DAM BREAK MODELLING BY USING HEC-RAS AND HEC-GEO RAS: A CASE STUDY OF DIRE EMBANKMENT DAM ON LEGADADI RIVER

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ABSTRACT

Dam is essential hydraulic structure constructed across river for the purpose of creating reservoir to store water. The study focused on piping dam breach analysis of Dire dam located in Oromiya region. The analysis was carried out through HEC-RAS and HEC-Geo RAS model integrates with GIS. Unsteady flow simulation was done in HEC-RAS model. HEC-Geo RAS model prepares geometric data of Legadadi River in GIS. Input data for HEC-RAS model, dam breach parameters were calculated by using the empirical method of Froehlich 2008. The breach parameters value of breach bottom width (B), breach formation time (tf), and breach side slopes (bss) for piping failure mode were 45.98 m, 0.75 hr, and 0.7. The maximum breach outflow discharge 7712.10 m^3/sat the dam location due to piping failure was found through unsteady flow simulation performed in HEC-RAS model.

Keywords: Dam breach, HEC-Geo RAS, HEC-RAS, Piping

1. INTRODUCTION

The historic dam break data sets over the worldwide from 1900 until 1975 depicted that, dams of height more than 15 meters experienced break commonly caused by overtopping failure mode followed by wearing down of the dam crest and several of the dam failures were triggered by seepage, piping and other failure due to earthquake events (Ekaningtyas, 2017). Dam break may be summarized as the partial or catastrophic failure of a dam which results in quick release of water from the reservoir (Sharma, 2016).

Dam break analysis is performed as part of a dam safety assessment in order to evaluate downstream hazard potential for a dam failure which will assist the decision making authorities in land use planning and in developing emergency action plans to help mitigate catastrophic loss to human life and property. Accurate simulation of the dam break flood wave and its propagation along the downstream valley resulting from a potential dam failure are typically undertaken by hydraulic models (Derdous *et al.*, 2015).

Piping is also major causes of embankment dam failures which causes erosion and saturation in the dam body or foundation material and causes it to lose strength. Erosion generally begins in the downstream portion of the dam, and works backwards toward the upstream end. While Water is leaking through the dam at a substantial enough rates, it is firstly eroding material and moving it out of the dam. The eroded material results formation of large hole which have a capable of carrying more water and erode extra material. As the piping hole continues to grow concurrently, the head cutting and sloughing processes will continue to move back towards the upstream face of the dam. As the head cutting and erosion process continues back via the dam and downward, the break will be widening. The break may continue to cut down and widen until the natural river bed is developed based on the volume of water in the dam reservoir (Joy, 2016).

The two primary study approaches for dam breach analysis are an event-based approach and a risk-based approach (FEMA, 2013). The event-based approach is the most extensively used for dam breach analysis. An event-based approach is a method that requires the use of series of particular precipitation and non-precipitation events for the analysis of dam failure. This approach is more preferable to a risk-based approach since it is a direct, is less complex to execute, order, and produces more conservative breach flood zone mapping. The Risk-based approach to dam breach analysis have become more suitable for dam safety and dam design purposes. This approach is usually used for dam design purposes to establish the Inflow Design Flood for a dam.

2. METHODOLOGY

For analyzing dam break, a specific hydraulic model based on the complete one-dimensional Saint-Venant unsteady flow equations, is chosen as the basic hydraulic routing process for the HEC-RAS model. The model has been selected based on its capability to deliver more accuracy in simulating the unsteady flow for dam breach analysis. The HEC-RAS model is based on an extended version of the original equations developed by Saint-Venant of mass and momentum equations.

2.1 Case Study

Dire dam has been selected for the study. Dire dam was a zoned rock fill dam with an impermeable central clay core. The dam height is 41.8 m and dam crest length is 2000 m. The study area was geographically bounded between 38°56′02″E longitude and 9°08′53″N latitude. The dam was constructed along the Legedadi River for the purpose of providing potable water for Addis Ababa city. The mean annual rainfall range in this study area is 1230 -1,300 mm. The

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elevation in the study area ranges from 2,277 m to 3,237 m. The 960 m elevation difference exhibits the steepness of the area.

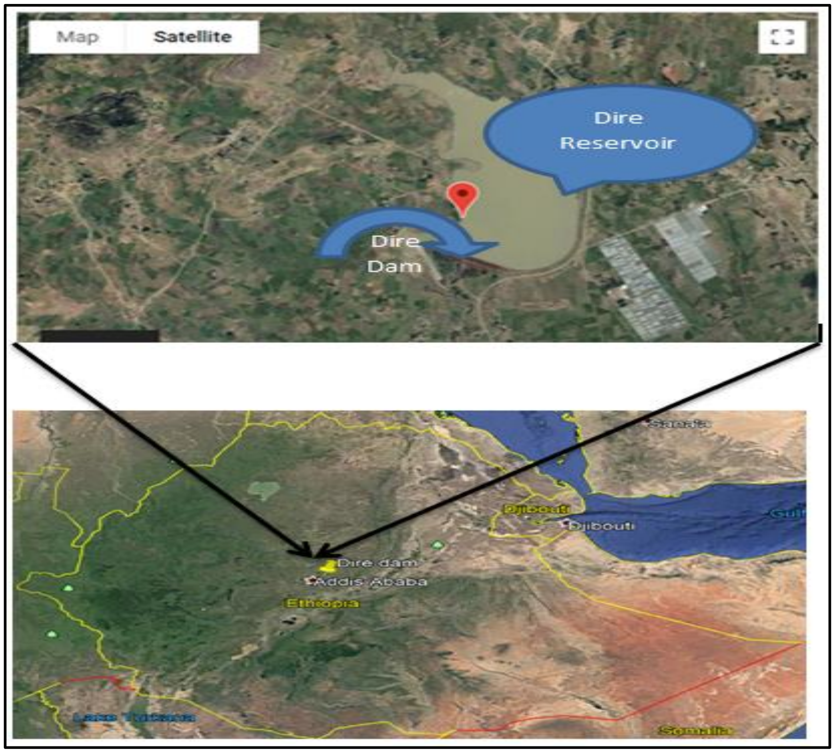

Figure 1: Satellite image of the Study Area, Source: Google Earth

2.2 Input Data

HEC-RAS model for dam break simulation allows simulating piping (through dam body) failure mode of embankment dam using the required input data. These data includes Dire dam breach parameters, Dire dam geometric data, Dire reservoir elevation-volume data, unsteady flow data, and geometric data of Legadadi River as an input data, and manning roughness coefficient.

1) Dire dam breach parameters

Dam breach parameters of input data for HEC-RAS model were computed through the empirical method of Froehlich 2008. The break parameters of average break width (Bavg) in meter and break development time (tf) in hour were expressed as follows.

$$Bavg = 0.27\, Ko\, Vw^{0.32}\, hb^{0.04} \qquad (1)$$

$$tf = 63.2\sqrt{\frac{Vw}{g(hb)^2}} \quad (2)$$

Where: ko signifies, constant (1 for piping failure mode); V_w and $h_b$de note reservoir volume at time of failure in cubic meter, and height of the final breach in meter respectively; g indicates gravitational acceleration (9.81) in meter per second squared.

2) Dire reservoir elevation-volume data

Table 1: Dire reservoir Elevation- volume data

Elevation (m) a.m.s.l	Volume (10^6 m^3)
2518.00	0.000
2529.50	0.003
2532.50	0.326
2534.00	0.650
2536.50	1.354
2538.50	2.088
2540.50	2.970
2543.00	4.260
2545.50	5.911
2547.00	7.085
2548.500	8.404
2550.50	10.420
2552.50	12.840
2554.50	15.651
2555.50	17.160
2557.00	19.550
2558.25	23.550

Source: (Addis Ababa Water and Sewerage Authority, 2016).

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3) Dire damgeometric data

Table 2: The main characteristics of Dire dam and Dire reservoir

Dam crest elevation (m a.m.s.l)	2559.8
Dam height (m)	41.8
Dam crest length (m)	2000
Dam crest width (m)	7
Upstream Embankment slope	4:1
Downstream Embankment slope	2.5:1
Spillway flood discharge (m^3/s)	500
Peak Probable maximum flood (m^3/s)	570
River bed level (m a.m.s.l)	2518
Normal water level or full supply level (m a.m.s.l)	2557
Low water level (m a.m.s.l)	2529.5
Maximum water level (m a.m.s.l)	2558.25
Reservoir area (m^2)	1.75×10^6
Reservoir Volume at the maximum water surface elevation (m^3)	23.5×10^6
Reservoir Volume at full supply level (m^3)	19.55×10^6

Source: (Addis Ababa Water and Sewerage Authority, 2016).

4) Geometric data of Legadadi River and manning roughness coefficient

The geometric data comprises combined information nearby the physical characteristics of the river channels, banks elevations, hydraulic structures (dam and reservoir), and cross sections. The geometric data creation was done in GIS via HEC- GeoRAS before being imported in to HEC-RAS. Manning roughness coefficient was provided for river channel and river banks based on their features.

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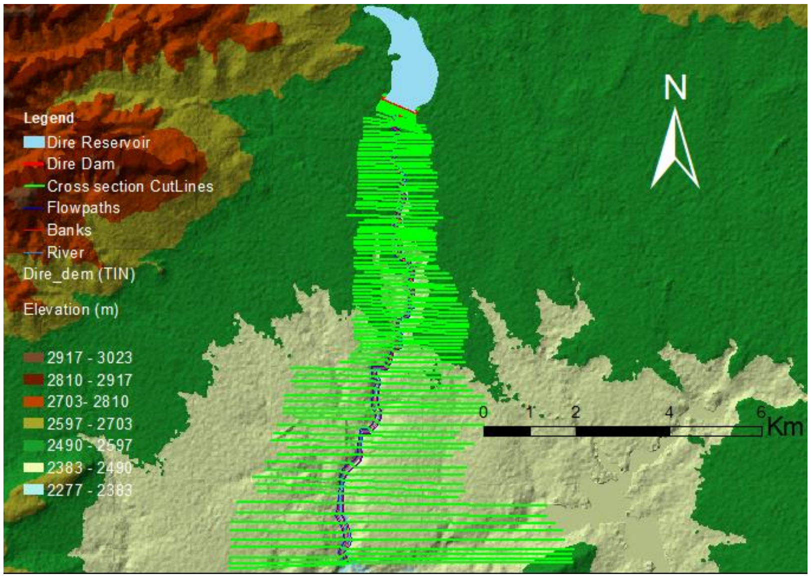

Figure 2: Geometric data of Legadadi River

5) Unsteady flow data

Unsteady flow data required in HEC-RAS was boundary conditions. Boundary conditions are essential to describe the upstream and downstream ends of the river system. These Boundary conditions were upstream boundary condition and downstream boundary condition. The upstream boundary condition for this study was the PMF inflow flood hydrograph. The 24 hour PMF inflow flood hydrograph of Legadadi River conducted during feasibility study of Dire Dam design project was taken as in the table 3 below. In this study, normal depth was used as downstream boundary condition. Therefore frictional slope 0.01655 was used as normal depth for downstream boundary condition and found from the profile graph for frictional slope computation of the Legadadi River profile.

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Table 3: PMF inflow flood hydrograph of Legadadi River

Time (hrs)	Inflow (m^3/s)	Time (hrs)	Inflow (m^3/s)
0	45	13	180
1	98	14	130
2	160	15	100
3	300	16	77
4	500	17	65
5	570	18	50
6	560	19	39.5
7	520	20	30
8	480	21	21
9	405	22	13
10	355	23	8
11	305	24	5
12	235		

Source: (Addis Ababa Water and Sewerage Authority, 2016).

3. RESULTS AND DISCUSSIONS

The output found from the study after using required input data in HEC-RAS model were reached. The breach parameters value of breach bottom width (B), breach formation time (tf), and breach side slopes (bss) for piping failure mode were 45.98 m, 0.75 hr, and 0.7. The routing of breach outflow discharge due to piping was performed starting from the upstream end RS of 12086.49 to the downstream end RS of 26.77806.The maximum breach outflow discharge7712.10m^3/sat the dam location due to piping failure was found through simulation performed in HEC-RAS model.

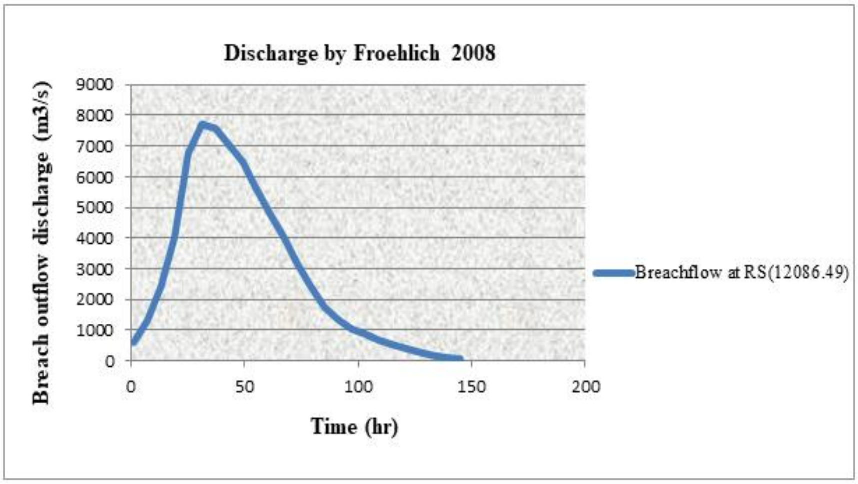

Figure 3: Breach outflow discharge at River station 12086.49 by piping

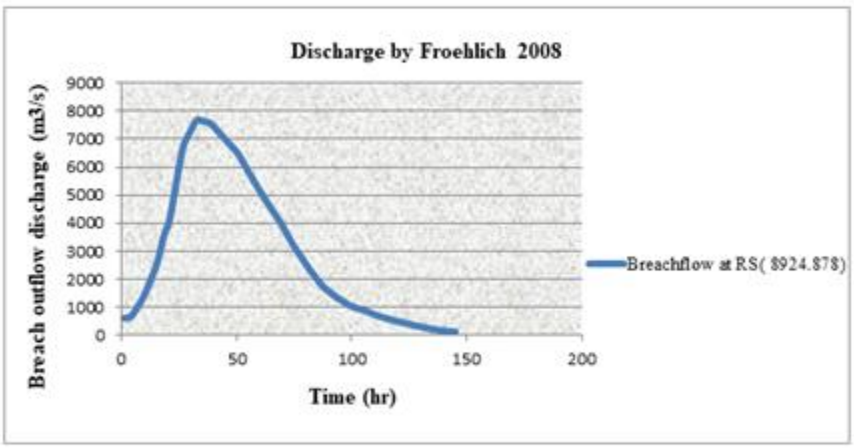

Figure 4: Breach outflow discharge at River station 8924.878 by piping

4. CONCLUSION

Dire dam has been selected for the study. The dam was a zoned rock fill dam with an impermeable central clay core. In order to meet this objective, the one dimensional HEC-RAS model and HEC-Geo RAS were used. Also Froehlich 2008 of empirical method was used for estimating dam breach parameters. The breach parameters value of breach bottom width (B), breach formation time (tf), and breach side slopes (bss) for piping failure mode were 45.98 m, 0.75 hr, and 0.7. Unsteady flow simulation in HEC-RAS model for piping failure found the maximum breach outflow discharge of 7712.1 m^3/s.

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