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Flood hazard mapping using HEC-RAS and QGIS for Meja dam

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Abstract

The study was conducted on the Meja dam which is located at Mirzapur Uttar Pradesh. The dam failures can cause immense damage and loss of life and property. Complete hydraulic simulation and analysis for a hypothetical dam break of Meja dam were performed using United States Army Corps of Engineers (USACE), Hydrologic Engineering Center's River Analysis System (HEC-RAS) computer model with river geometry derived from DEM. Public domain HEC-RAS programme for the use of combined flood routing and estimation of flood levels. The flood inundation map was generated by HEC-RAS and imported into QGIS 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 the extent of flooding. The average breach width and breach development time of dam are calculated by using the geometric information of the Meja dam through the regression equation of the Froehlich (2008). The average breach width and breach development time calculated by Froehlich (2008) are 194 m and 4.20 hr for overtopping and 141m and 3.81 hr for the piping mode of failure respectively. The bottom breach elevation of the dam which used as input for the HEC-RAS model is 155 m for both modes of failure. The maximum discharge flows out from the breached dam is 4836.42 m³/s (CMS) noted at 5:00 hours after a dam breached due to overtopping and 4169.04 m³/s (CMS) at 5:15 hours after a dam breached due to piping mode of failure. The maximum volume of water accumulated is 128900.8 and 127502.3 due to overtopping and piping failure respectively at end of simulation time. The simulation results showed that in the event of Meja 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 the dam.

Keywords: DEM, HEC-RAS, Q-GIS, Dam breach, flood mapping

Introduction

The construction of reservoirs and dams will offer a variety of benefits to society, such as the protection of water supplies, the diversion of water and sediment, power generation, and irrigation. Accidents that occur downstream of a dam break, though, have devastating consequences on community, the economy, and the environment. A large collection of water and flood in the upstream of the high incidence area of Often make the downstream river facing the serious problem. once the river burst its banks will form the new waterlogging area, and then lead to the tragedy of river diversion, flood land, highway interrupted and real pour news. So that the dam break has greatly increased the danger of flood disaster on both sides of the river valley. In view of the above problems and challenges, the river flood simulation and risk prediction in regions have gradually become a research hotspot. The ascertain of flow profile is the basis of the analysis of flood routing, and the research on the application of HEC-RAS (Hydrologic Engineering Center – River Analysis System) model to simulate the water surface is very extensive both at home and abroad.

Simulation of dam break result and resulting floods are essential for characterizing and reducing negative effects occurred in the downstream area. Development of an emergency action plan requires exact estimation of inundation level and the arrival time of flood wave at the downstream point. This study provides a realistic view of using Arc GIS analysis and its display capabilities combined with hydraulic modelling tools to develop a flood inundation map. HEC-GeoRAS was used to extract geometric information from a digital elevation model

and provide the tools to develop and modify HEC-RAS model simulation as well as to perform flood extent mapping analysis. The hydraulic modelling results were displayed in the map using Geometric Information System which is currently the most widely used tools in the management of floods.

Material and Methods

Description of the Study Area

Meja dam is located 63 km south of Mirzapur city, in Mirzapur district of U.P., India and has been constructed by Sirsi Dam Division, Mirzapur which comes under Irrigation department of U.P. Government. It is situated on the Bealan River. It is located at 25.15°N, 82.58°E. It has an average elevation of 80 metres. The southwest monsoon (summer monsoon) is the major source of rainfall, which generally lasts from mid-June to mid-October. The average annual rainfall of district varies between 850 mm to 1350 mm.

Software Used

HEC-RAS 5.0.3 The program was developed by the US Department of Defence, Army Corps of Engineers in order to manage the rivers, harbours, and other public works under their jurisdiction. HEC-RAS is a computer program for modeling water flowing through systems of open channels and computing water surface profiles. HEC-RAS finds particular commercial application in floodplain management and flood insurance studies to evaluate floodway encroachments. Some of the additional uses are: dam breach analysis, bridge and culvert design and analysis, levee studies and channel modification studies.

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

St. Venant's Equations

Continuity equation

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \quad \dots 1$$

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

Momentum equation

$$\frac{1}{A} \frac{\partial Q}{\partial x} + \frac{\partial Q^2}{\partial x} + \frac{\partial}{\partial t} (S_0 - S_f) = 0 \quad \dots 2$$

$$\frac{g}{A} \frac{\partial Q}{\partial x} + \frac{\partial Q}{\partial t}$$

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_0 = bed slope

S_f = friction slope

QGIS 2.18 QGIS is a free and open-source cross-platform desktop geographic information system (GIS) application that supports viewing, editing, and analysis of geospatial data. QGIS 24 functions as geographic information system (GIS) software, allowing users to analyse and edit spatial information, in addition to composing and exporting graphical maps. QGIS supports both raster and vector layers, vector data is stored as either point line, or polygon features. Multiple formats of raster images are supported by the software.

Methodology

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

Dam break analysis was performed using HEC-RAS for two major types of dam breach cases, i.e. overtopping and piping. Overtopping dam failure is most common type of dam failure in 32 earthen dam. A head-cut is formed on the top of earthen dam due to large amount of water inflow in the reservoir. Water erodes a part of dam gradually and it creates a devastating situation. Piping dam failure occurs due to seepage of water inside the dam. The dam erodes from the inside and gradually, pipe like structures are formed inside it which leads to failure.

Flood Hydrograph of breached dam

Fig. 1 shows the the maximum discharge flows out from the breached dam is 4836.42 m³/s (CMS) noted at 5:00 hours after dam breached due to overtopping and 4169.04 m³/s (CMS) at 5:15 hours after dam breached due to piping mode of failure. The peak discharge rate of overtopping mode of failure is greater than that the piping mode of failure. Further, the peak of overtopping failure occurs after peak of piping failure. Finally we can say that the overtopping failure more dangerous than piping failure.

Fig 1: Outflow hydrograph of breached dam by overtopping failure

Fig 2: Outflow hydrograph of breached dam by piping failure

Volume of water accumulation at downstream river

Fig 3 shows the maximum volume of water accumulated is 128900.8 and 127502.3 due to overtopping and piping failure

respectively at end of simulation time. The flood volume accumulation along a profile line (downstream river) with respect to time is also simulated in RAS mapper.

Fig 3: Volume of water accumulation v/s time graph

Developing the 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. Water depth at different points of downstream area after arrival of flood is exported as a raster layer from the RAS Mapper and shape file of settlement of study area also add in QGIS, then it is used to prepare flood hazard map. 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.

Flood Arrival Time

Flood arrival time maps for both overtopping and piping dam failure are generated using RAS Mapper and village map, road map and other settlement also add in flood arrival map by QGIS.

Fig 4: Flood inundation map based on arrival time (Overtopping failure)

Fig 5: Flood inundation map based on arrival time (Piping failure)

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