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Dam break analysis and flood inundation mapping using HEC-RAS for piping failure

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Abstract
The study was conducted on the Adwa dam, located at Mirzapur Uttar Pradesh. When they occur, the dam failures can cause immense damage and loss of life and property. The study considers Complete hydraulic simulation and analysis for a hypothetical breakdown of the Adwa dam was carried out using the DEM (Digital Elevation Model) computer model of the United States Army Corps of Engineers (USACE), the River Analysis System (HEC-RAS) hydrological engineering centre. The average breach width and breach development time of the dam is calculated through the Froehlich regression equation (2008) using the Adwa dam geometrical information. The flood inundation map was generated by HEC-RAS and imported into Q-GIS to delineate the areas flooded under the assumed dam break scenario. The details of water surface elevations, depth of flood, flood arrival time and velocity of flood wave at different locations of downstream gives an idea about extent of flooding. Study showed that a total of 52 villages were affected by the flood, with the average discharge flow from the dam being breached being 4436.9175m3/s (CMS) at 5:30 hours following dam breach due to piping failure mode. The average water volume collected at the end of the simulation period is 273305.68 1000m3 due to piping failure, respectively. The simulation results showed that in the event of Adwa dam failure, some areas including residential, agricultural and industrial areas were listed as having a very high risk of flooding due to the significant difference in water surface level and ground elevation value. Emergency evacuation will take place within 41 minutes of breach of dam.

Keywords: HEC-RAS, Q-GIS, DEM, dam breach, piping

Introduction
Dams provide our society with many benefits including drinking and irrigation water supply, electric power generation, and flood protection. But, when a dam fails, large amounts of water are suddenly released, creating large flood waves which can harm downstream areas [WAHL 1998] [9]. Dams provide civilisation with many benefits, but floods resulting from the failure of built dams have also produced some of the most devastating disasters of the last two centuries.
Basically two major consequences of a dam failures are: - Life loss: Because of heavy flood resulting from dam-break this loss may occurs if the villages and the residing families are washed away.
Economic loss: This loss is calculated in terms of revenue that will be required in terms of infrastructure and other related facilities to rebuild the washed away villages. Analysis of dam breakage will make it possible to predict the downstream flood and flood-affected areas due to breach. This helps in cost estimation in rehabilitation cases. The study predicts the potential of precautionary measures that can be taken to avoid the dam break which prevents or minimizes damage completely. This paper considers dam failure due to piping failure. General description of piping failure occurs when water is seeping through the dam at a significant enough rate, such that it is internally eroding material and transportation it out of the dam. As the material is eroded a large hole is formed, so that more water can be carried and more material eroded. During this process the movement of water through the dam is modelled as a type of flow in the pressurized orifice. Erosion and head cutting may continue Margate-off and fall into the flowing water during the piping flow method. Its cutting of the head and the sloughing process of the material will move down towards the upstream side of the dam, because the piping whole will continues to grow around each other. If the piping hole is wide enough, the weight of the material above the hole may be too high to sustain and there will be a mass cave of concrete.

This will result in a large rise in the outflow through the breach and will speed up the breach process as well as the hydraulics of the flow transition from a pressure / orifice type flow to an open-air weir type flow at this point. The process of head cutting and erosion then goes back through the dam, as well as downwards. On top of that, the breach will widen. Depending on the volume of water behind the dam, the breach could continue to shrink and expand until entering the natural channel bottom. The violation will then undergo a spreading process. (Grey Brunner 2014)

Flood Inundation Mapping is an important tool for municipal and urban growth planning, emergency action plans, flood insurance rates and ecological studies used by engineers, planners and government agencies. By understanding the extent of flooding and floodwater flooding, decision-makers can choose how best to allocate resources to prepare for emergencies and improve the quality of life in general (Warren, c. *et al*. 1994) [10]. HEC-RAS was used to determine water-surface profiles, velocity and arrival time of in-place and dam-break scenarios for the inflow design floods that were simulated. Inundation maps were developed for the area downstream. [PIERRE, CAZAILLET 2005] [8].

Material and Methods

Adwa dam is located at Mirzapur, Uttar Pradesh, India. It is located at 24º45'15" North latitude and 82°18'40" East longitude. The altitude of the place above main sea level is 94.00 meter. Average rainfall of that area considering ten years rainfall data is 970.45mm. Adwa reservoir is used for irrigation purposes.

For Dam Break analysis HEC-RAS works on St. Venant's Equation St. Venant's Equations

Continuity equation

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=0$$

Momentum equation

$$\frac{1}{A}\frac{\partial Q}{\partial t}+\frac{1}{A}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)+g\frac{\partial y}{\partial x}-g(S_0-S_f)=0$$

Where

x = space coordinate along the channel axis.

t = time

A = cross-sectional area of the flow at location x

Q = discharge

g = acceleration due to gravity

S_o = bed slope

S_f =friction slope

Dam breach analysis is simulated as an unsteady flow simulation with a computational interval of 5 seconds and mapping interval of 5 minutes for 24 hours. Raster layers of water depth imported from RAS Mapper are again exported into QGIS. Village boundary, roads and railways maps of study area are downloaded from Open Street Map and loaded as shapefile. Web imagery (Google Hybrid) is also added as background reference. Then, depth-based flood hazard maps are created for different conditions for our area of interest.

Results and Discussion

Fig 1 shows the breach bottom width 93 m and breach development time 2.62hr calculated by Froehlich (2008) for piping mode of failure respectively. The maximum discharge that flows out from 4436.9175m^3/s at 5:30 hours after dam breach due to piping mode of failure respectively. The maximum volume of water accumulated is 273305.68 1000m^3 due to piping failure respectively at the end of simulation time. The flood volume accumulation along a profile line (downstream river) with respect to time is simulated by RAS mapper, a tool included in HEC-RAS.

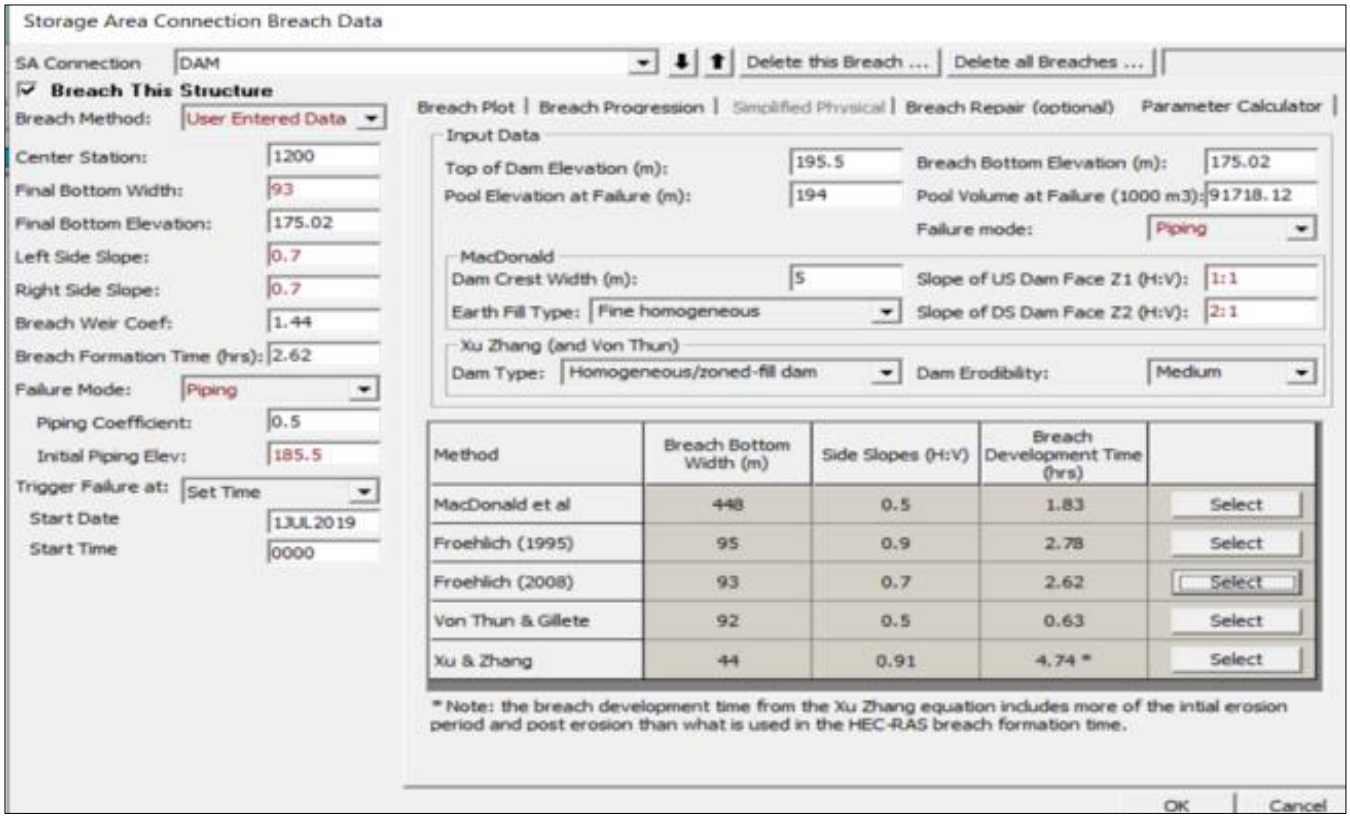

Fig 1: Dam Breach Parameter Due to Piping Failure

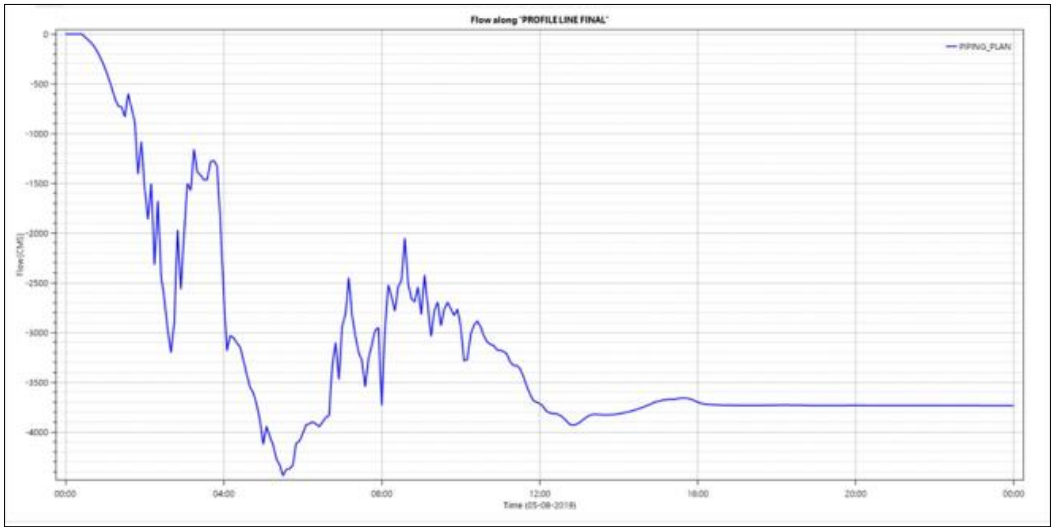

Fig 2: Outflow hydrograph of breached dam by overtopping failure

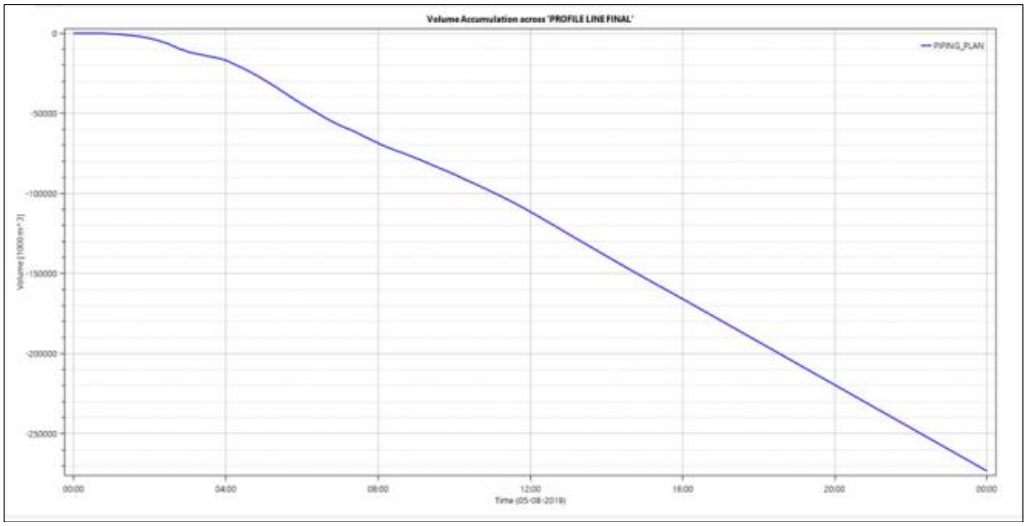

Fig 3: Volume of water accumulation after dam breached with respect to time

Flood Inundation Map

Dam break flood inundation map is a graphic display that can be used to indicate areas that may be flooded as a result of dam failure. For this study, flood inundation map was generated using HEC-RAS and QGIS. These maps can be used to identify areas, important roads and railways as a potential hazardous area due to dam failure. These maps are also extensively used by dam authorities to prepare Emergency Action Plan (EAP) for disaster management.

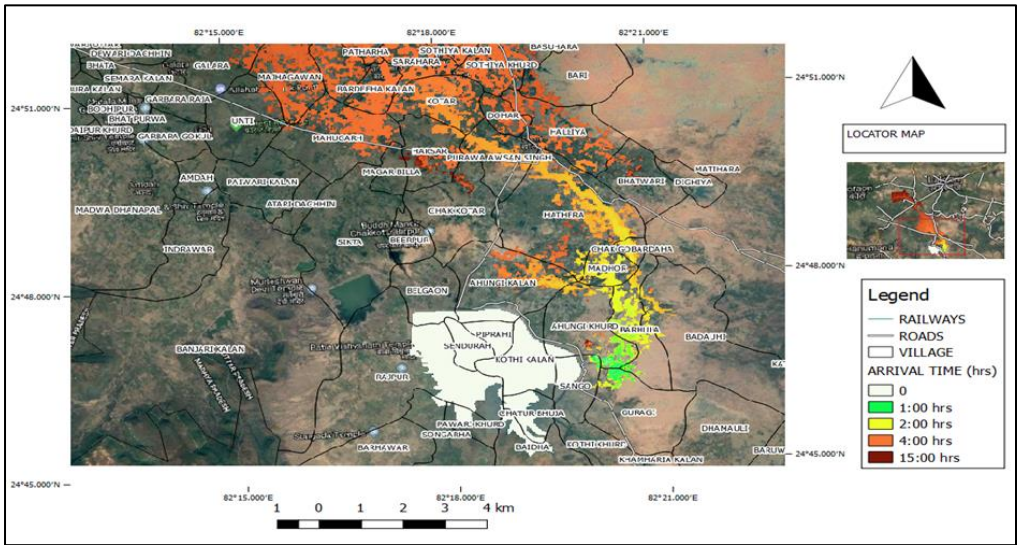

Fig 4: Arrival Time (hr) based flood inundation map of Adwa dam (Piping failure)

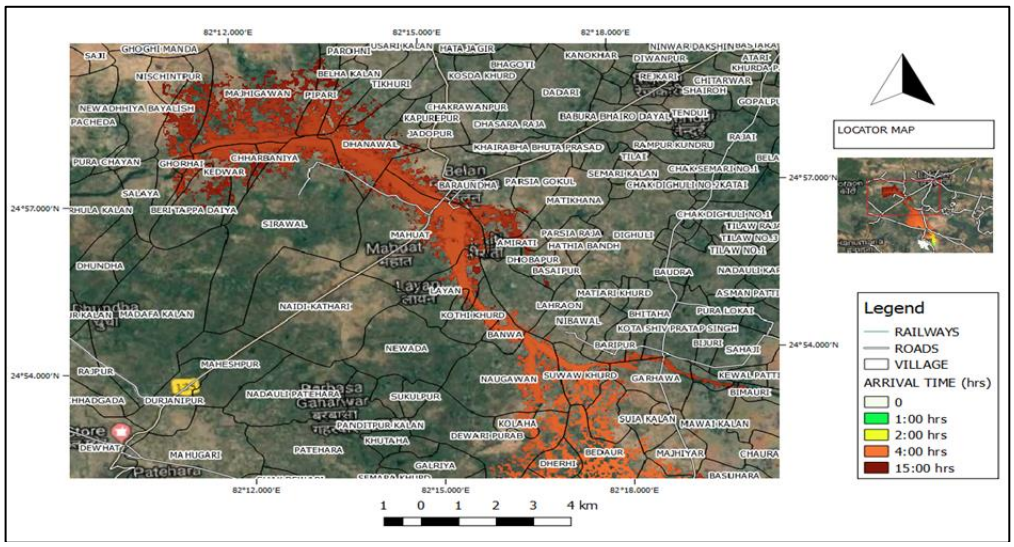

Fig 5: Arrival Time (hr) based flood inundation map of Adwa dam (Piping failure)

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