storm profile for durations up to 7 hours (420 minutes).

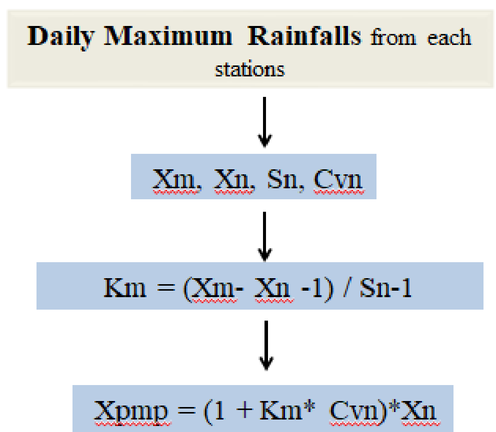

Figure 2: Workflow of PMP calculation.

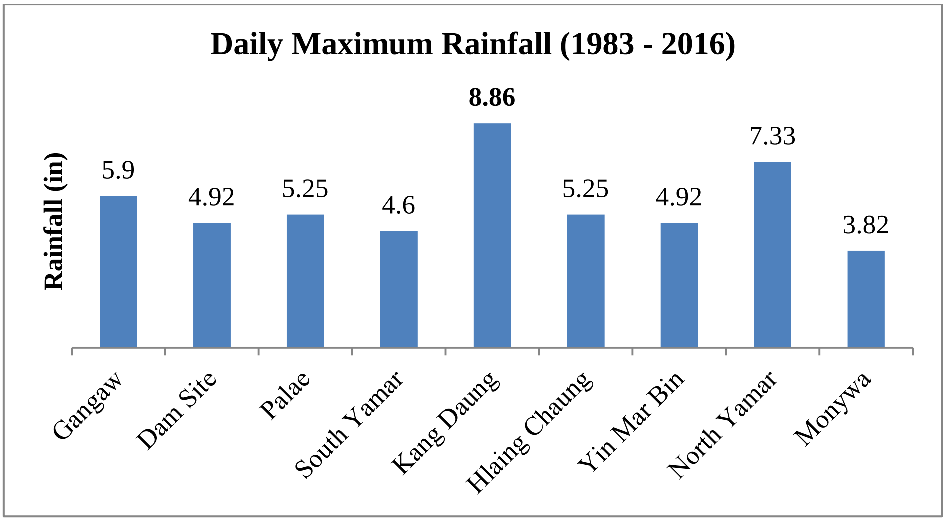

Figure 3: Daily maximum rainfall data from nine stations

2.2.2. Hydrologic Model (HEC-HMS)

HEC-HMS 4.0 (Hydraulic Engineering Center's Hydrological Monitoring System) which was developed by the U.S. Army Corps of Engineering was used to create catchment, reservoir and downstream (sink-1) to determine water flow from catchment to the reservoir as shown in Figure 4. The SCS Curve Number method is used to calculate the infiltration and Clark Unit Hydrograph is for calculating runoff. The HEC-HMS model required the following input data for reservoir routing. : (1) time-series data: precipitation data and discharge data of selected durations, (2) reservoir elevation-storage relationship data, (3) reservoir and spillway information for North Yamar dam [9]. In this study, the regression equation of Froehlich-1995a for overtopping and Froehlich-2008 [10]for piping was used to calculate breach parameters such as bottom width of breath and time of failure as suggested in training document by U.S. Army Corps of Engineers [4].

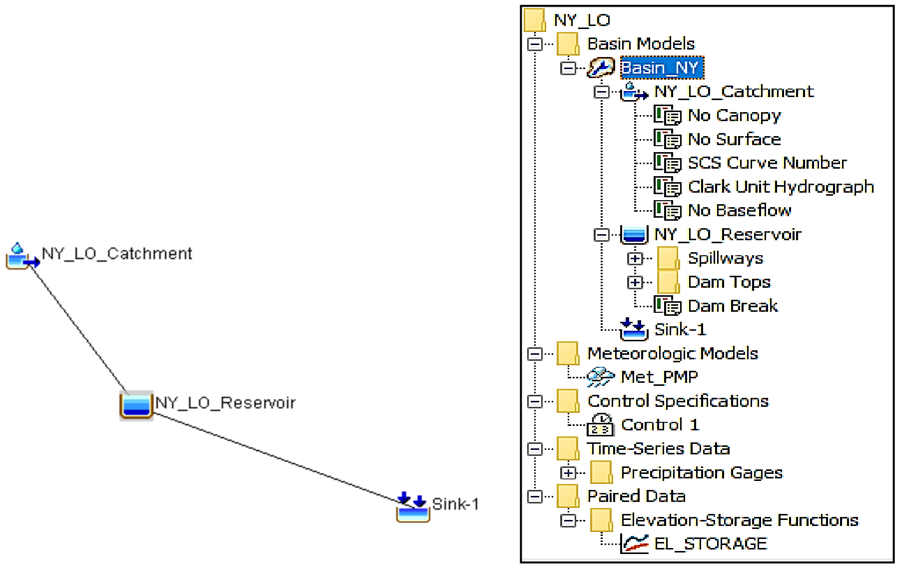

Figure 4: HEC-HMS Model set up

Froehlich Breach Predictor Equations[10]

(1) Average width of breach

$$: \bar{b} = 0.27\, k_0 (V_r)^{0.32} (h_d)^{0.04} \qquad (1)$$

where,

$\bar{b}$ = average breach width (m),

k_0 = 1 for piping and 1.3 for overtopping,

V_r = reservoir storage volume (m^3),

h_d = the height of water over the breach bottom (the height of the dam) (m).

(2) Time of failure:

$$\tau = 0.0176\sqrt{V_r / g(h_d)^2} \qquad (2)$$

In which, τ is time of failure (hrs),

(3) *Bottom width of breach= (Average width) – (h_d / 2) * (side slope) * 2 (m)* *(3)*

2.2.3. Hydraulic Model (HEC-RAS)

HEC-RAS 5.0.7 (Hydraulic Engineering Center's River Analysis System) is free downloadable software which was developed by Hydrologic Engineering Center of the U.S. Army Corps of Engineering[11]. The 30 m resolution ASTER GLOBAL DEM downloaded from USGS Earth explorer website (http://earthexplorer.usgs.gov/) was imported into RAS Mapper and the terrain was created and overlain Google Satellite in HEC-RAS as shown in Figure 5. This served as the working layer in generating the geometry of North Yamar River network. Using the geometric data tool of HEC-RAS, River, Bank lines and Cross sections were drawn in RAS Mapper as in Figure 6. The cross-section data is automatically entered into HEC-RAS from start of river up to 26.5 km. The Manning roughness coefficient value is assumed to be 0.025 for bed channel and 0.04 for river banks since the natural streams which has rocky river beds with grass banks usually steep, trees and brush along banks has manning roughness coefficient in the range of 0.03 to 0.05 [12]. Then unsteady flow analysis is done for the mixed flow regime with the boundary conditions incorporated as outflow hydrograph from HEC-HMS, normal depth as 0.01 and computation interval 30 second. Then the model is run one by one for the unsteady flow analysis file with the failure mode overtopping and once piping. Further the detailed output table can be viewed in view section and the velocity in channel, water surface elevation, discharge, and energy gradient level and be observed for each station. Then floodplain layer is generated by RAS Mapper. Thus the shape file of floodplain area can be viewed on map and more hazardous zone can be recognized.

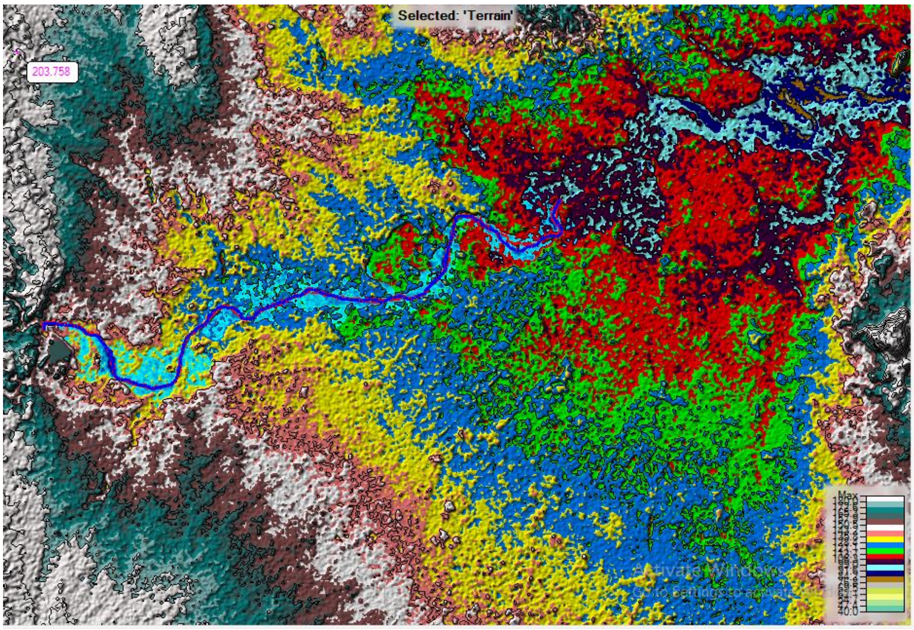

Figure 5: North Yamar Terrain in RAS-Mapper

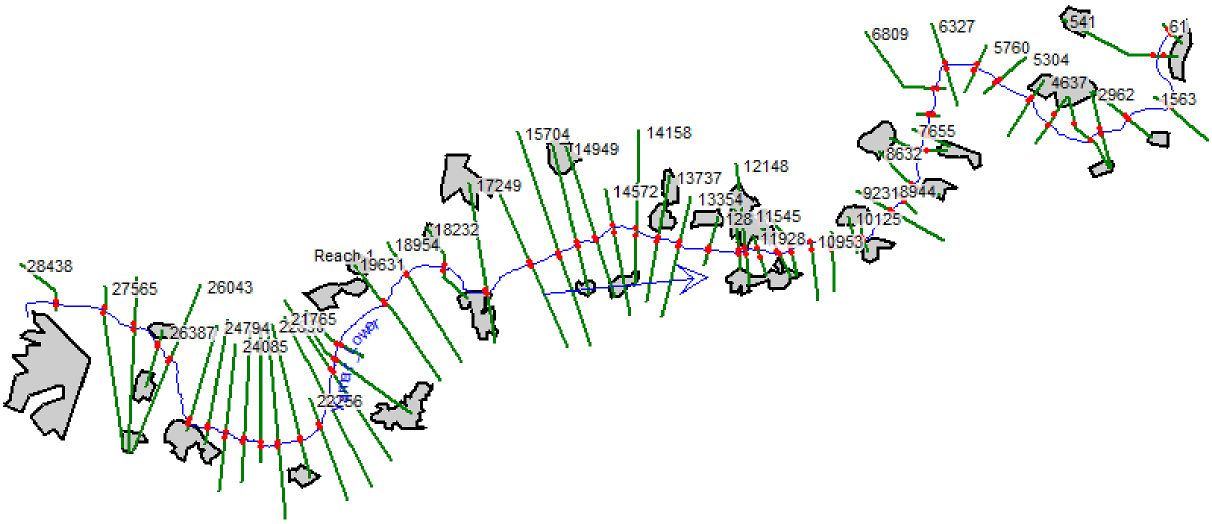

Figure 6: Geometrical view of North Yamar River in HEC-RAS

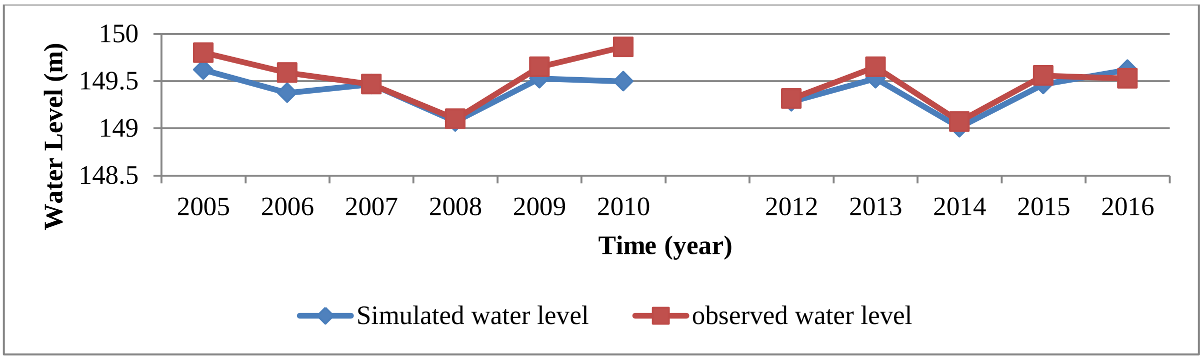

Figure 7: Comparison between simulated and observed spill elevation

3. Results and Discussions

3.1. Calibration

In model calibration, the elevation spilled discharge relationship data for 2005 to 2010 and 2012 to 2016 from North Yamar Dam are compared with simulated stage –discharge relationship. The HEC-HMS model was used to estimate possible maximum peak elevation from spillway for each year and compared the observed peak elevation (Figure 7). Probable parameters from the model are adjusted during calibration to obtain the satisfied coefficient of determination (R^2) value (0.78) as shown in Figure 8.

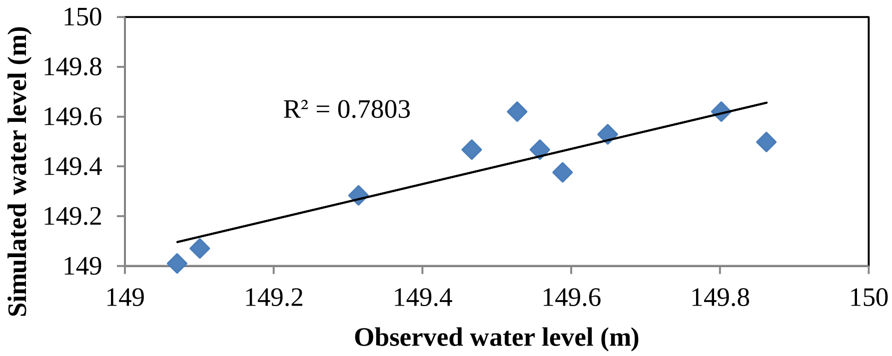

Figure 8: Comparison between simulated and observed spill elevation

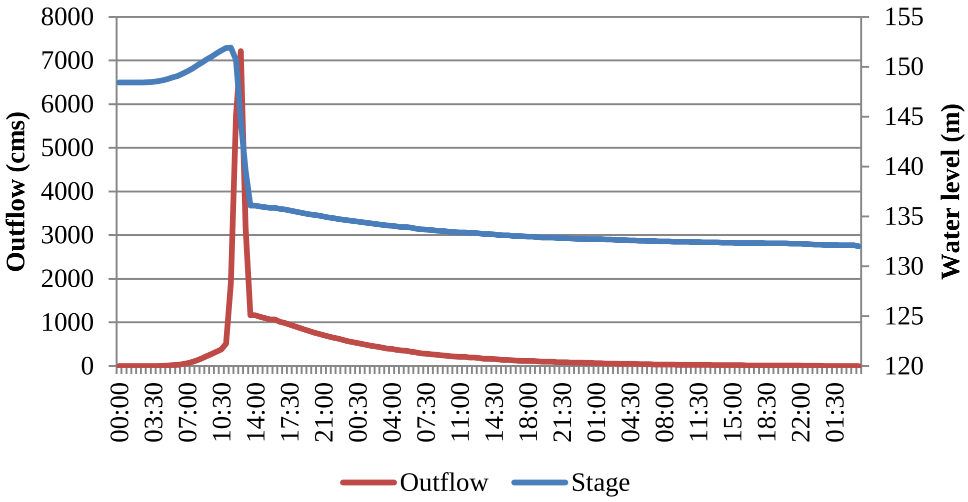

Figure 9: Without emergency spillway on overtopping failure.

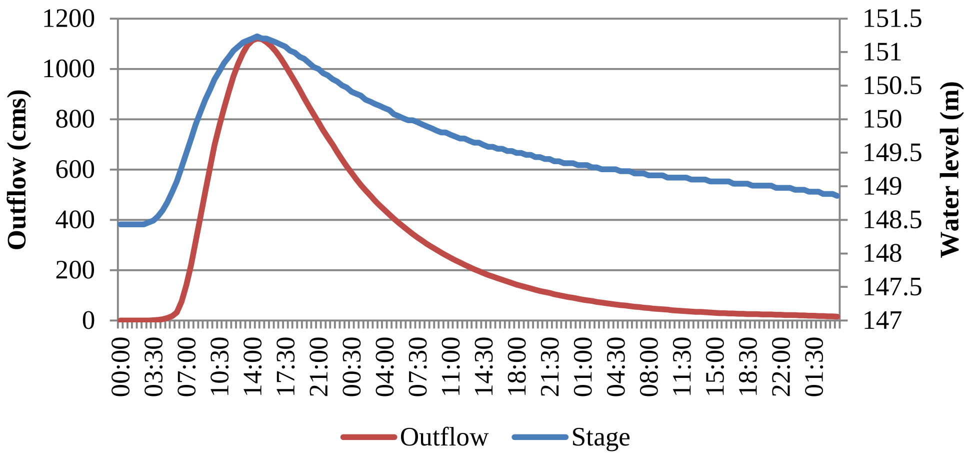

Figure 10: With emergency spillway on overtopping failure

3.2. Scenario analysis of overtopping and piping failures in Terms of Peak Discharge and Water Level

The scenario analysis of failure modes is undergone by different scenarios such as with and without emergency spillway and different piping elevations to model dam break and analyzing what is the effect on discharge values and water level.

3.2.1. Effect of Emergency Spillway

In this scenario, the results of overtopping failure mode were compared by with or without emergency spillway in modeling of breach outflow hydrograph in HEC-HMS. Without emergency spillway, dam breach occurred with the peak discharge 7,211 m^3/s and peak elevation 151.9 m as shown in Figure 9. No dam break occurs if there is an emergency spillway. Flow emerges into 151.23 m with magnitude 1,120.36 m^3/s and descends again as shown in Figure 10. In piping failure mode, no significant effects resulted in both scenarios of with and without emergency spillway. The results indicate that an emergency spillway is needed in North Yamar Dam. For only one spillway (no emergency spillway), overtopping dam breach happened with 0.12 m flood depth over the dam crest.

3.2.2. Effect of Piping Elevation

In this scenario, sensitivity of dam break model is analyzed by changing piping elevations and keeping constant the other parameters. When piping elevation is at the first berm (R.L – 144 m), the peak discharge is 3,805.79 m^3/s with elevation – 148.43 m (Figure 12) and when piping elevation is at the near toe level (R.L – 135 m), the peak discharge is 7,090.68 m^3/s with peak elevation – 150.35 m (Figure 11). The result showed that piping at lower elevation resulted in higher peak discharge and elevation. So, with the change of piping elevation, there is significant increment of peak discharge and increment peak water level along the downstream location is observed. Previous study by Hajime and scientists from Kyoto university also showed that the vertical location of piping have significant effects on magnitude and occurrence of peak discharge at their experiment in 2011 [13].

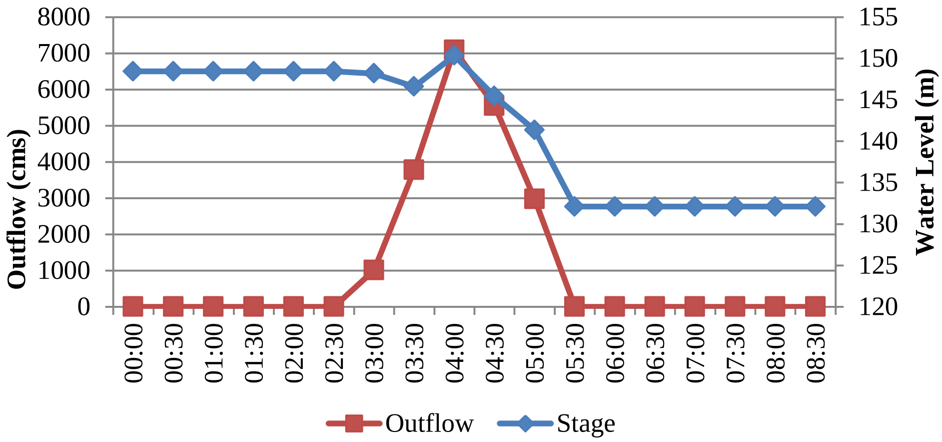

Figure 11: Piping at near Toe (R.L – 135 m)

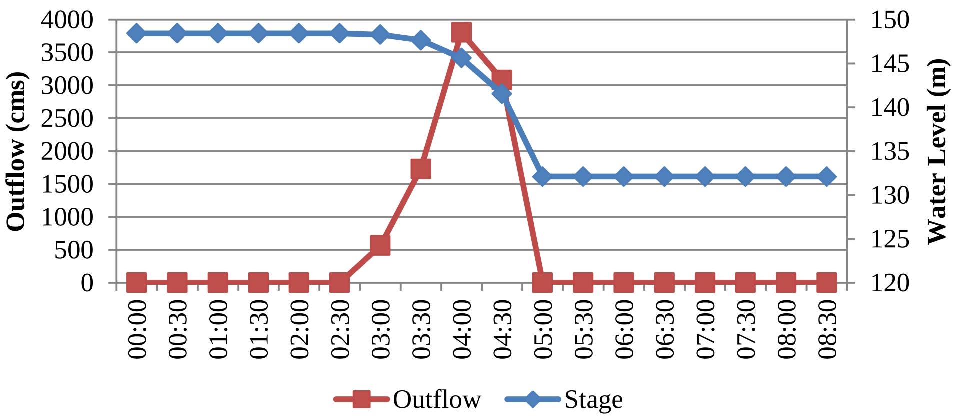

Figure 12: Piping at first berm (R.L – 144 m)

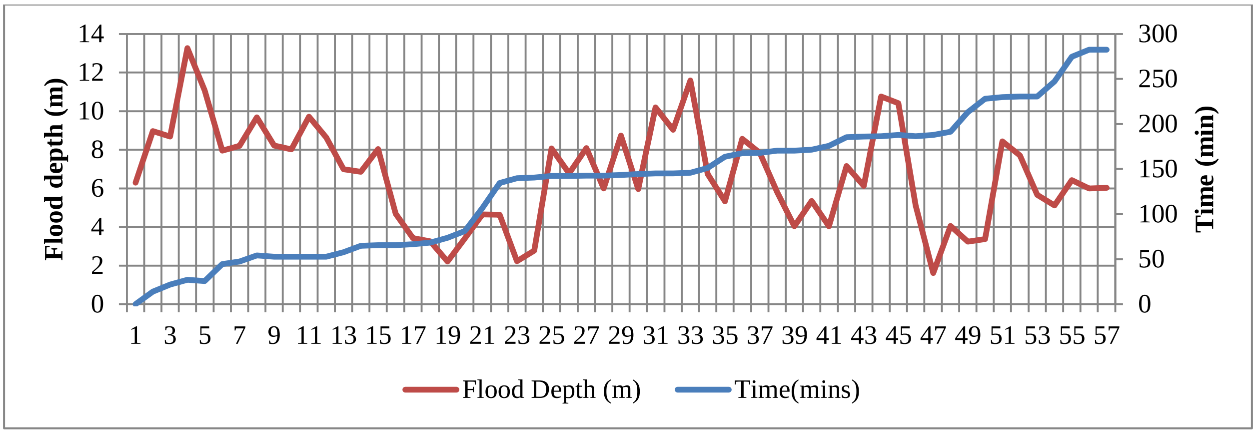

Figure 13: Maximum Flood Depth and Arrival Time for piping at bottom failure

3.3. Inundation mapping

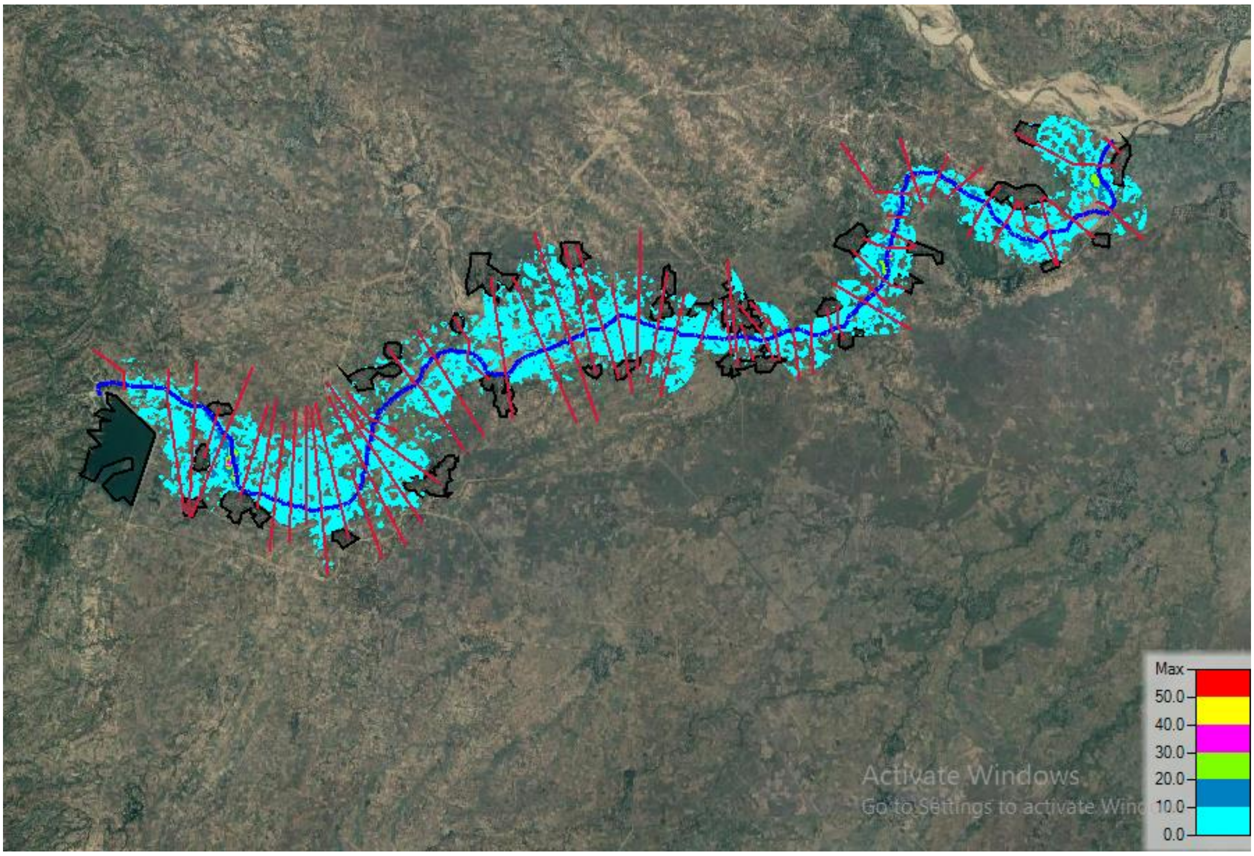

Figure 14: Flood inundation map of North Yamar dam breach by pipping failure mode

Inundation mapping of North Yamar Dam was taken in account only for piping failure mode because overtopping failure will not occur according to the present spillway situation of North Yamar Dam and according the analyzed scenario results. The potential piping analysis at R.L – 135 m was considered to be the worst piping breach for North Yamar Dam and inundation maps for that was evaluated for downstream consequences. Figure 13 shows arrival time and flood depth of North Yamar dam break by piping at bottom elevation (R.L- 135 m). Figure 14 shows the flood inundation map of North Yamar dam break by potential piping failure mode which would be used for planning effective and urgent emergency action. Figure 15 shows the selected specific areas which inundation covered due to piping with description of risk measurement parameters. Depending on this condition, authorities could give urgent protective measures. Table 1 shows the maximum water level and arrival time of peak discharge at specified location downstream of the dam for piping mode of failure.

Table 1: Downstream distance with maximum water depth, WSE, and arrival time for piping mode

Downstream Distance (km)	Max.water Depth (m)	W.S.E (m)	Arrival Time (Minutes)
2	13.26	133.31	27
14.46	10.19	120.63	145.2
26.5	6.02	102.79	282.6

According to Figure 15 and Table 1, maximum flood depth 13.26 m would occur at 2 km downstream distance 27 minutes after peak discharge happened during breach time. At 2km distance, Chinbyit village and Padaukon village is located on left bank and right bank respectively so that emergency preparedness plan should be taken in account for that two villages. Similar plan should also be prepared for Yinbungdaing village which is 14.46 km distance in downstream and flood coverage would be 10.19 m depth with arrival time 145.2 minutes.

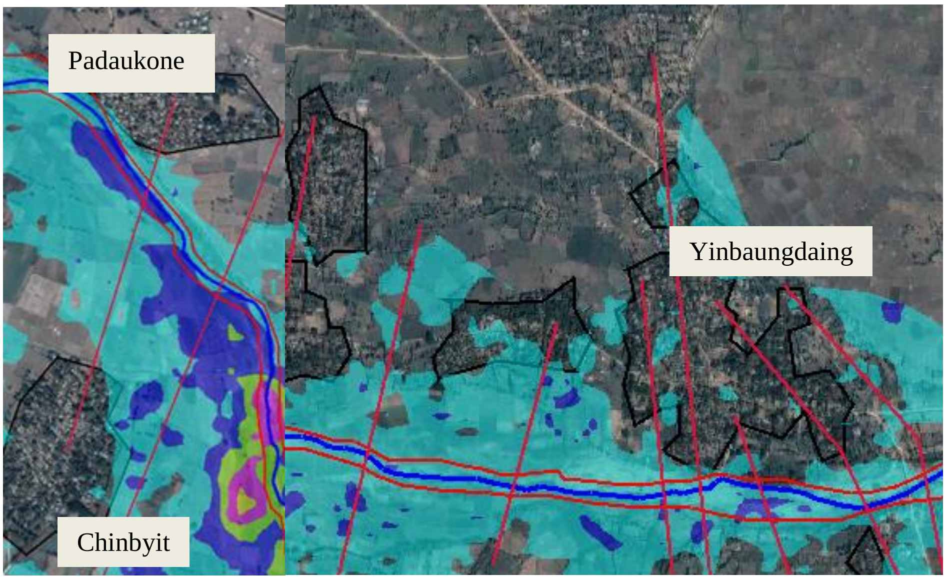

Figure 15: Flood inundation map of North Yamar dam break by piping that shows flood coverage over Padaukone, Chinbyit and Yinbaungdaing villages

4. Conclusion

A simple experimental study of Dam Breach was carried out successfully at North Yamar Lower earth dam. Further the scenario analysis of the effect of spillway, and piping elevations are carried out for overtopping mode and piping failures mode. In accordance with scenario analysis, the change of piping level had pretty much influence on the downstream maximum discharge and water surface elevation. From the analysis of spillway effect, it is found that overtopping dam breach would not happen in the existing spillway condition with emergency spillway. However, piping at bottom would result the peak discharge 7090.68 m^3/s and piping at top be 3805.79 m^3/s. The piping at bottom (RL- 135 m) of dam was considered as the worst condition and the inundation map was developed from the resulting water surface elevations, discharges, etc for the failure mode. Since peak discharge and maximum water depth resulted from dam break is the highest for 2 km downstream of the dam, effective and urgent action plan is required for that area which is near Chinbyit and Padaukon villages. Developed inundation map guides the authority to give emergency action plan for the highly affected area by flooding and used for planning future economic development area. The authority should guide communities those living and farming downstream of the dam near the river by using map of flood prone areas.

5. Recommendations

This research can be refined by using actual surveying data or high resolution DEM data. The results of this study can be re-checked using different dam breach and flood models with higher accuracy and strong computational algorithms, such as 2D and 1D-2D hybrid models. Dam Safety should be monitored at different times and remedial actions have to be made on identified problems. Emergency Action Plans (EAP) should be set in order to evacuate people potentially at risk. Further studies based on hypothesis of this research should be taken including sensitivity analysis regarding breach parameters.

Acknowledgements

First of all, the author wishes to give special thanks to her family for their kind support and encouragement. The author owes a debt of gratitude to U Kyaw Lin Oo, Director of Hydrological Branch, Irrigation and Water Utilization Management, for his kindness guidance and precious help. The author would like to express her heartfelt gratitude to U Win Maung, Patron of Myanmar Commission of Large Dams (MNCOLD) for his supports, valuable suggestions and discussions.

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